Draft

Technical Background Document on Ground Water Controls at CKD Landfills

Office of Solid Waste
U.S. Environmental Protection Agency

June 1998

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Chapter 1: Characteristics of CKD Waste

Under Subtitle C of the Resource Conservation and Recovery Act (RCRA), the U.S. Environmental Protection Agency (USEPA) is proposing a tailored set of standards for the management of cement kiln dust (CKD) waste and to control releases to ground water. The proposed standards are designed to protect human health and the environment, while allowing for flexibility in their implementation by facilities and the States. This technical background document (TBD) describes the Agency's development of proposed performance standards and design and operating criteria for controlling releases to ground water at CKD landfill (CKDLF) units.

1.1 Regulatory History

Under the 1980 amendments to RCRA, CKD was exempted from hazardous waste regulations, pending completion of a Report to Congress required by §8002(o) and a determination by the Administrator either to promulgate regulations under Subtitle C or that such regulations are unwarranted. In December 1993, EPA issued a Report to Congress (RTC) on the hazards posed by CKD. EPA solicited public comments on the report and held a series of public meetings in early 1994 before determining that CKD warranted additional controls.

To supplement the information included in the RTC, the Agency analyzed the public comments submitted on the RTC and undertook several additional data collection and analysis efforts. The new data generated by EPA were placed into the RCRA docket for public inspection and comment and a Notice of Data Availability (NODA) was published in the September 14, 1994, Federal Register (59 FR 47133).

In February 1995, EPA announced its intention to develop controls on CKD under Subtitle C of RCRA to protect public health and the environment (60 *FR* 7366, February 7, 1995). The decision followed an extensive evaluation that included consultation with states, industry and citizen groups. In that regulatory determination, EPA announced its intention to use, as appropriate, its various authorities under the Clean Air Act, Clean Water Act, and RCRA to address the relevant pathways of potential contaminant releases from CKD. This document was prepared to provide technical background information on the need for ground water controls at CKDLF units. Controls for CKD fugitive air emissions are described in a separate docket report on standards for control of fugitive dust at CKD landfills.

After publication of the Regulatory Determination on CKD in 1995, EPA embarked on a series of analyses to identify and evaluate options for the protection of ground water resources at CKDLF units. The objective of these analyses was to develop tailored technical standards that are protective of human health and the environment but with sufficient flexibility for local implementation by facilities and the States. To develop the proposed standards, EPA evaluated the results of risk modeling, documented damage cases, conducted hydrogeologic modeling, and conducted other technical and regulatory analyses to evaluate a range of alternative performance and technical standards. After consideration of these analyses, the Agency developed and is proposing a set of performance standards and operating criteria to minimize the impact of CKD land disposal practices to ground water.

1.2 CKD Generation and Waste Management

Recent information collected by the Agency[1] suggests that the cement industry consisted of 110 plants in the United States and Puerto Rico operated by 46 companies. The five largest clinker[2] producing states are California, Texas, Pennsylvania, Missouri, and Michigan. Cement production occurs in very large rotary kilns at high temperatures; finely ground raw material enters and rolls downward from the "cool end" of the kiln, while fuels and combustion are introduced and drawn upward from the "hot end". Large amounts of high Btu fuels, primarily coal and other fossil fuels are used during the cement manufacturing process to maintain adequate burning temperatures within kilns. In 1997, hazardous waste was found to have been burned as a cement kiln fuel at a total of 18 cement plants. As air exits the cool end, entrained solid matter, including CKD, is collected before the air is vented to the atmosphere through large gas emission smokestacks. CKD generation results directly from this control of particulate matter that would otherwise be discharged. Usually 98 to 100 percent of all particulate matter generated during cement production is captured by air pollution control devices before existing the kiln system (USEPA, 1993). This material is comprised of raw materials, dehydrated clay, decarbonated (calcined) limestone, ash from burnt fuel, and newly formed minerals produced by the cement manufacturing process. This gross CKD may be recycled, treated and reused; taken off-site for beneficial use; or disposed of in waste management units (see Figure 1-1).

1.2.1 Current CKD Generation Rates

Based on an analysis of existing data, including data collected by the Portland Cement Association (PCA) and separately by EPA under RCRA section 3007 authority from operators of cement manufacturing facilities, the Agency estimates that in 1995 the cement industry had a clinker capacity of 77 million metric tons and a net CKD generation of 4.08 million metric tons. The 1995 data indicate that 24 of the 110 cement plants (22 percent) recycle all collected dust back to the kiln, and an additional 12 plants (11%) ship all generated CKD off site for beneficial use. The Agency estimates that the remaining two-thirds of cement plants (74 facilities) had a combined annual CKD land-disposal requirement of 3.3 million metric tons in 1995.

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[1] Portland Cement Association (PCA) 1995 survey of the cement industry in 1995.

[2] Clinker is the cement kiln's raw product which is subsequently ground with a smaller amount (approximately 5 percent) gypsum to make cement.

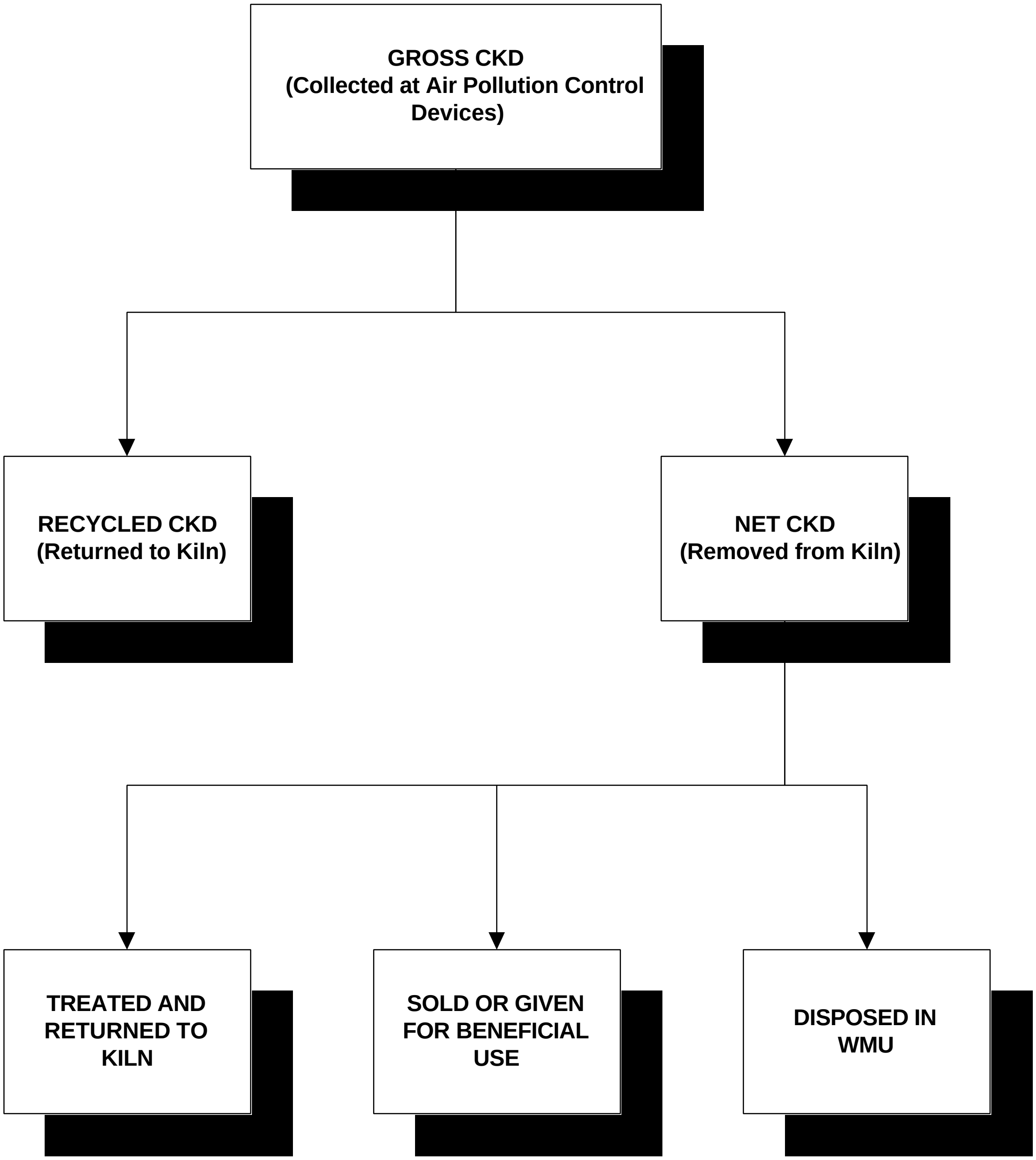

Figure 1-1. Flow Chart of Gross CKD Management Practices.

(Adapted from EPA, 1993)

These facilities employ on-site disposal for CKD quantities ranging from less than 1,000 metric tons per year up to more than 200,000 metric tons per year. (See Section 5 of this background document for a more detailed description of facility-specific CKD generation rates).

1.2.2 CKD Recycling

Recycling of CKD reduces the need for land disposal or other alternative uses of CKD. Accordingly, most facility operators recycle CKD to some degree. Based on data from a 1995 PCA survey (representing usable data from 108 facilities), most facilities recycle some of their gross CKD, and 24 facilities were able to recycle all of their CKD (PCA, 1995). In 1995, two thirds of the gross CKD that was generated by the cement industry - 7.8 million metric tons - was recycled directly back into the kiln or raw feed system. If a cement plant achieves 100 percent recycling, alternative CKD management practices, such as land disposal, are deemed unnecessary. However, direct recycling generally results in a gradual increase in the alkali content of generated dust that may damage cement kiln linings, produce inferior cement, and increase particle emissions from the plant. Depending on the quality of the raw materials used, increased concentrations of chloride and sulfur in cement may produce structurally-defective concrete. Some CKD removal from the kiln system as waste is therefore usually necessary (USEPA, 1993).

Several cost-effective treatment technologies are available or are being developed to treat CKD with high concentrations of alkalies and/or other undesirable constituents before re-entry to the kiln system. At some cement plants, dust reuse is preceded by pelletizing or alkali leaching. (At least two facilities are known to treat waste CKD with water leaching: the Ash Grove Cement Co., Inkom, Idaho, and Holnam Inc., Dundee, Michigan.) Pelletizing gives CKD the strength to withstand firing upon re-entry into the kiln system without resuspending large quantities of particulate matter or changing the chemical characteristics of clinker. The leaching process increases the amount of recyclable CKD but generates wastewater that must be treated for high pH values and high concentrations of dissolved and suspended solids. However, no wastewater discharge is associated with this procedure. At one facility, a modified version of this leaching and return process reportedly results in 100 percent recycling of CKD (USEPA, 1993).

In addition, the Agency has received some evidence, in comments from cement companies, that raw material substitution may be a highly effective means of increasing CKD recycling rates. This may be done by controlling the input of contaminants (in raw materials and fuels) to the kiln system, thereby reducing or eliminating the need to purge the kiln system of contaminants (60 FR 7366).

1.2.3 CKD Beneficial Use

Alternatively, CKD may be sold or given away for off-site applications. Beneficial uses of waste CKD include the stabilization of municipal sewage sludges, waste oil sludges, and contaminated soils; the neutralization of acid mine drainage; the addition to agricultural lands as a fertilizer and/or liming agent, and inclusion in Portland cement as a materials additive. In 1990, about 7 percent of the CKD generated (897,000 metric tons) was sold for off-site use. Mostly, CKD was used as waste stabilizer, liming agent, and materials additive (60 FR 7366). In 1995, approximately 767,740 metric tons were sold off-site for beneficial use (PCA, 1995).

1.2.4 CKD Disposal

In 1995, land disposed CKD averaged 30,150 metric tons per plant, and land disposed CKD from the entire cement manufacturing industry was estimated to be 3.3 million metric tons (PCA, 1995). Typically, CKDLF units are on-site, non-engineered, unlined and uncovered landfills and piles located in abandoned quarries, retired portions of operating quarries or nearby ravines. Some active piles are also managed underwater or adjacent to surface water and/or agricultural lands (60 FR 7366). Based on data from the 1990 PCA survey, the Agency has estimated that 52 percent of active CKD disposal facilities were landfills, 43 percent were piles, and less than 1 percent were ponds (USEPA, 1993). The average pile was 15 meters (15 m) thick or 1 m thicker than the average landfill. Maximum reported thicknesses for CKD landfills and waste piles were 56.4 m and 34.6 m, respectively. However, the average basal area for landfills (7.9 hectares) was approximately twice that of piles (3.6 hectares). Landfills may therefore cover significantly larger land areas than piles. In contrast, the average basal area of ponds was less than 1 hectare.

Non-CKD waste materials such as, furnace brick, concrete debris and tires may be co-disposed with CKD in CKDLFs. Responses to the PCA survey reveal that of 66 CKDLFs, 23 percent co-disposed non-CKD material amounting to 1 percent of the material disposed in these units in 1990.

Based on the Agency’s analysis of current CKD waste management practices and the causative factors of releases to ground water at CKDLFs, current landfill designs appear to be inadequate to limit contaminant releases from CKDLFs. Current trends in CKD waste management practices are discussed in greater detail in Section 2.1.3.

1.3 CKD Waste Characteristics

CKD waste characteristics generally are affected by natural variations in the raw materials used for cement manufacture, product specifications, the type of process employed by the facility, and the type of fuel burned. This section describes the physical and chemical characteristics of CKD, and CKD toxicity based on corrosivity and trace metal concentrations. The presence of volatile and semi-volatile organic compounds in CKD also will be discussed.

1.3.1 Physical Characteristics of CKD

Fresh CKD is a fine, dry alkaline dust that readily absorbs water. CKD particle sizes generally vary by kiln process type (see Table 1-1) and range from 0-5μm (approximately clay size) to greater than >50μm (silt size) (USEPA, 1993).

Table 1-1. Particle Size Distribution of CKD by Process Type.

Particle Size (μm)	Source 1[a]	Source 2[b]		
	Unspecified Process Type (weight percent)	Wet Kilns (weight percent)	Long Dry Kilns (weight percent)	Dry Kilns with Precalciner (weight percent)
0-5	5	26	45	6
5-10	10	19	45	11
10-20	30	20	5	15
20-30	17	9	1	23
30-40	13	8	1	18
40-50	7	1	0	9
>50	18	17	3	18
Median Particle Size	**No Data**	**9.3**	**3.0**	**22.2**

[a] Kohlhaas et al. 1983. Cement Engineer's Handbook. Bauverlag GMBH, Wiesbaden and Berlin. p. 635. The number of samples used to develop data was not specified.

[b] Todres et al. 1992. CKD Management: Permeability. Research and Development Bulletin RD103T, Portland Cement Association, Skokie, Illinois, p. 2.

Permeability or saturated hydraulic conductivity data for CKD samples collected from four locations are as follows:

Minimum:	2.6×10^{-8} cm/s
Maximum:	1.7×10^{-4} cm/s
Median:	1.2×10^{-5} cm/s
Average:	1.8×10^{-5} cm/s

These values are based on 175 construction and test plot results using samples collected during the design and/or pre-construction phase of CKDLF units. This range of CKD permeability values is similar to permeabilities found in natural materials ranging from that of a typical unweathered clay (a nearly impervious soil type with permeabilities less than 10^{-7} cm/sec) to that of a silty sand (a low permeability soil type with permeabilities ranging from 10^{-3} to 10^{-5} cm/sec). Additional data on the physical properties of CKD and an evaluation of the use of compacted CKD as a landfill liner or cap are presented in Section 6 of this background document.

1.3.2 Chemical Characteristics of CKD

The primary bulk constituents in CKD (those found in quantities greater than 0.05 percent by weight) are silicates, calcium oxide, carbonates, potassium oxide, sulfates, chlorides, various metal oxides and sodium oxide. EPA found that CKD may contain seven trace metals (antimony, cadmium, lead, mercury, selenium, silver, and zinc) at levels above the range commonly found in native soils.[3] In addition, CKD may contain arsenic and strontium at levels that are within the range of naturally occurring soils, but that exceed the average native soil concentration by a factor of two or more (USEPA, 1993).

1.3.3 CKD Toxicity

CKD contains certain metals listed in 40 CFR 261 Appendix VIII ("Hazardous Constituents"). Table 1-2 presents the range of total concentration levels for a number of toxic metals identified in CKD. EPA found that when total metals detected in kiln dust are considered, no significant distinction can be made between CKD generated from kilns that burn hazardous waste and those that do not burn hazardous waste. However, for individual metals such as, lead and cadmium, the mean concentration found in CKD generated by kilns that burn hazardous waste is measurably higher than that produced in kilns that do not burn hazardous waste. Conversely, thallium and barium concentrations are measurably higher in CKD from kilns that do not burn hazardous waste (60 FR 7366).

Due to the generally alkaline nature of CKD, the pH level in storm water runoff that contacts CKD waste piles typically exceeds 12.5 standard units (SU) (60 FR 7368), the federal standard for the corrosivity characteristic for hazardous wastes (40 CFR 261.22). Ground water releases and surface water runoff from CKD piles can have significant impacts on aquatic environments. For example, as a part of a preliminary site characterization of the Lehigh Portland Cement Company site in Metaline Falls, Washington, fish toxicity testing was conducted on juvenile rainbow trout in accordance with Washington State Department of Ecology Static Acute Fish Toxicity Test, No. DOE 80-12 (Dames and Moore, 1992). The test was performed to evaluate if CKD could be considered a dangerous waste under Washington regulations (Washington Administrative Code 173-303-100). Testing involved adding 1,000 ppm of CKD to water in an aquarium containing rainbow trout and observing fish mortality over 96 hours. Of the ten non-neutralized bioassays conducted, four of the tests exceeded the toxicity criteria for dangerous waste. Two fish bioassay tests had pH values exceeding 10.5 SU and had 97 percent and 100 percent mortality rates. Four of the tests had pH values equal to 10.5, but the two of these tests that failed the toxicity criteria showed mortality rates of 100 percent (Dames and Moore, 1992).

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[3] Source: *Hazardous Waste Land Treatment*. Table 6.46 - Trace Elements of Soils, U.S. Environmental Protection Agency, Cincinnati, Ohio, PB89-179014, April 1983, page 273. See Section 3 of EPA's *Report to Congress on Cement Kiln Dust (Vol. II Methods and Findings)* for a more detailed discussion of the chemical characteristics of CKD.

Table 1-2. Trace Metal Concentrations in CKD [mg/kg (parts per million), total basis].[a]

Analyte	No. of Samples	Mean	Minimum	Maximum
Antimony	52	11.5	0.99	102
Arsenic	60	14.1	0.26	80.7
Barium	59	181	0.43	900
Beryllium	53	1.03	0.1	6.2
Cadmium	61	9.7	0.005	44.9
Chromium	61	31.2	3.9	105
Lead [b]	63	287	3.1	2620
Mercury	57	0.33	0.003	2.9
Nickel	45	19.9	3	66
Selenium	52	12.2	0.1	103
Silver	56	5.9	0.25	40.7
Thallium	57	33.5	0.44	450

(From USEPA 1995)

[a] Metals data sources include 1992 PCA, EPA sampling data, and public comments on the RTC.

[b] The median value for lead is 113 mg/kg.

The CKD present at the site was subsequently designated as a Washington State dangerous waste (Ecology, 1994).

Volatile and semi-volatile organic compounds are generally not found in CKD due to the combustion of these compounds at the high temperatures encountered in the kiln. However, generally low concentrations of 2,3,7,8-substituted dioxin (0.5 to 20 parts per trillion (ppt)) and 2,3,7,8-substituted dibenzofuran (non-detected to 470 ppt) were detected (USEPA, 1995).

1.4 Need for a Standard

Although CKD is a solid waste under RCRA, present Federal regulations only apply to landfills used to dispose of hazardous wastes (under RCRA Subtitle C) and municipal wastes (under RCRA Subtitle D). Unless covered by existing state regulations or the cement manufacturing facility burns RCRA hazardous waste, CKDLF units are not required to comply with any operations code, meet any design criteria, or monitor for off-site leachate migration. The findings of EPA’s 1995 Regulatory Determination (supported by the Report to Congress, the NODA, and subsequent work) demonstrate that new regulatory controls under RCRA are justified based on potential and actual impacts to ground water from current CKD management practices.

Screening level risk analyses showed that CKD poses a potential threat to ground water resources at cement plants land disposing CKD over aquifers located in physiographic areas characterized by karst topography[4], and more than half of cement plants in the United States are located in karst areas. Due to the methodological limitations of quantitative modeling of karst hydrogeologic settings, EPA is using damage cases to document potential risks to ground water posed by the mismanagement of CKD. Damage cases account for actual site conditions that cannot be replicated easily in risk modeling (e.g., karst hydrogeology, combined contamination from other release sources, or elevated background levels of chemicals at specific sites), or consider non-compliance or upset situations that are not considered within the scope of a risk assessment. These damage cases are described in Chapter 2 of this background document.

The proposed regulatory controls to protect ground water resources at CKD disposal sites were developed after an evaluation of a range of potential landfill designs and consideration of regulatory mechanisms already in place to protect ground water at municipal solid waste landfills and hazardous waste landfills. The framework of how the proposed CKD waste management regulations were developed is described in Chapters 3 and 4. The proposed regulations to control the release of waste CKD constituents to ground water are summarized in Chapter 5. An evaluation of how effectively the standards are expected to perform and factors to be considered during implementation of the rule are discussed in Chapter 6 and 7, respectively. The proposed ground water controls are flexible, and can be tailored to site-specific conditions. EPA believes this approach avoids over regulation and provides adequate environmental protection at a reasonable cost.

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[4] A type of topography that is formed on limestone, dolomite, gypsum, and other soluble rocks by dissolution. It has a distinctive hydrogeology and landforms, composed of soluble rocks and well developed secondary porosity enhanced by dissolution. Ground water flow generally occurs through an open system with both diffuse and conduit flow end member components, and typically has rapid ground water flow velocities. See Sections 2.2.1 and 2.2.2 of this Technical Background Document for additional information on the dangers posed by CKD disposal in karstic hydrogeologic settings.

References

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USEPA, 1993. *Report to Congress on Cement Kiln Dust, Volume II Methods and Findings*. EPA Office of Solid Waste. December 1993.

Chapter 2: Reasons for Agency Concern

This chapter summarizes the Agency's concern about past and current CKD waste disposal practices. This chapter focuses on the dangers posed by mismanagement of CKD and the causative factors for the release of CKD constituents into the subsurface environment. At least thirteen CKD disposal sites have been identified where ground water has been contaminated with CKD constituents. These ground water damages cases are described in Section 2.1. Many of the damage cases involve release of CKD constituents into karst aquifers which are characterized by conduit ground water flow (Section 2.2) and to wetlands (Section 2.3). Contamination of karst aquifers and wetlands poses a unacceptable threat to human health and the environment. In Section 2.4, the Agency concludes that current CKD waste management practices are inadequate and that it is necessary to establish performance standards and technical design standards for CKD waste management units.

2.1 Dangers to Ground Water Posed by Management of CKD

In the Report to Congress on CKD (USEPA, 1993a) and the subsequent Notice of Data Availability (NODA) (59 FR 47133) and Regulatory Determination (60 FR 7366), EPA presented data showing CKD contains certain toxic metals (40 CFR Part 261 "Appendix VIII - Hazardous Constituents"), low concentrations of dioxin and dibenzofuran, and when mixed with water often exhibits the characteristic of corrosivity (40 CFR Part 261.22)[1]. EPA documented evidence of damage to ground water and identified potential risks to human to human health and the environment from on-site management of CKD. Evaluation of CKD management practices, site-specific hydrogeologic information, and damage cases revealed potential risks not identified by means of conventional risk modeling studies. For example, screening level and subsequent modeling did not adequately model the intrinsic on-site variability of current CKD disposal practices. Neither the MMSOILS model nor the EPACMTP model can simulate disposal below the ground water table, which is a factor in some of the damage cases. Also, EPA has determined that approximately half of all cement plant sites are underlain by carbonate formations (limestone or dolomite) which may exhibit a distinctive hydrology typical of karst settings (60 FR 7366). In karst hydrogeologic settings, CKD leachate potentially can enter ground water in a relatively undiluted state and rapidly migrate off-site through open conduits enhanced by dissolution. In addition, EPA has found that on-site management practices for CKD include land-disposal of CKD in quarries below the natural water table and in unlined landfills, piles, and ponds. CKD landfills generally lack liners, covers, leachate controls, or run-on/run-off collection systems.

For these reasons, EPA developed and applied an alternative screening analysis. The results of this analysis, as described in Section 2.2.2, showed that CKD poses a potential threat at cement plants land-disposing CKD over karst aquifers.

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[1] EPA hazardous waste identification rules do not include a characteristic or definition for solid corrosives.

EPA also prepared new damage case reports to supplement those prepared for the Report to Congress (RTC) and the NODA. Damage cases account for actual site conditions that cannot be replicated easily in risk modeling (e.g., complex, site-specific contaminant fate and transport). Damage cases also can account for regulatory non-compliance or upset situations that are not captured by risk modeling. In areas where the quantitative modeling results are limited or cannot be generated because of methodological limitations, EPA is using the damage cases to document releases to ground water posed by current CKD management practices.

2.1.1 Ground Water Damage Cases

In the 1993 RTC, EPA identified and documented 19 cases of damage to ground water and surface water in response to Section 8002(o)(4) of RCRA which required EPA to study CKD waste to examine "documented cases in which danger to human health or the environment has been proved".[2] Of these 19 damage cases, five cases documented damages to ground water. EPA's analysis of documented evidence of damage showed that migration of potentially hazardous constituents, including toxic metals, has occurred from cement kiln dust waste sites.

Since publication of the RTC and the Regulatory Determination on Cement Kiln Dust (see 60 FR 7366), eight additional ground water damage cases came to the attention of the Agency (USEPA, 1997a). In total, thirteen of these damage cases involve contaminant releases to ground water, and these cases are summarized in Table 2-1. Each of the cases presented in Table 2-1 meets the requirements outlined in Section 5.0 of the Report to Congress (USEPA, 1993a). These "tests of proof" consist of three separate tests; a case that satisfies one or more of these tests is considered "proven." The tests are as follows:

- <u>Scientific investigation</u>. Damages are found to exist as part of the findings of a scientific study. Such studies should include both formal investigations supporting litigation or a state enforcement action, and the results of technical tests (such as monitoring of wells). Scientific studies must demonstrate that damages are significant in terms of impacts on human health or the environment. For example, information on contamination of a drinking water aquifer must indicate that contamination levels exceed drinking water standards.[3]

- <u>Administrative ruling</u>. Damages are found to exist through a formal administrative

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[2] These documented and potential damages from the management of cement kiln dust are described in Chapter 5 of the *Report to Congress on Cement Kiln Dust* (see 59 FR 709, January 6, 1994) and subsequent Notice of Data Availability (see 59 FR 47133, September 14, 1994). Supporting documentation for damage cases described in the Report to Congress and subsequent Notice of Data Availability are available for public inspection in the USEPA RCRA Docket Nos. F-94-RCRA-S0106 to -S0179, and F-94-RC2A-S0003 to -S0015. Additional documentation of six ground water damage cases is provided in a Technical Background Document entitled "Additional Documented Damages to Ground Water from the Management of Cement Kiln Dust" (USEPA, 1997a).

[3] EPA recognizes that comparison of drinking water standards and constituent levels in ground water is not routine, but because of the lack of benchmark standards for constituents in leachate, the Agency believes it is a useful comparison.

ruling, such as the conclusions of a site report by a field inspector, or through existence of an enforcement action that cited specific health or environmental damages.

- Court decision. Damages are found to exist through the ruling of a court or through an out-of-court settlement.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Alamo Cement Co. - Highway 281 Disposal Area, San Antonio, Texas	An unknown quantity of CKD and mine overburden waste was disposed of in two landfills at a now abandoned cement manufacturing facility. One landfill has a clay liner and cap. The other, a quarry covered with a clay cap, contains CKD, chromium brick, and an estimated 40 million gallons of leachate. Falling leachate levels suggest downward migration into the underlying faulted bedrock. However, elevated levels of Cr or pH have not been detected by surrounding monitoring wells. A golf course has been constructed on the site, and lands adjacent to the quarry have been converted into residential areas. In 1990, a plan to close the facility as a Class I Non-Hazardous Industrial Solid Waste Management Facility was submitted to the Texas Natural Resources Conservation Commission (TNRCC) and approved, with modifications, in 1992. On February 14, 1994, a letter from TNRCC rejected the plan, requested a post closure plan, stated that the Texas Water Code had been violated and that falling leachate levels in the landfill indicated that a release had occurred.	Releases beyond facility boundary undetermined. *Within landfill* (a) exceeds EPA's toxicity level: Cr; (b) elevated: pH	Possibly ground water infiltration into the pile	The site is located in karst terrain. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) could have prevented releases.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Ash Grove Cement Plant, Chanute, Kansas	CKD disposed in two landfills located in a nearby abandoned limestone quarry. One landfill has been inactive since the early 1970s. The other is a permitted solid waste landfill a part of which is used to dispose of CKD. In early 1996, disposal activities began in the formerly unused portion of the landfill. On March 16, 1996, the Kansas Department of Health and Environment (KDHE) filed a Notice of Non-Compliance with the plant after a KDHE inspector noted seeps with elevated pH values leaving the landfill and entering a local tributary of the Village Creek. In response, Ash Grove conducted a site assessment which included a hydrogeologic investigation, and implemented immediate remediation control measures. Approximately 3,000 people and one private well are within 1.6 km (one mile) of the main facility. *Implemented Controls:* surface regrading, interim trench pumping, application to dispose of deactivated leachate at Chanute's POTW. *Proposed Controls:* interceptor trench with geosynthetic liner, pump and treat trench leachate.	*Ground Water* (a) exceeds MCLs: As, Be, Pb; (b) exceeds Federal Secondary Drinking Water Standards: Fe; (c) elevated: pH *Surface Water* elevated: pH	(a) Surface water (rain) infiltration and percolation through the landfill and underlying fractured Paola Limestone unit, and (b) man-made drainage features (e.g. drainage sumps and ditches) cut into the former quarry floor that facilitate gravity-driven lateral ground water flow through the landfill.	The landfills are underlain by a limestone unit with a high potential for conduit (non-Darcy) flow. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) could have prevented releases.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Holnam Inc., Mason City, Iowa	From 1969 to 1985, CKD was landfilled in an abandoned, unlined quarry partially filled with precipitation and ground water (water table rises into quarry). Two shallow aquifers in vicinity of facility supply potable water. In 1980, the quarry water pH had risen to 12.8. A quarry dewatering program was initiated in 1987 and resulted in lowering the pH level to 10.5 by 1990. A blowout, or seep, was observed in quarry wall in 1984, with high pH (11.3) and elevated SO_4, Na, K, and phenol. This seepage flowed to Calmus Creek, which exhibited elevated turbidity, SO_4, and K. The State of Iowa ordered Holnam to cease disposal of CKD in quarry in 1985. Elevated pH levels in Calmus Creek resulted in a fish kill in September 1986. The site was listed on the NPL in August, 1990 due to contaminated surface and ground water, primarily elevated pH and mineral deposition. The site was removed from the NPL in 1996. *Implemented Controls:* Facility ceased disposal in the quarry in lieu of recycling CKD to kiln. Also completely dewatered quarry in 1989; constructed drain system in quarry to collect run-off and ground water inflow; placed clay cap over CKD in quarry to minimize infiltration; and installed bedrock extraction wells to prevent migration of contaminated ground water from site.	*Ground Water* (a) exceeds Federal. Primary Drinking Water Standard Cr; (b) exceeds Federal. Secondary Drinking Water Standards: pH, TDS, Fe, SO_4 *Surface Water* exceeds state standard: pH in Calmus Creek	(a) Disposal of CKD in quarry below water table, creating hydrogeologic communication with ground water, (b) overland flow of quarry water to Calmus Creek, and (c) ground water discharge to Calmus Creek.	The site is located in a karst area and CKD is disposed below the natural water table. A prohibition on disposal of CKD below the natural water table would have prevented direct contact of CKD leachate and ground water. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) could have prevented releases.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Lehigh Portland Cement Co., Mason City, Iowa	This plant lies to the north of the Holnam Inc. site. Calmus Creek flows between the two plants. Prior to beginning landfilling CKD in 1986, Lehigh deposited CKD at various locations throughout site, including several inactive quarries and on a site adjacent to the Winnebago River known as the "Badlands" area. Elevated pH was observed in 1981 in one of the four quarries. In 1984, it was found that contamination of Calmus Creek was related to discharges from one of the quarries via a tile drain outlet. The discharges exhibited a pH of 11.4 and TDS of 4,700 mg/L. At the State's request, Lehigh eliminated discharge to the creek. EPA determined in 1987 that the quarry ponds and ground water underlying the site were contaminated. Elevated pH was also observed in ground water beneath the Badlands area. Ground water underlying the adjacent Lime Creek Nature Center, a past disposal site, was also found to be contaminated during a RI/FS investigation conducted in 1989-90. EPA listed the site on the NPL in 1990, but following litigation, removed the site due to issues regarding the site's hazard ranking score. *Implemented Controls:* Diversion ditches, dikes, capping and slurry walls around quarries. A water treatment system was constructed.	*Ground Water* exceeds (a) Federal primary drinking water standards: As, Pb; (b) exceeds Federal Secondary Drinking Water standards: pH, TDS, SO_4, Fe *Surface Water* exceeds State surface-water discharge standards: pH	(a) Disposal of CKD in quarry below water table, creating hydrogeologic communication with ground water, (b) overland flow of quarry water to Calmus Creek, and (c) ground water discharge to Calmus Creek.	The site is located in a karst area, and CKD is disposed below the natural water table. A prohibition on disposal of CKD below the natural water table would have prevented direct contact of CKD leachate with ground water. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) could have prevented releases.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Medusa Cement Co., Charlevoix, Michigan	CKD (2 million tons since 1968) disposed of in nine different piles in an abandoned, on-site quarry underlain by fractured limestone bedrock. The present quarry floor is approximately 31 feet below Lake Michigan's water level. Medusa estimates that 75% of the materials have been placed above ground surface. At pile 9 (current disposal site), a portion of the CKD is below the water table. A dewatering system is in place to control shallow ground water flow at the base and rim of the quarry. Surface runoff from the base of the quarry is discharged into Lake Michigan in accordance with an NPDES permit. Leachate impacted ground water from piles 4, 5, 6, and 9 within the quarry appear to be responsible for several discolored seeps on the Lake Michigan shoreline. Three private water wells are within one-half mile of piles 6 and 9.	*Ground Water* (a) exceeds Michigan GSI regulatory limit: Cu, Mn, Ni, Se; (b) exceeds HBDW limit: Se; (c) exceeds State Aesthetic Drinking Water Value: Fe; (d) elevated: pH, K, Cl, SO_4 *Surface Water* elevated: pH, As, K	(a) Infiltration of ground water into the CKD materials, and (b) the movement of leachate impacted ground water into the shallow flow system at the rim of the quarry and into the deeper bedrock aquifer via conduit flow.	The site is within a matured karst terrain that is characterized by numerous sinkholes, closed depressions and vertical shafts that extend beneath the land surface. Proposed ground water controls (including a composite liner, leachate collection system, effective dewatering system that extended at least 150 meters from the landfill, stormwater management controls, and a ground water monitoring system) could have reduced surface and ground water damage. However, additional engineering measures might be required to prevent releases through the highly fractured and porous limestone walls of the quarry.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Penn-Dixie Cement, Petroskey, Michigan	The site, approximately 430 hectares (1060 acres), lies along 10 km (6.5 miles) of Little Traverse Bay shoreline which is adjacent to Lake Michigan. It has been inactive since approximately 1980, when it was purchased by the Bay Harbor Company for redevelopment into a resort area. CKD was disposed of on-site in three piles overlying fractured limestone bedrock. Impacted ground water and surface runoff flow into Lake Michigan from one large pile (the central western pile). Ground water damage is also attributed to the eastern pile. Surface water damage was documented in the damage case supporting the 1994 Notice of Data Availability. Hydrogeologic investigations of the central western and eastern piles were conducted as part of the Bay Harbor Administrative Agreement and a Covenant-Not-To-Sue between the developers and the State of Michigan. In 1995, a Closure Activity Plan was initiated.	*Ground Water* exceeds (a) MCL: Pb; (b) Federal Secondary Drinking Water Standards: pH, TDS; (c) State Ground water Criteria: Na, SO_4, As, Fe, Pb, Cd; (d) State Water Quality Standards: As, Cr, Cu, Pb, Hg, Ni	(a) Surface water (precipitation) infiltration into the pile; (b) possibly ground water infiltration into the pile	Since the site is in a karst terrain, CKD disposal in a covered landfill with a bottom liner, leachate collection system, stormwater management system, and a ground water monitoring and sampling system could have prevented impact on surface water and ground water. Damage could also have been avoided if location restrictions on siting the landfill adjacent to the lake had been in place.

Table 2-1. Summary of Documented Ground Water Damages

Site	**Damage Case Summary**	**Reported Releases**	**Causative Factors**	**Effectiveness of Proposed Ground Water Controls**
Signal Mountain Cement Co., Chattanooga, Tennessee	Approximately 900,000 metric tons of CKD were disposed of by the previous owner, General Portland Cement Company, in a closed landfill located in an old on-site quarry. CKD was also emplaced in wall cavities adjacent to the landfill. These cavities are connected to underground caverns beneath Signal Mountain. Ground water from the cavities and surface runoff from the landfill discharge into a tributary of the Tennessee River. The plant is located near to the Signal Hills and Carriage Hill communities. Since 1977, the State has attempted to have the discharges brought into compliance with its effluent standards. After a 1994 State inspection, a NOV was issued to the current owner. *Proposed Controls:* Dewatering the landfill to (a) prevent ground water seeps and (b) control annual recharge.	*Ground Water* exceeds Federal Secondary Drinking Water Standard: pH *Surface Water* exceeds RCRA hazardous characteristic of corrosivity: pH	(a) Disposal of CKD into ground water pools inside quarry cavities, (b) ground water infiltration into the pile, and (c) uncontrolled surface runoff from the pile	The site is located in a mature karst terrain. Stormwater management and proposed ground water controls for CKD landfills (composite liner with leachate collection system and ground water monitoring system) could have prevented surface and ground water damage.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Southdown, Inc., Fairborn, Ohio	CKD disposed in ten unlined landfills in on-site quarries between 1924 and 1978. Contaminant releases have been observed in surface and ground waters adjacent to Landfills #1 and #6. Ohio EPA collected samples from seeps and streams at the toe of Landfill #6 having elevated levels of As, Fe, Se, Pb, and pH. Ground water samples revealed elevated levels of As, Fe, and Se. In 1992, OEPA issued an administrative enforcement order requiring a CERCLA Remedial Investigation and Feasibility Study; as of December, 1993, this study had yet to be initiated. OEPA also reported elevated levels of As, Fe, and Se in seeps at the toe of Landfill #1.	*Ground Water* exceeds (a) Federal primary drinking water standards: Pb; (b) State drinking water standards: As, Cd, Cr, Ni *Surface Water* exceeds State drinking water standards: As, Cd, Cr, Fe, Se, pH	Disposal of CKD in unlined landfills. CKD leachate released to ground water and surface water.	The site is located in a karst area. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) could have prevented releases to ground water.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Texas Industries, Inc., Midlothian, Texas	In 1992, Texas Water Commission inspectors observed pools of reddish-brown liquid seeping from an inactive, unlined CKD pile that lies in the facility's quarry. Elevated levels of As, Pb, and pH were observed. TWC issued a NOV letter to the facility for violations of solid waste rules. After a subsequent inspection yielding similar results, EPA filed a letter of complaint for violations of RCRA Subtitle C regulations. Though seepage was observed only in localized pools, potential is believed to exist for contaminant to migrate beyond plant boundaries. In particular, uncontrolled run-off from the CKD pile would flow into two adjacent streams. Furthermore, the TWC concluded in a 1990 inspection that the potential exists for contaminant release from both the active and inactive landfills due to (1) a shallow water table, (2) a high volume of dust in the active disposal area, (3) the lack of a landfill liner, and (4) the proximity of the active landfill to ponded water.	No off-site releases observed. *Potential Releases to Surface Water* elevated: As, Pb, Cr, and pH in pools collected at the base of the inactive CKD pile. *Potential Releases to Ground Water* elevated pH, laboratory conductivity significantly above background elevated Pb, Cr, Cd in soil	(a) Disposal of CKD in unlined piles in a quarry overlying shallow ground water, creating potential for contaminant migration to nearby perched ground water bodies (b) potential for storm water run-off from CKD piles to enter adjacent streams. Ground water contamination attributed to rain water percolating through CKD.	The site is located in a karst area. Proposed ground water controls for CKD landfills in karst (composite liner with a leachate collection system) would prevent potential releases to ground water. Furthermore, the Agency's storm-water permitting program would require run-on/run-off controls that could prevent surface water contamination.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Lehigh Portland Cement Co., Metaline Falls, Washington	Until 1989, CKD (estimated to be approximately 544,000 tons) was disposed in a waste pile along the margin of Sullivan Creek valley. The creek is populated by cutthrout trout and drains to the Pend Oreille river. Ground water flowing beneath the pile appears to discharge to seeps and springs along the creek, as well as to wetlands and distributary channels adjacent to the creek. Damage to soil, surface and ground water is documented. In 1981, the State began enforcement of RCRA and its solid waste and water pollution control laws. In 1989, Lehigh sold the facility to Lafarge Corporation. Ownership of the CKD disposal site was retained. Since 1990, the State has sought closure of the disposal site. In 1995, Lehigh submitted its Final Closure Plan which was later revised on April 11, 1996. A "Post Closure Care and Maintenance Plan" has also been presented. *Implemented Controls:* regrade the pile, construct and maintain a cover, construct and maintain a storm water management system, and continue ground water sampling and monitoring to determine if cap construction reduces surface water infiltration and improves the ground water quality of the site.	*Ground Water* (a) exceeds MCLs: Ag, As, Cr, Ni, Pb, Tl, pH, Fe; (b) exceeds State MTCA A Cleanup Level: As, Ba, Cr, Cd, Ni, Ag, Tl, Pb, pH; (c) exceeds State water quality levels: pH, Fe *Surface Water* exceeds State MTCA B Cleanup Level: pH, Pb, As, Hg, Se, Zn *Soil* elevated: pH, Cr	(a) Ground water seepage into the pile, (b) capillary rise of the ground water table into the pile, and (c) surface water infiltration into the pile.	The waste pile is located near to a floodplain and wetlands area, and underlain by limestone bedrock. Location restrictions (such as those for solid waste landfills), a storm water management system, and the proposed ground water controls for CKD landfills (a cover, composite liner, leachate collection system), could have prevented surface and ground water damage.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Markey Machinery Property, Seattle, Washington	Site consists of a four-acre CKD landfill on industrial property located within 4,000 feet of the Duwamish River, a state-designated fishery. CKD is believed to have been disposed by Ideal Cement. Run-off from the site flows to Ham Creek, which discharges to the Duwamish River. Depth to ground water is less than 25 feet. Ground water samples collected in 1989 revealed concentrations of metals below drinking water limits, but lead concentrations exceeded state cleanup levels. Surface-water samples collected from a ditch on the eastern edge of the site had a pH of 10.2 and a lead concentration approximately 25 times the federal drinking water limit. The state has ranked the site three on a scale of one to five, with one representing the highest level of concern and five the lowest.	No off-site releases observed. On-site surface water concentrations of Pb observed at levels 25 times the federal drinking water standard. *Potential Releases to Surface Water:* Elevated pH and Pb. *Potential Releases to Ground Water:* Elevated levels of Pb. Elevated levels of As, Cu, Pb, and Zn in soils exceeding state soil cleanup standards	(a) Large volume (38,250 cubic meter) of CKD; (b) absence of run-on/run-off controls, cover, liner, or leachate containment system; (c) proximity to population center; and proximity to waters designated as a state fishery.	Use of a composite liner and leachate collection system could prevent ground water damage. Best management practices required under the NPDES storm-water permit system would alleviate concern over run-off to the Duwamish River.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
National Gypsum Co., Alpena, Michigan	National Gypsum formerly disposed CKD on a 30 hectare site on the shore of Lake Huron. Disposal began in the early 1900s and ceased in 1986, when Lafarge took over operations. Erosion channels from the pile lead to the lake, and wave action has eroded the pile's southern edge. Surface water samples collected from the erosion channels and Lake Huron show levels of As and Pb in excess of state standards specified under the Michigan Environmental Response Act. The state has negotiated interim response actions with the company to prevent further erosion and deposition of contaminants into the lake. New information indicates the pile has contributed to ground water contamination. Monitoring wells located adjacent to and hydraulically downgradient of the pile (on the Systech property) show ground water contamination attributable to the pile. *Implemented Controls:* Final closure and a maintenance and monitoring plan for the site are in progress. No ground water response actions have been proposed as no ground water contamination has been detected in the monitoring wells currently on the Lafarge property.	*Ground Water* exceeds State cleanup criteria: Cl, SO_4, Ba, Cr, Pb *Surface Water* exceeds State standards: As, Pb *Soil* exceeds State soil cleanup criteria: As, Se, Zn, Pb	(a) Location of the pile along the shores of the lake, (b) lack of surface water runoff controls, (c) surface water (rain) infiltration into the pile, and (d) CKD leachate released into the ground water.	The area is underlain by a limestone bedrock. Releases could have been prevented if (a) CKD had been disposed of in a landfill with a cover, a bottom liner, a leachate collection system, a stormwater management system, and a ground water monitoring system, and (b) location restrictions had been applied to prohibit siting of the landfill next to a lake.

Table 2-1. Summary of Documented Ground Water Damages

Site	Damage Case Summary	Reported Releases	Causative Factors	Effectiveness of Proposed Ground Water Controls
Portland Cement Company, Salt Lake City, Utah	From 1965 to 1983, CKD was disposed in five off-site, unlined piles in and around Salt Lake City. The two largest sites are listed on the NPL as the Portland Cement Superfund Site. This site is adjacent to two surface water features, a storm water drain and an irrigation canal. Chromium-bearing refractory bricks were co-disposed with the dust. The Record of Decision concluded that soil, ground water and surface water are contaminated with CKD constituents (As, Cr, Pb). A contaminant plume is present in shallow ground water underlying and adjacent to the piles, with elevated pH, Mo, As, Cr, Cd, and Pb. In addition, elevated pH, Pb, and As have been observed in surface water at the site. *Implemented Controls:* Excavation and off-site disposal of CKD and As- and Pb- contaminated soil in a state-approved, solid waste landfill. Off-site disposal of chromium-bearing bricks at a hazardous waste TSD facility. A minimum of two feet of clean backfill will be used to cover the site and additional ground water monitoring and institutional controls will be initiated following CKD removal actions in 1997.	*Ground Water* exceeds Federal Primary or Secondary Drinking Water Standards: As, Cd, Cr, Pb, pH, TDS *Surface water in On-Site Ephemeral Ponds* exceeds Federal Primary or Secondary Drinking Water Standards: As, Pb, pH *Surface Water in City Storm Water Drain* contains elevated levels of K and pH.	(a) Disposal of CKD in unlined piles overlying shallow, unconfined ground water adjacent to surface water features; (b) lack of surface-water controls.	Location restrictions against CKD disposal in wetlands, floodplains, and below the natural water table could have prevented damage to ground water. EPA's new storm water permit program could have prevented the surface-water damages through best management practices such as run-on/run-off controls.

Al=aluminum, As=arsenic, Ba=barium, Be=beryllium, Cd=cadmium, Cl=chloride, Cr=chromium, Cu=copper, F=fluoride, Fe=iron, Hg=mercury, Pb=lead, Mn=manganese, Mo=molybdenum, Ni=nickel, K=potassium, Se=selenium, Na=sodium, SO_4=sulfate, Tl=thallium, TDS=total dissolved solids, Zu=zinc

In 12 of the 13 damage cases listed in Table 2-1, Federal Primary or Secondary Drinking Water Maximum Contaminant Levels [MCLs] or state clean-up levels were exceeded in ground water. At one additional site, Alamo Cement in San Antonio, Texas, no analytical ground water data are available but regulators with the Texas Natural Resource Conservation Comission have stated that declining leachate levels in the landfill indicate releases of hazardous constituents into waters of the State. At eight of the ground water the damage case sites, concentrations of arsenic, beryllium, cadmium, chromium, lead, selenium, and/or thallium exceed the Federal Primary Drinking Water MCLs.

Of the thirteen ground water damage cases, the Portland Cement Company site in Salt Lake City, Utah is listed on the Superfund National Priority List (NPL) Holnam, Inc. and Lehigh Portland Cement Company sites in Mason City, Iowa were formerly listed on the NPL. The Holnam site is remediated and the Lehigh and Portland Cement Company sites are in the process of remediation. Constituents of concern most commonly released to ground and surface waters included arsenic, chromium, and lead, and contaminated waters also show a significant increases in pH. When constituents were found at elevated levels, they were generally less than two orders of magnitude above Federal or State MCLs for drinking water.

Although environmental releases and resultant damages generally affected the area in the immediate vicinity of the waste disposal site, in some cases, nearby wetlands and streams that are off-site were also impacted. For example, releases of toxic constituents from the Lehigh and Holnam facilities in Mason City, Iowa caused severe degradation of the aquatic habitat in nearby Calmus Creek. Discharges of contaminated water from surface water run-off, drainage tiles, and ground water seeps to Calmus Creek resulted in a fish kill in September 1986 and a dominance of pollution-tolerant fish and benthic species for about 2 miles down stream from the two facilities (USEPA, 1997b and 1997c).

Releases from the Lehigh and Southdown, Inc. CKD disposal units in Metaline Falls, Washington and Fairborn, Ohio, respectively, have resulted in ground water and local surface water contamination and pose a threat to wetland environments. Off-site ground water seeps near the Metaline Falls facility have been documented to be very alkaline (pH up to 14 SU) and to contain elevated concentrations of lead (up to 0.027 mg/L) and arsenic (up to 0.077 mg/L) (USEPA, 1997d). Surface water at the Fairborn facility have pH levels as high as 13.6 SU and contained elevated concentrations of arsenic (up to 0.83 mg/L), cadmium (up to 0.02 mg/L), chromium (up to 0.105 mg/L), lead (up to 0.070 mg/L) and selenium (up to 0.07 mg/L) (USEPA, 1993a). Damages to wetlands and surface water bodies from CKD units are discussed in greater detail in Section 2.3.

2.1.2 Factors Responsible for the Release of CKD Constituents into the Environment

As documented in Table 2-1 there are many factors which have contributed to causing the release of CKD constituents to ground water or the subsurface environment. Factors which are noted to have contributed to the release of CKD constituents into the sub-surface environment include:

- Presence of a shallow ground water flow system with conduit flow characteristics (e.g., karst aquifer or fractured bedrock aquifer) (Alamo Cement, San Antonio, TX; Ash Grove, Chanute, KS; Holnam, Mason City, IA; Lehigh, Mason City, IA; Medusa, Charlevoix, MI; and Signal Mountain, Chattanooga, TN);

- CKD disposal below the natural water table or ground water infiltration into the waste unit (Ash Grove Cement, Chanute, KS; Holnam, Mason City, IA; Lehigh, Mason City, IA; Medusa, Charlevoix, MI; Penn-Dixie, Petrosky, MI; Signal Mountain, Chattanooga, TN; Southdown, Fairborn, OH; Lehigh, Metaline Falls, WA; Portland, Salt Lake City, UT);

- Lack of a bottom liner and/or leachate collection system to control leakage from the waste unit (all ground water damage cases);

- Lack of an impermeable cover to control percolation of rain water and/or surface water into the waste unit (none of the damage case sites maintained a cover during the active life of the disposal unit);

- Surface run-off or erosion transporting CKD constituents to surface water bodies and/or wetlands which can serve as a source of ground water recharge (Holnam, Mason City, IA; Lehigh, Mason City, IA; Signal Mountain, Chattanooga, TN; Southdown, Fairborn, OH; National Gypsum, Alpena, MI; Portland Cement, Salt Lake City, UT); and

- Construction of man-made drainage features which contributed to the lateral migration of CKD constituents (Ash Grove, Chanute, KS).

The frequency at which the first five of these factors has occurred at the thirteen CKD ground water damage case site is presented in Table 2-2. All of the damage cases were associated with CKD waste units which did not have bottom liners, leachate collection systems and impermeable covers in place during the active disposal period. Since the release, a number of these facilities have installed impermeable covers and/or dewatering systems to minimize the migration of CKD constituents and mitigate further environmental damage.

The damage cases presented in Table 2-1 and Table 2-2, indicate that conduit ground water flow in karst aquifers and in fractured bedrock is an important factor in the migration of CKD constituents in the subsurface environment for at least six of the damage case sites.

Disposal of CKD below the natural water table is of particular concern to EPA. Contaminated ground water and surface water near at least nine of these facilities resulted primarily from CKD disposal below the water table and/or from direct CKD contact with the shallow ground water system. Figured predominantly among these damage cases are three sites that were listed on the NPL (Holnam, Mason City; Lehigh, Mason City; and Portland, Salt Lake City). At the two

Mason City sites, contaminant migration was facilitated by diffuse and conduit flow within a fractured and locally karstic limestone formation. The environmental dangers posed by CKD releases to karst aquifers and wetlands/surface water bodies are discussed in more detail in Sections 2.2 and 2.3, respectively. As discussed in greater detail in Chapter 3 and 6 of this background document, the Agency believes the use of ground water controls such as bottom liners, impermeable landfill covers, and leachate collection systems will minimize the threats to ground water such as those documented in the damage cases, especially in areas with karst hydrogeologic environments.

At many of these sites, environmental damages are persistent and continuing. Receipt of additional environmental monitoring data since the 1995 Regulatory Determination has enabled the Agency to identify eight more cases of ground water damage (USEPA, 1997a). This indicates that damage to ground water resources near CKD disposal sites may be more common that originally thought in 1995. At the former National Gypsum (Alpena, Michigan), Penn Dixie Cement (Petoskey, Michigan), and Texas Industries (Midlothian, Texas) sites ground water contamination has been found which corroborated the surface water damage cases which were reported in the 1993 RTC. Many of these sites have been slow to implement remedial measures to control off-site migration of contaminants. For example at the old National Gypsum waste pile, CKD has been eroding into Lake Huron over a number of years.

At only seven of the ground water damage case sites have remedial measures been initiated, such as removal of contaminated materials (i.e., Portland Cement Co., Salt Lake City, Utah), installation of an impermeable cap and/or construction of a seep/ground water extraction and treatment system. Releases from the Portland Cement Superfund Site in Salt Lake City, Utah have resulted in a ground water plume of about 50 acres in size with arsenic, chromium, cadmium, and lead concentrations exceeding Federal and Utah drinking water MCLs. The clean up costs associated with excavation and off-site disposal of CKD, contaminated soil, and chromium-bearing refractory bricks have exceeded $30 million at this site (USEPA, 1997e).

The Agency expects that there are many other CKD disposal sites with damages to ground water, besides those listed in Tables 2-1 and 2-2. Based on the Portland Cement Association (PCA) Plant Information Summaries for the years 1974, 1990, and 1993, there are about 1200 inactive CKD piles located at 96 active and 95 inactive cement plants in the United States. At the end of 1995, approximately 180 million metric tons of CKD was stored in these piles (SAIC, 1996). It was noted in the 1995 Regulatory Determination, that of the 14 CKD disposal sites where ground water monitoring data have been collected, all but one of the sites indicate some ground water contamination has occurred (60 FR 7366). Clearly there is a need to perform ground water monitoring at CKD disposal sites in order to identify and remediate contaminated ground water and to evaluate and remediate potential releases to ground water from active CKD landfill (CKDLF) units.

Table 2-2. Factors Contributing to Release of CKD Constituents to Ground Water

Damage Case, City, State (Reference)	Geologic Condition Contributing to Release	CKD In Contact with Ground Water or Disposed Below Natural Water Table?	Bottom Liner Present?	Leachate Collection System Present at Time of Release?	Impermeable Cover Present?	Close Proximity to Wetland or Surface Water Body?
Alamo Cement Co., San Antonio, TX (59 FR 47133)	Faults located in close proximity to landfill. Area underlain by Edwards Limestone which exhibits karst features.	No	One landfill has a clay liner the other is unlined	No, accumulation of rainwater during active period is source of leachate	Yes, clay caps installed during landfill closure	No
Ash Grove Cement, Chanute, KS (USEPA, 1997a)	Fractured limestone bedrock	Portion of landfill located below water table	No	No	No	Seeps from landfill discharged to a local tributary
Holnam, Inc., Mason City, IA (USEPA, 1993a and 1997b)	Shallow karst aquifer	CKD disposed of in a former quarry which later filled up with rain and ground water	No	No, dewatering system installed to collect and treat ground water in the disposal area	86-acre clay cap installed as part of remedial measure	Blow out from quarry disposal area to Calmus Creek resulted in a fish kill
Lehigh, Inc., Mason City, IA (USEPA, 1993a and 1997c)	Shallow karst aquifer	CKD disposed of in former quarries which later filled up with rain and ground water	No	No, dewatering system installed to collect and treat ground water from the disposal area	Clay caps over CKD disposal areas installed as part of remedial measure	Contributed to contamination in Calmus Creek
Medusa Cement Co., Charlevoix, MI (USEPA, 1997a)	Mature karst terrain, shallow karst aquifer	The lowermost portions of three CKD piles are below the water table	No	Quarry dewatering system does not capture all contaminated ground water migrating from disposal site	No	High pH seeps are located near the Lake Michigan shoreline

Damage Case, City, State (Reference)	Geologic Condition Contributing to Release	CKD In Contact with Ground Water or Disposed Below Natural Water Table?	Bottom Liner Present?	Leachate Collection System Present at Time of Release?	Impermeable Cover Present?	Close Proximity to Wetland or Surface Water Body?
Penn-Dixie Cement, Petrosky, MI (59 FR 47133, USEPA, 1997a)	Site underlain by karst and fractured limestone bedrock which potentially facilitated the release	Likely potential for ground water infiltration into CKD waste piles	No	No, sump collection system proposed near seepage areas	Soil cover proposed as part of remedial measures	High pH seepage from CKD piles have flowed into Lake Michigan
Signal Mountain Cement Co., Chattanooga TN (USEPA, 1997a)	Cavernous karst aquifer	CKD disposed of in water-filled quarry cavities	No	No, a landfill dewatering program has been proposed	Unlikely, landfill closed before 1984	CKD sediment and High pH leachate have been released to an unnamed tributary of the Tennessee River since 1977
Southdown, Inc., Fairborn, OH (USEPA, 1993a)	Thin bedded limestone bedrock dominated by diffuse flow ground water system	CKD was landfilled in unlined quarries, high pH seeps near Landfills #1 and #6 indicate that CKD is in contact with ground water	No	None present	Unspecified	Landfill #1 is adjacent to Mud Run, Landfill #6 is adjacent to wetlands
Texas Industries, Inc., Midlothian, TX (59 FR 47133)	Shallow contaminated ground water is perched on shale unit; deeper potentially karst aquifer is not believed to have contributed to the release	CKD disposed of in an unlined quarry, high pH seeps and ponds near one of the waste piles indicate that CKD is in contact with shallow ground water	No	None present	Unspecified	Disposal area is adjacent to two streams
Lehigh Portland Cement Co., Metaline Falls (USEPA, 1997d)	Underlain by alluvial deposits (non-karst)	Lowermost portion of CKD pile below water table	No	None Present	Engineered composite cap installed as part remedial measure	Waste pile adjacent to two intermittent creeks which discharge to Sullivan Creek

Damage Case, City, State (Reference)	Geologic Condition Contributing to Release	CKD In Contact with Ground Water or Disposed Below Natural Water Table?	Bottom Liner Present?	Leachate Collection System Present at Time of Release?	Impermeable Cover Present?	Close Proximity to Wetland or Surface Water Body?
Markey Machinery Property, Seattle, WA (USEPA, 1993a)	Non-karst area	Unspecified if CKD is in contact with ground water	No	No	No	Adjacent to the site are two surface drainages which discharge to Ham Run and Duwamish River
National Gypsum Co., Alpena, MI (USEPA, 1997a)	Waste pile located on carbonate bedrock, but local conditions are not karst	Unspecified	No	No	No	Wave from Lake Huron has eroded the CKD pile for a number of years
Portland Cement Co, Salt Lake City, UT (USEPA, 1993a and 1997e)	Alluvial and lacustrine sediments (non-karst)	CKD was used as fill over alkali saltmarsh land, lower portions of former waste piles were below shallow water table	No	No	No	Site is adjacent to City Drain and Jordan Surplus Canal
Summary	At least 4 cases where karst conditions and 2 cases where fractured bedrock contributed to a release	9 cases where CKD was in direct contact with ground water	13 cases with no bottom liner	13 cases with no leachate collection system; 5 cases proposed or are using ground water dewatering systems	4 cases involve installation of covers during site closure; none used covers during the active life of waste unit	There are concerns over wetlands or nearby surface water features for 12 cases

2.1.3 Current Trends in CKD Waste Management Practices

In the 1993 RTC, it was noted that current waste management practices appear to be inadequate to limit contaminant releases from CKD waste management units (WMUs). According to a PCA survey, 78 percent of all respondents indicated that their landfills had liners, but none included synthetic liners for the year 1990. Only 11 percent of the facilities reported using a modified natural liner. The remainder considered in-situ bedrock or clay/shale units to be liners. Fifty-one percent practice some form of run-off control, but only 18 percent practice some form of leachate control. Approximately 14 percent of existing WMUs use slurry walls around the units, and just 20 percent use other forms of environmental protection including soil caps, clay caps, berms, rip-rap caps, and trees (USEPA, 1993a).

A more recent survey was conducted by the PCA in 1995 (PCA, 1996). According to this survey, sixty-five percent of all respondents indicated that their landfills had liners, but only one respondent (1.5%) used a synthetic liner. About thirteen percent of the respondents used recompacted shale/clay and about thirty-two percent of the respondents used compacted CKD as a bottom liner, respectively. The remainder considered bedrock or native clay/shale materials to be liners. Seventy-seven percent of the respondents claimed to use some form of run-on/run-off controls and twenty two percent used leachate controls. The 1991 and 1995 PCA surveys indicate that CKD waste management practices generally rely on inadequate measures to control the release of contaminants to ground water and that these practices have not changed substantially or have only marginally improved over the past several years.

2.2 Dangers Posed by Location of CKD Disposal Areas Above Karst Aquifers and Highly Fractured Media

The Agency believes that there are increased risks to ground water when CKD is disposed in an area with karst aquifers or highly fractured geologic media. These areas of concern may have ground water flow systems with rapid ground water flow velocities which can exceed the upper limit of Darcy’s Law (e.g., conduit flow). Many cement plants are located in limestone karst areas due to the fact that cement plants frequently locate near a minable source of limestone.

Sections 2.2.1 and 2.2.2 discuss the characteristics of karst aquifers and the dangers associated with disposal in karst areas, respectively. Section 2.2.3 examines the dangers of disposal in non-karst areas but also characterized by ground water systems with non-Darcy, conduit-flow. The Agency’s evaluation of CKD disposal in potentially karst and/or highly fractured areas is summarized in Section 2.2.4

2.2.1 Characteristics of Karst Aquifers and Ground Water Flow

The hydrogeology of karst terrain has been studied extensively due to the importance of karst aquifers as sources of drinking water throughout the U.S. and their susceptibility to contamination. EPA’s Environmental Research Laboratory, Athens, Georgia, prepared a status report on flow and transport modeling karst aquifers (USEPA, undated) that reviews current literature and presents an excellent overview of the physical characteristics of karst terrain. Karst aquifers are characterized by diffuse and conduit ground water flow systems where ground water flow may be very rapid and controlled by fractures and dissolution channels.

The fundamental hydrologic difference between porous media aquifers and karst (and fractured media) aquifers is ground water flow in excess of the Darcian ground water velocity. In mature karst systems, the dominant basin wide flow component is rapid, turbulent ground water movement (non-Darcian flow) through conduits to one or more springs that can vary in magnitude based on the size of the basin and seasonal ground water conditions. A ground water basin in the initial stages of karst development with almost none of or widely dispersed surface features characteristic of a mature karst terrain may have a basin-wide conduit system that consists of small tubes less than one foot in diameter with ground water flow velocities exceeding hundreds of meters per day (Smith, 1997).

Characterization of hydraulic parameters (e.g., porosity, hydraulic conductivity) associated with karst aquifers is much more difficult than that associated with porous media aquifers (e.g., sands and gravel). The difficulty of characterizing karst aquifers with a conduit-flow component is due its heterogenous distribution of the fractures and dissolution channels. Modeling of ground water flow pathways and velocities in a karst aquifer will have a high degree of uncertainty unless there is effort to accurately characterize the hydraulic characteristics of the karst aquifer and to locate the preferential flow paths.

Karst terrain is characterized by both surface and subsurface features such as sinkholes, karst windows, springs, caves, and losing, sinking, gaining, and underground streams (Mull et al., 1988). Sinkholes represent a common hazard in karst terrain and can provide a direct conduit for surface runoff to recharge karst aquifers, potentially acting as a direct source of contamination to the aquifer. Karst aquifers are sometimes difficult to identify, particularly if the karst aquifer is overlain or masked by a competent geologic formation or if affected by recent geomorphic processes such as glaciation or alluviation (covered with stream deposits).

Most karst terrain is underlain by limestone or dolomite rock, although some may be underlain by gypsum, halite, or other soluble rocks. EPA's status report provides a brief overview of how karst aquifers are formed (USEPA, undated). In the limestone and dolomite bedrock systems in which karst aquifers are principally formed, the calcium carbonate and magnesium carbonate forming the bedrock system are dissolved by a weak carbonic acid formed by the dissolution of carbon dioxide in water. Over time, the movement of this weak acid through fissures and pores in the limestone bedrock dissolves the carbonate rock and forms progressively larger openings that facilitate fluid flow through these conduits. This progressive dissolution results in an evolution of karst aquifers over time; "immature" karst aquifers primarily consist of small pores and fractures that may only be interconnected to a limited extent, and "mature" karst aquifers consist of highly interconnected dissolution channels, conduits, and caves that facilitate rapid flow of ground water.

Based the current understanding of karst terrain and the relative importance of karst aquifers as a drinking water source susceptible to contamination, the Agency is proposing the following definition for karst terrains:

> Karst terrains means areas where karst landscape, with its characteristic hydrogeology and/or landforms are developed. In karst terrain ground water flow generally occurs through an open system with both diffuse and conduit flow end member components, and typically has rapid ground water flow velocities which exceed Darcian flow velocities. Composed of limestone, dolomite, gypsum and other soluble rock, karst terrain typically has well developed secondary porosity enhanced by dissolution. Landforms found in karst terrain include, but are not limited to, sinkholes, sinking streams, caves, springs and blind valleys. Karst terrains always include one or more springs for each ground water basin, and underground streams except where ground water flow is diffuse or the host rock has megaporosity.

Ground water flow in karst aquifers is different from ground water flow in porous aquifers because of the common presence of conduits (i.e., fractures, fissures, and large interconnected voids). Ground water flow in porous aquifers can be characterized by Darcy’s Law, which relates the flow rate to the hydraulic gradient, the porosity of the aquifer medium, and the hydraulic conductivity of the aquifer medium. Ground water flow in karst aquifers with a conduit flow component does not follow the conceptual model reflected by Darcy’s Law, but represents a more complex and heterogeneous process. Darcy’s Law does not apply to situations where ground water flow is turbulent and where the aquifer media can not be characterized by a “representative elementary volume” or a volume which permits meaningful statistical averaging of the aquifer’s hydraulic properties. Fractures and dissolution channels in karst aquifers cause ground water to flow along preferential pathways and will have a much higher ground water flow rates (e.g., turbulent flow may occur in large fractures or dissolution channels) than the adjacent media. Ground water flow controlled by preferential pathways (e.g., fractures and dissolution channels) is termed conduit flow, which is in contrast with flow which occurs through out a porous media. Because the distribution of these preferential pathways is often heterogeneous, the porosity and hydraulic conductivity associated with the karst aquifer’s representative elementary volume will have little meaning on a practical (site-specific scale) or have a high degree of uncertainty. Karst aquifers have been classified into three types based on ground water flow characteristics (Mull et al., 1988):

- **Diffuse-flow karst aquifers:** Diffuse-flow karst aquifers form in areas where the solution activity has been retarded, limiting the development of caves and large conduits. Rather than concentrating flow in large caves or conduits, flow occurs through relatively diffuse seeps and fractures.

- **Free-flow karst aquifers:** Free-flow or conduit flow aquifers are characterized by well-defined and integrated systems of enlarged conduits that behave hydraulically, like a system of pipes. Flow velocities are similar to surface streams and are often turbulent. Regional discharge may be through a single large spring. Water levels and flow rates may often respond rapidly to precipitation events.

- **Confined-flow karst aquifers:** Confined-flow karst aquifers represent karst aquifers that are bounded by low permeability confining beds, resulting in karst flow at greater depths than typically found in surficial free-flow aquifers. The flow occurs in systems of interconnected joints rather than the master conduits found in free-flow aquifers.

Because ground water flow in more developed karst aquifers can be similar in nature to surface stream flows, such aquifers can be highly susceptible to contamination. Whereas the relatively slow movement of ground water through a porous aquifer (such as a sand/gravel sedimentary aquifer) can naturally retard or fix through adsorption the movement of organic and inorganic contaminants, there may be little opportunity for contaminant attenuation in conduit flow karst aquifers. Consequently, contaminants entering these aquifers can be transported rapidly to discharge points with only that reduction in concentration associated with the dilution of the leachate in the base ground water flow. The vulnerability of a karst aquifer will vary according to the ability of the waste unit to contain waste constituents, the nature of the contaminant, the presence of surface karst features such as piping or solution conduits, the degree of contact between the infiltrating water and the soil zone, and the type and volume of karst aquifer flow.

Where a karst aquifer is used as a source of drinking water, the potential for contamination of the drinking water supply will depend on the extent to which flow underlying the contaminant source (e.g., a CKD pile) is interconnected with the ground water withdrawal points (i.e., public or private wells or springs). In cases where the source and the withdrawal points are directly connected through large conduits, there is a significant potential for direct and rapid long distance transport of constituents to the drinking water well (diluted by the base ground water flow). In certain diffuse flow systems or even free-flow karst aquifers where the solution cavity flow paths do not connect the contaminant source to the withdrawal point, there may be virtually no transport of contaminants from the source to the exposure point (even in cases where the two points may be in relatively close proximity). Consequently, the exposure potential in karst settings can range from very high to negligible, depending on highly site-specific aquifer characteristics. At the Holnam damage case site in Mason City, Iowa, the blow out of CKD contaminated water, flowing at a rate of up to about 150 gallons/minute, to Calmus Creek from the CKD disposal area, demonstrates that conduit flow in karst aquifers can be an important factor in the migration of CKD contaminants.[4] This blow out, as well as other seeps from the Holnam and Lehigh properties, were noted to have contributed to the September 1986 fish kill

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[4] At the Holnam and Lehigh sites in Mason City, IA, the upper aquifer consists of Devonian limestones with “solution-enlarged fractures”, and physiographic features include “karst topography”. Source: Layne Geosciences, Inc, 1989, Remedial Investigation/Feasibility Study on the West Quarry, Mason City, Iowa, prepared for Northwestern States Portland Cement (project No. 61.1099), page 13 and Figure 4, respectively.

and degraded the aquatic habitat in Calmus Creek from 1984 until 1992 (USEPA, 1997b).

2.2.2 Dangers Posed by Disposal in Karst Areas

Risks associated with CKD disposal in karst areas include structural failure of the waste unit due to ground instability and the potential for contaminated ground water to migrate long distances through open conduits with little filtration, adsorption, and dispersion that are typical of contaminant dispersal in porous geologic formations. Concerns about potential adverse foundation conditions in karst areas are discussed in Section 2.2.2.1. The risks posed by CKD waste units in karst areas to contaminate ground water are evaluated in Section 2.2.2.2.

2.2.2.1 Foundation Conditions in Karst Areas

Stable foundation conditions are fundamental to the successful performance of any engineered structure. Foundation soils, such as expansive clay and soils subject to rapid settlement and liquefaction, are examples of foundation conditions that could result in impairing or destroying the integrity of landfill design elements such as liners, leachate collection systems, and caps (USEPA, 1993b). Foundation stability in karst areas is of specific concern due to the potential for sudden failure of the subsurface, causing sinkholes that can be more than 100 feet or more in depth and 300 feet or more in width (USEPA, 1993b). The principal engineering concern with karst areas is progressive and/or catastrophic failure of the subsurface due to the presence of sinkholes, solution cavities, and subterranean caverns. The unpredictable and catastrophic nature of subsidence in these areas makes them difficult to develop as landfill sites (USEPA, 1993b). Given these potential problems, EPA believes that thorough site characterization is required prior to siting any landfill in a karst area.

In reporting many years of investigations of damages caused by sinkholes, Sowers (1996) describes the principles of sinkhole formation, outlines investigation techniques, describes measures available to stabilize foundations, cites a number of sinkhole cases, and offers explanations for their causes. The most widespread and serious limestone engineering problem is the development of a dome-shaped cavity in the overburden soil above a much smaller opening in the rock below. The sudden collapse of the roof of such domes is responsible for virtually all of the sinkhole failures that cause serious property damage and occasional loss of life. Water is the enabling medium. Two conditions enable the cavities in the overburden to continue to enlarge: continuous or repeated wetting of the overburden soil, accompanied by; downward flow or percolation of ground water into an opening in the rock surface, and; a hydraulic connection with water circulating in the rock cavities below (Sowers, 1996).

A large proportion of serious subsidence in areas underlain by solutioned limestone have accompanied or have followed substantial lowering of the ground water table, and most incidences of subsidence are induced by human activity such as water supply wells and quarry construction dewatering. The decreased pore pressure in these areas reduces the bearing capacity of the materials near the cavity and results in a sinkhole (Sowers, 1996).

In the 1970's and 1980's numerous sinkholes, 10 to 33 feet in diameter, formed in an open undeveloped field near Frederick, Maryland, where no sinkholes were visible in 1970 aerial photographs. These sinkholes were attributed to the combined influence of dewatering activities in a large limestone quarry and increased storm water run-off associated with urban development. The risk of large cover-collapse sinkholes was found to be greatest in innocuous-looking dry valleys for the following four reasons:

- Because the size of the sinkhole is dependant on the thickness of the overburden, deep sinkholes are likely to form where the overburden is deepest;
- Swales were found to be underlain by well-developed, fracture-controlled solution cavities capable of transporting (piping) soil out of the area and allowing large voids to grow rapidly;
- Swales often contain permeable alluvial soils that provide a pathway for perched surface drainage to reach subsurface conduits; and
- Developers and civil engineers tend to regard swales as convenient and logical places to locate detention ponds and to direct surface run-off (Boyer, 1997).

EPA has described methods for use in the characterization of subsurface structural conditions in karst areas. These methods include subsurface drilling, sinkhole monitoring, geophysical techniques, and remote sensing (USEPA, 1992 and 1993b). Methods to mitigate structural problems in karst terrain include:

- control of ground water and surface water conditions to minimize the rate of dissolution within near-surface limestone,
- excavation and/or over-compaction of loose soils overlying the limestone to achieve the required stability (in areas where development of karst topography is minor), and
- infilling of the voids with grout (in areas where the karst voids are relatively small and limited in extent) (USEPA, 1993b).

Engineering solutions that try to compensate for weak geologic structures can be complex and costly. Sowers reports methods for treatment of sinkhole areas to include excavation to the narrowest point of the sinkhole bottom and plugging with concrete. Other methods for foundation stabilization include grout injection, piles, caissons, reinforced concrete mat foundations, and other complex solutions such as shafts to bedrock which, in many situations, is the only way to build heavily loaded structures on solutioned limestone foundations (Sowers, 1996).

To ensure that foundation conditions are suitable when locating CKD landfills in karst areas, EPA believes that a site-specific characterization is required to include consideration of the potential for the presence of sinkholes or sinkhole-like subsurface conditions. This characterization should be conducted in concert with the delineation of ground water flow pathways.[5] Of particular concern are those karst areas where the karst is considered mature. As described in Section 2.2.4 of this background document, of the 110 cement plant locations in the EPA data base, 18 are located in mature karst areas where there is a potential for subsidence (sinkholes). EPA believes, however, that special consideration for the stability of foundation material is warranted in all karst areas because surficial evidence of sinkholes may not be present. EPA notes that relatively small subsurface voids may result in sinkhole formation and the absence of large voids is insufficient evidence that sinkholes are not likely to develop at a specific site.

2.2.2.2 Consequences of Contaminant Releases in Karst Areas

As described in Section 2.2.1, releases from CKD landfills, where conduit flow is present in the subsurface, may travel rapidly in relatively undiluted form. Where conduit flow is continuous, contaminants present in the release may travel a significant distance with potential for impacting water supplies and surface water resources when discharged. Of the thirteen ground water damage cases summarized in Table 2-1, there are at least four cases (Holnam, Inc., Mason City, Iowa; Lehigh, Inc., Mason City, Iowa; Medusa Cement Co., Charlevoix, Michigan; and Signal Mountain Cement Co., Chattanooga TN) in which the underlying karst aquifer played a significant role in the off-site release of CKD constituents via the ground water pathway. In two another cases, the presence of a karst aquifer is suspected to have contributed to the release (Penn-Dixie Cement, Petrosky, MI, and Southdown, Inc., Fairborn, OH).

2.2.3 Dangers Posed by Disposal in Highly Fractured Media

Ground water in non-karst areas which are intensely fractured and faulted may be at risk from uncontrolled CKD disposal practices. Saturated open fractures may form ground water systems that could exhibit non-Darcy, conduit ground water flow. As in the case with karst aquifers, ground water flow in fractured geologic media is commonly rapid and contaminant concentrations may under go little attenuation relative to porous media. For example, at the Alamo Cement (San Antonio, Texas) damage case site, natural fractures caused by faulting is suspected of having contributed to the migration of CKD constituents into the surrounding environment. A total of 9 cement plants in the United States are estimated to be located in non-karst areas and have a moderate to high potential to be underlain by ground water systems with conduit flow characteristics (see Table 2-3). Many of these sites are estimated to have a moderate to high potential for conduit ground water flow because of their proximity to major fault systems (e.g., San Andreas Fault System in California). Given the potential for ground water contamination at sites with conduit-flow ground water systems, the Agency believes that ground water controls are necessary to limit the potential for releases in areas with high fracture permeabilities. As described in Chapter 5, performance and technical standards to protect ground water are being

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[5] See Section 7.1 of this background document for additional information on site characterization strategies.

proposed for new and actively managed CKD landfills.

2.2.4 Agency Evaluation of Potentially Karstic Areas and Areas of High Fracture Permeability

The 1995 Regulatory Determination stated that about half of all the cement plants in the U.S. are underlain by limestone formations in areas of karst landscape. This fact is noted to be a significant qualification to the general findings of low or negligible risk from the ground water pathway risk modeling result, which were described in the 1993 RTC and the 1994 NODA.

Table 2-3 lists all the U.S. cement plants which are in operation[6], the geographic location of each plant, the potential presence of karst features, and the potential for conduit ground water flow at these sites. This table was developed from a variety of data sources including topographic maps, tectonic maps, formation correlation and bedrock maps, and water vulnerability maps. The specific topographic maps which were examined are listed in Table 2-3 and other larger-scale maps and references which were reviewed are listed in Table 2-4. The geologic factors examined at each cement plant fall into four basic categories:

- The presence of underlying soluble rock such as limestone, dolomite, or other carbonate rock formations. Carbonate rocks are often associated with karst aquifers and conduit-type ground water flow regimes;

- The presence of physiographic and morphological features indicative of karst hydrogeologic settings such as sinkholes, springs, caves, sinking streams, blind valleys, pipes, and tubes;

- Tectonic features that indicate potential fractured bedrock (e.g., faults and fractures); and

- Site-specific information obtained from damage cases.

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[6] Information on which cement plants are active is based on the 1995 PCA survey and 1997 information in EPA files on hazardous waste burning status of cement kilns.

Table 2-3. Potential for Non-Darcy (conduit or fracture) Flow at U.S. Cement Manufacturing Facilities

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Alamo Cement Co.	San Antonio (Cementville)	TX	Longhorn, Schertz	Austin Chalk/Taylor Marble	Yes: Carbonate	Immature	Faulting within 60 ft of CKD landfill	High	See damage case summary Table 2-1.
Allentown Cement Co. Inc.	Blandon	PA	Temple	Jacksonburg Formation, Limestone	Yes: Carbonate	Immature	Appalachian Mountains	High	
Armstrong Cement & Supply Corp.	Cabot	PA	Worthington	Crenshaw Formation	Yes: Carbonate	Immature	Edge of a large uplift (dome)	High	
Ash Grove Cement Co.	Chanute	KS	Chanute	Paola Limestone	No	None	Fractured limestone	High	See note 4.
Ash Grove Cement Co.	Durkee	OR	Durkee	Volcanics	No: Springs	None	Highly faulted area	Medium	
Ash Grove Cement Co.	Foreman	AR	Foreman	Marble/Chalk	Yes: Carbonate	Immature	Ouchita Orogeny	High	
Ash Grove Cement Co.	Inkom	ID	Bonneville Peak, Inkom	Cambrian Dolomite, Marine Limestone	Yes: Carbonate	Immature	Portneuf and Pocatello Mtn. Ranges	High	
Ash Grove Cement Co.	Louisville	NE	Springfield	Penn Aquifer	No	None		Low	
Ash Grove Cement Co.	Montana City	MT	East Helena	Limestone, Dolomite/Schist	Yes: Carbonate	Immature	Rocky Mountains	High	
Ash Grove Cement Co.	Nephi	UT	Champlin Peak	Mississippian Limestone	Yes: Carbonate	Immature		Medium	
Ash Grove Cement Co.	Seattle	WA	South Seattle	Oligocene Marine Strata	No	None		Low	
Blue Circle Inc.	Atlanta	GA	Northwest Atlanta		No	None	Moderate Faulting in Area	Low	
Blue Circle Inc.	Calera	AL	Ozan, Montevallo	Limestone	Yes: Carbonate	Immature		Medium	
Blue Circle Inc.	Harleyville	SC	Harleyville		Yes	Immature		Medium	
Blue Circle Inc.	Ravena	NY	Ravena	Carbonate	Yes: Carbonate	Immature	Catskills	High	
Blue Circle Inc.	Tulsa	OK	Mingo	Mississippian Seminole Formation	Yes: Carbonate, Springs	Mature (due to presence of springs)		High	
Calaveras Cement Co	Redding	CA	Project City	Paleozoic Limestone	No	None		Low	
Calaveras Cement Co.	Tehachapi	CA	Tehachapi North, South, and Northeast,	Paleozoic Limestone	No	None		Low	
Calif. Portland Cement	Colton	CA	San Bernardino South	Limestone or Dolomite	No	None	Tehachapi Valley	Low	

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Calif. Portland Cement	Mojave	CA	Monolith	Paleozoic Limestone	No: Springs	None	San Andreas Fault Area	Medium	
Calif. Portland Cement	Rillito	AZ	Marana, Avra		No	None	San Andreas Fault Area	Medium	
Capitol Aggregates, Inc.	San Antonio	TX	Longhorn	Taylor Marble	Yes: Carbonate	Immature	Localized Faulting in Vicinity	High	
Capitol Cement Corporation	Martinsburg	WV	Martinsburg	Martinsburg Formation Limestone	Yes: Carbonate	Immature	Appalachian Mountains	High	
Centex	Fernley	NV	Fernley East and West, Two Tips, Wadsw	NA	No: "Sink" to NE of facility	None	Sierra Nevada Mountains	Low	
Centex	Laramie	WY	Laramie	Alcova Limestone (plant located over Quaternary Alluvium)	Yes: Carbonate	Immature	Rocky Mountains	Medium	
Centex	La Salle	IL	Lasalle	Limestone	No	None		Low	
Continental Cement Co., Inc.	Hannibal	MO	Hannibal East	Mississippian Limestone	Yes: Carbonate, Caves	Mature (due to presence of caves)		High	
Dacotah Cement	Rapid City	SD	Rapid City West	Cretaceous Limestone	Yes: Carbonate, springs	Mature (due to presence of springs)	Uplift (Dome) - Blackhills	High	
Dixon-Marquette	Dixon	IL	Dixon East, Grand Detour	Ordovician Limestone	Yes: Carbonate rock, Sinkholes	Mature		High	
Dragon Products Co..	Thomaston	ME	Thomaston	Ordovician Limestone	No	None		Low	
Essroc Materials	Bessemer	PA	New Middletown, Cambell, Bessemer	Allegheny Group Limestone	Yes: Carbonate	Immature	Edge of large uplift (dome)	High	
Essroc Materials	Frederick	MD	Buckeystown, Point of Rocks	Ordovician Grove Limestone	Yes: Carbonate	Immature	Appalachian Orogeny	High	
Essroc Materials	Logansport	IN	Clymers, Lucerne	Ordovician Limestone	Yes: Carbonate beneath non-carbonate overburden	Immature		Medium	
Essroc Materials	Nazareth	PA	Nazareth	Allegheny Limestone? Jacksonburg	Yes: Carbonate rock and extensive historical subsidence and springs	Mature	Appalachian Orogeny	High	

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Essroc Materials (Lone Star)	Nazareth	PA	Nazareth	Allegheny Limestone? Jacksonburg	Yes: Carbonate rock and extensive historical subsidence and springs	Mature	Appalachian Orogeny	High	
Essroc Materials	Speed	IN	Speed, Charlestown	Ordovician Limestone	Yes: Carbonate rock with non-carbonate overburden	Immature		High	
Florida Crushed Stone	Brooksville	FL	NA	NA	Yes: area of historical subsidence	Mature		High	
Giant Cement Holding, Inc.	Harleyville	SC	Harleyville	NA	Yes: Carbonate	Immature		Medium	
Giant Cement Holding (Keystone)	Bath	PA	Catasuqua	Jacksonburg Formation Limestone	Yes: Carbonate rock. Extensive Historical Subsidence	Mature	Appalachian Orogeny	High	
Glens Falls Cement CO., Inc.	Glens Falls	NY	Hudson Falls, Glen Falls	Carbonate	Yes: Carbonate rock	Immature	Appalachian orogeny	High	
Holnam Inc.	Ada	OK	Ada	Penn. Francis Formation Limestone	No	None		Low	
Holnam Inc.	Artesia	MS	Crawford East and West, Bent Oak, Autecia	Demopolis Chalk & Arcola Limestone	Yes: Carbonate	Immature		Medium	
Holnam Inc.	Clarksville	MO	Pleasant Hill West, Clarksville	Mississippian Limestone	Yes: Carbonate	Immature		Medium	
Holnam Inc.	Dundee	MI	Dundee	NA (surface is lake sediments)	Yes: Carbonate	Immature	Michigan Basin	High	
Holnam Inc.	Florence	CO	Florence	Shale/limestone	Yes: Carbonate	Immature	Edge of Rocky Mountain Foothills	Medium	
Holnam Inc.	Fort Collins	CO	Laporte	Shale/limestone	Yes	Immature	Edge of Rocky Mountain Foothills	Medium	
Holnam Inc.	Holly Hill	SC	Holly Hill		Yes: Carbonate	Immature		Medium	
Holnam Inc.	Mason City	IA	Mason City	Lime Creek Formation Limestone/dolomite	Yes: Carbonate underneath non-carbonate overburden	Immature		High	See damage case summary Table 2-1.
Holnam Inc.	Midlothian	TX	Venus, Midlothian, Britton, Cedar Hill	Austin Chalk	Yes: Carbonate rock	Immature	Fractured limestone	High	

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Holnam Inc.	Morgan	UT	Devil's Slide, Henefer	Mississippian Limestone	Yes: Carbonate	Immature		Medium	
Holnam Inc.	Seattle	WA	Seattle South	Olgicene Marine Strata	No	None	Low	Low	
Holnam Inc.	Theodore	AL	Theodore, Hollingers Island	Beach, Floodplain, Terrace Deposits (Sedimentation)	Yes: Fissures and voids (karstic). Unconsolidated deposits	Mature		High	
Holnam Inc.	Three Forks	MT	Logan	Limestone/shale	Yes: Carbonate rock; springs	Immature	Rocky Mountains	High	
Independent Cement Corp.	Catskill	NY	Cementon	Carbonate	Yes	Immature	Catskill Mountains	High	
Independent Cement Corp.	Hagerstown	MD	Hagerstown	Ordovician Shenadoah Limestone	Yes: Carbonate	Immature	Appalachian Orogeny	High	
Kaiser Cement Corp.	Permanente	CA	Cupertino	Tertiary Limestone	No	None	San Andreas Fault area	Medium	
Kosmos Cement Co.	Kosmosdale	KY	Kosmosdale	Quaternary Alluvium	Yes: Carbonate rock	Immature	Heavily Faulted	High	
Kosmos Cement Co.	Pittsburgh	PA	Pittsburgh West, Emsworth	Penn. Sandstone/limestone	No	None	Edge of a Large Uplift (Dome)	Low	
Lafarge Corporation	Alpena	MI	Alpena	Limestone bedrock, surface is lake sediment	No	None (but karst features are found to the north of the facility)	Michigan Basin	Low	See damage case summary Table 2-1.
Lafarge Corporation	Buffalo	IA	Andalusia	Cedar Valley Limestone	No	None		Low	
Lafarge Corporation	Fredonia	KS	Fredonia	Limestone	No	None		Low	
Lafarge Corporation	Grand Chain	IL	Joppa, Bandana	Sandstone/shale	Yes: Carbonate rock	Immature	Proximal to highly faulted area	High	
Lafarge Corporation	Paulding	OH	Paulding	Devonian - Columbus and Delaware Limestone	Yes: Carbonate rock	Immature	South edge of Michigan Basin	Medium	
Lafarge Corporation	Sugar Creek	MO	Liberty	Kansas City Group Limestone	Yes: Carbonate beneath non-carbonate overburden	Immature		Medium	
Lafarge Corporation	Whitehall	PA	Cementon, PA	Jacksonburg Formation, Limestone	Yes: Carbonate with historical subsidence	Mature	Appalachian Mountains	High	

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Lehigh Portland Cement	Leeds	AL	Leeds	Limestone	Yes: Carbonate rock; historical subsidence; springs	Mature	Highly faulted mountainous region (in the Chaba Valley)	High	
Lehigh Portland Cement	Mason City	IA	Mason City	Lime Creek Formation Limestone/dolomite	Yes: Carbonate beneath non-carbonate overburden	Immature		Medium	See damage case summary Table 2-1.
Lehigh Portland Cement	Mitchell	IN	Bedford East, Mitchell	Mississippian Limestone	Yes: Carbonate rock	Immature		Medium	
Lehigh Portland Cement	Union Bridge	MD	Union Bridge	NA	Yes: Carbonate	Immature	Appalachian Orogeny	High	
Lehigh Portland Cement	Waco	TX	Lorena, South Bosque	Austin Chalk	Yes: Carbonate	Immature		Medium	
Lehigh Portland Cement	York	PA	West York	Kinzeras Formation Limestone	Yes: Metamorphic limestone, marble, and dolostone	Immature	Appalachian Orogeny	High	
Lone Star Industries	Cape Girardeau	MO	Cape Girardeau	Ordovician Limestone	Yes: Carbonate, area of historic subsidence (Davies, et al, 1984)	Mature	Edge of highly faulted area	High	
Lone Star Industries	Greencastle	IN	Cloverdale, Greencastle, Reelsville, Clinton Falls	Mississippian Limestone	Yes: Carbonate rock beneath non-carbonate overburden	Immature		Medium	
Lone Star Industries	Oglesby	IL	Lasalle	Limestone	No	None		Low	
Lone Star Industries	Pryor	OK	Salina	Mississippian - Pitkin/Hindsville Limestone	Yes: Carbonate	Immature		Medium	
Lone Star Industries	Sweetwater	TX	Maryneal, Lake Trammell	Glen Rose Limestone	Yes: Carbonate/gypsum; springs	Immature		Medium	
Medusa Cement Co.	Charlevoix	MI	Charlevoix	Surface - lake sediments	Yes: Carbonate	Mature (based on damage case findings)	Michigan Basin	High	See damage case summary Table 2-1.
Medusa Cement Co.	Clinchfield	GA	Perry East	Limestone	Yes: Carbonate beneath non-carbonate overburden	Immature		Medium	
Medusa Cement Co.	Demopolis	AL	Demopolis	Selma Chalk	Yes: Fissures, tubes, and caves	Mature (based on presence of karst features)		High	

Facility Name	City	State	Topographic Map Name	Formation Name and/or Lithology	Potential for Karst Hydrogeologic Setting (see Note 1)	Degree of Karstification (none/ immature/mature) (see Note 2)	Tectonic Features or Evidence of Fractured Bedrock	Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)	Note
Medusa Cement Co.	Wampum	PA	New Castle South	Allegheny Ordovician Limestone	Yes: Carbonate rock	Immature	Edge of large uplift (dome)	Medium	
Mitsubishi Cement Corp.	Lucerne Valley	CA	NA	NA	No	None		Low	
Monarch Cement Co.	Humboldt	KS	Humbolt	Limestone	No	None		Low	
National Cement Co. Of Alabama	Ragland	AL	Ragland	Shale/sandstone with Coal	Yes: Carbonate Rock	Immature	Highly faulted	High	
National Cement Co. Of California	Lebec	CA	Lebec, La Liebre Ranch	Paleozoic Limestone	No: Springs	None	San Andreas Rift Zone	High (due to presence of springs and faulting)	
North Texas Cement	Midlothian	TX	Venus, Midlothian, Britton, Cedar Hill	Austin Chalk	Yes: Carbonate	Immature		Medium	
Pennsuco Cement Co. (Tarmac)	Medley	FL	Hialeah, Hialeah SW, Pennsucola, Opa-l	Limestone	Yes: Carbonate rock	Immature		Medium	
Phoenix Cement Co.	Clarkdale	AZ	Clarksdale	Limestone	Yes: Carbonate rock; springs	Mature (due to presence of springs)		High	
Puerto Rico Cement Co.	Ponce	PR	Ponce, Penuelas	Ponce Limestone	No	None		Low	See note 5.
RC Cement Co. Inc. (Heartland Cement Co.)	Independence	KS	Independence	Limestone/shale	Yes: Carbonate rock	Immature		High	
RC Cement Co. Inc. (Hercules Cement Co.)	Stockertown	PA	Wind Gap	Jacksonburg Formation Limestone	Yes: Carbonate; extensive historical subsidence	Mature	Appalachian Orogeny	High	
RC Cement Co. Inc. (River Cement Co.)	Festus	MO	Selma	Ordovician Joachim Dolomite	Yes: Carbonate	Immature	Localized faulting	High	
RC Cement Co. Inc. (Signal Mountain Cement Co.)	Chattanooga	TN	Chattanooga	Silurian Limestone	Yes: Carbonate	Mature (based on damage case findings)	Appalachian Mountains	High	See damage case summary Table 2-1.
Rinker Portland Cement Corp.	Miami	FL	Hilaleah Southwest	Oolitic/biodastic/otz Sandstone/limestone	Yes	Immature		High	
Rio Grande Cement Co. (Holnam Inc.)	Tijeras	NM	Tijeras	Mississippian Madera Limestone	Yes: Carbonate; springs	Immature	Edge of Localized Fault Area	High	
Riverside Cement Co.	Oro Grande	CA	Victorville	NA	No	None		Low	
Riverside Cement Co.	Riverside	CA	NA	Limestone or Dolomite	No	None	San Andreas Fault Area	Medium	
RMC Lonestar - Santa Cruz	Davenport	CA	Davenport	Carboniferous Limestone/Paleozoic	No	None	San Andreas Fault	Medium	

Facility Name	**City**	**State**	**Topographic Map Name**	**Formation Name and/or Lithology**	**Potential for Karst Hydrogeologic Setting (see Note 1)**	**Degree of Karstification (none/ immature/mature) (see Note 2)**	**Tectonic Features or Evidence of Fractured Bedrock**	**Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)**	**Note**
Roanoke Cement Co.	Cloverdale	VA	Catawba	Ordovician Limestone	Yes	Immature		Medium	
Royal Cement Co., Inc.	Logandale	NV		NA	No	None		Low	
San Juan Cement Co.	Dorado	PR	Vega Alta	Limestone	No	None		Low	See note 6
Southdown	Brooksville	FL	Brooksville	Limestone	Yes: Area of historical subsidence	Mature		High	
Southdown	Fairborn	OH	Fairborn, Yellow Springs	Devonian - Columbus and Delaware Limestone	Yes: Carbonate rock	Immature		High (based on damage case)	See damage case summary Table 2-1.
Southdown	Knoxville	TN	John Sevier	Ordovician Limestone	Yes: Carbonate	Immature	Appalachian Mountains	High	
Southdown	Lyons	CO	Hygiene	Shale/limestone	Yes	Immature	Edge of Rocky Mountain Foothills	High	
Southdown	Odessa	TX	Penwell, Douro	Glen Rose Limestone	Yes: Carbonate rock; karst-like topographic features; fissures and voids	Mature		High	
Southdown	Victorville	CA	Fairview Valley, Stoddard Well, Apple Valley, Turtle Valley	Carboniferous marine limestone	No	None	Fairview Valley/San Andreas Fault	Medium	
Sunbelt Cement Corp. (Lafarge Corporation)	New Braunfels	TX	New Braunfels West	Anacacho Limestone	Yes: Area is underlain by Edwards Aquifer	Mature		High	
Texas Industries	Midlothian	TX	Venus	Austin Chalk	Yes: Carbonate	Immature		Medium	See damage case summary Table 2-1.
Texas Industries (TXI Cement)	New Braunfels	TX	Geronimo, New Braunfels East	Taylor Marble	Yes: Carbonate	Immature	Highly Faulted Area	Medium	
Texas-Lehigh Cement Co.	Buda	TX	Buda	Austin Chalk	Yes: Carbonate	Immature	Fractured Limestone	Medium	

Facility Name	**City**	**State**	**Topographic Map Name**	**Formation Name and/or Lithology**	**Potential for Karst Hydrogeologic Setting (see Note 1)**	**Degree of Karstification (none/ immature/mature) (see Note 2)**	**Tectonic Features or Evidence of Fractured Bedrock**	**Potential for Non-Darcy Flow (i.e., conduit or fracture flow) (see Note 3)**	**Note**

Notes to Table 2-3:

1. "Yes" indicates subterranean karst features are present in the vicinity of the cement plant, as indicated on karst or geologic maps listed in Table 2-4. Karst hydrogeologic settings can be found in areas of limestone, dolomite or other soluble rock formations (e.g., carbonate rocks). Characteristic physiographic and morphological features that can be indicative of karst hydrogeologic settings include sinkholes, springs, caves, sinking streams, blind valleys, pipes, and tubes. Geologic and physiographic information obtained from topographic maps cited in the table and other references identified in Table 2-4.
2. "Mature" karst includes those areas in which extensive historical subsidence has occurred (unless otherwise noted).
3. "Non-Darcy Flow" refers to ground water flow rates that exceed the upper limit of Darcy's Law. Such flow rates are common in rock formations such as karstic limestones and dolomites, and cavernous volcanics (Freeze and Cherry, 1979). "Potential for Non-Darcy (i.e., conduit or fracture) flow" was determined based on the presence of karst features, degree of karstification, and tectonic features in the vicinity of each facility listed. "High" potential was assigned to areas with mature karst features or a combination of immature karst features, highly fractured media, or other "pseudokarst" features. In the absence of site-specific information, "Medium" was assigned to areas with either karst features or fracture flow conditions. "Low" was assigned to areas with no karst features or fractured bedrock.
4. Ash Grove, Chanute, KS is underlain by the fractured Paola Limestone unit. Ground water flow through fractured bedrock has been documented as causative in damage cases for the Ash Grove Chanute, KS facility. See Section 2.2 of this background document.
5. Source: Krushensky, Richard D. and Watson H. Monroe, 1975, Geologic Map of the Ponce Quadrangle, Puerto Rico, USGS Map I-863.
6. San Juan Cement, Dorado, PR is located near the north coast limestone region of Puerto Rico which is highly karstified. However, local conditions are not believed to be karstic. Source: review of Mapa de Carreteras Estatales de Puerto Rico (1978), Geologic Map of Puerto Rico (1933), map showing limestone areas and karst land forms in Puerto Rico (1976)

NA = information not available or not determined

Table 2-4. State-Specific Maps and Other References Used for Research Concerning Potential Ground Water Flow at Active Cement Plants

Alabama
- Geologic Map of Alabama (1926)
- Groundwater Availability in Jefferson County, Alabama (1990)
- State of Alabama and Part of Georgia Coal Fields and producing Districts

Arizona
- Geologic Map and Sections of the ASO Quadrangle, Pima County, Arizona (1946)
- Geologic Map of Arizona (1969)
- Geologic Map of the Bagdad Area, Yavapi County, Arizona (1945)
- Geologic Sections of the Bagdad Area, Yavapi County, Arizona (1945)
- Sample Sites, Mines, Prospects, and Mining Claims in the Rincon Wilderness Study Area, Pima County, Arizona (1977)

Arkansas
- Geologic Map of Arkansas (1976)
- Geology of Arkansas, Surface and Below Surface (1941)

California
- Geologic Map and Sections of the Eastern Part of the Clark Mountain Range, San Bernardino County, California (1967)
- Geologic Map of California (1938 and 1977)
- Geologic Map of California - San Bernardino sheet (1967)
- Geologic Map of California - Santa Cruz sheet (1958)
- Geologic Map of Shasta County, CA (1972)
- Geologic Map of Shasta Valley, CA showing location of wells and springs (1954)
- Geologic Map of the Kreyenhagen Hills-Sunflower (McLure) Valley Area, Fresno, Kern, Kings, and Monterey Counties, CA (1992)
- Geologic Map of the Redding Quadrangle, Shasta County, CA (1965)

Colorado
- Geologic Map of Colorado (1975)
- Map of Colorado Showing Coal Bearing Regions and Fields (1959)

Florida
- Environmental Geology Series - Miami sheet (1956)
- Geologic Map of Florida (1981)
- Mineral Resources of Hernando County, Florida (1988)
- Occurrence of Beds of Low Hydraulic Conductivity in Surficial Deposits of Florida (1984)

Georgia
- Geologic Map of Georgia (1939)
- Georgia Groundwater (1963)
- Water Resources Investigation in Georgia (1978)

Indiana
- Map of Indiana showing Locations of Coal and Industrial Minerals Operation (1984)
- Quaternary Geologic Map of Indiana (1989)

Iowa
- Geologic Map of Iowa (1969)

Kansas
- Geologic Map of Kansas (1964)

Kentucky
- Geologic Map of Kentucky (1988)

Maine
- Preliminary Geologic Map of Maine (1967)

Maryland
- Geologic Map of Frederick County (1938)
- Map of Maryland Showing all Geological Formations and Agricultural Soils (1907)

Michigan
- Map of the Surface Formations of the Southern Peninsula of Michigan (1955)

Mississippi
- Geologic Map of Mississippi (1945)

Missouri
- Geological Map of Missouri (1979)
- Groundwater Areas of Missouri (1962)

Montana
- Geologic Map of Montana

Nebraska
- Geologic Bedrock Map of Nebraska (1986)
- Groundwater Vulnerability to Contamination in Nebraska Using the Drastic Method (1991)

Nevada
- Geologic Map Index of Nevada (1955-1970)
- One Million Scale Set Geologic Map of Nevada (1977)

New Mexico
- Geologic Map of New Mexico (1965)

New York
- Geology of the Capital District (Albany and Vicinity) (1928)
- Groundwater in New York (1964)

Ohio
- A geological Map of Ohio (1909)

Oklahoma
- Geologic Map of Oklahoma (1954)
- Reconnaissance of the Water Resources of the Tulsa Quadrangle, Northeastern Oklahoma (1971)

Oregon
- Geologic Map of Oregon (1991)

Pennsylvania
- Geologic Map of Pennsylvania (1980)

Puerto Rico
- Geologic Map of Southeastern Puerto Rico (1967)

South Dakota
- Geologic Map of South Dakota (1953)

Tennessee
- Geologic Map of Tennessee (1933)

Texas
- Geologic Map of Texas (1937)

Utah
- Geologic map of Utah (1980)

Virginia
- Geologic Map of Virginia (1993)

Washington
- State of Washington Preliminary Geologic Map (1936)

West Virginia
- Geologic Map of West Virginia

Wyoming
- Geologic Map of Wyoming (1980)

Other References

Basement Rock Map of the United States, 1968.

Childs, Orlo E., *Correlation of Stratigraphic Units of North America - COSUNA*, The American Association of Petroleum Geologists Bulletin, Vol. 69, No. 2, February 1985.

Coal Map of North America, 1988.

Davies, W.E., J.H. Simpson, G.C. Ohlmacher, W.S. Kirk, and E.G. Newton, 1984. *Engineering Aspects of Karst,* Scale 1:7,500,000. U.S. Geological Survey, Map no. 38077-AW-NA-07M-00.

Generalized Tectonic Map of the United States, 1972.

Geologic Map of the United States, 1974.

Todd, D.K., *Ground-Water Resources of the United States.* Berkeley, CA; Premier Press, 1983.
United States Geological Survey, National Atlas of the United States - Surficial Geology, 1979.

United States Geological Survey, State Water-Data Reports: Hydrologic Records of the United States Water Years 1990, 1991, and 1992. Open-File Report 93-626.

Information on the presence of karst features such as sinkholes, springs, sinking streams, caves, and historical subsidence combined with other site-specific knowledge was used to indicate the potential for karst hydrogeologic settings and to indicate the relative maturity of the karst if found. The lithology was identified from USGS maps and other sources identified in Table 2-4. The presence of a soluble rock formation such as limestone (as indicated on geologic maps) is an indicator of a potential karst area. Topographic and karst maps were reviewed to identify surface geomorphologies which may suggest the presence of karst-like features including sinkholes (local zones of instability in karst terrain may result in ground collapse and subsidence), sinking streams, caves, large springs, blind valleys, pipes and tubes. The specific topographic maps used for this analysis are identified for each facility in Table 2-3. Karst maps (such as *Engineering Aspects of Karst* (Davies et al., 1984)) and State-specific geologic maps listed in Table 2-4 were reviewed to identify karst areas and tectonic features.

Areas with extensive historical subsidence or other obvious karst features such as caves, springs, and sinkholes are considered “mature” karst for the purpose of this analysis. Areas identified as karst, but without the characteristic morphological features of karst, are considered “immature” karst for the purpose of this analysis. Tectonic features were also identified to evaluate the potential for non-Darcy flow in the site vicinity. In the absence of site-specific information, such as the damage case information (Section 2-1), sites which are not located in either karst terrain or near tectonic features were assumed to have a “low” potential for non-Darcy ground water flow characteristics (i.e. conduit or fracture flow systems). Sites located in either fractured or karst terrain (but not both) were estimated to have a “medium” potential for non-Darcy ground water flow. Sites located in both fractured and karst terrain or were found to overlie mature karst aquifers were estimated to have a “high” potential for non-Darcy ground water flow.

Of the 110 cement plants, 79 are located in areas characterized by karst hydrogeology. Of these, 20 are considered in mature karst settings. The Agency believes that there is a potential for conduit ground water flow to occur at sites located in karst terrain and that CKD disposal sites found to be in karst areas should be subject to new standards for site characterization and landfill design (see Section 5 of this TBD). In addition, 9 cement plants sites not located in karst areas have a high or moderate potential for non-Darcy, conduit flow ground water systems due to fractured bedrock aquifers.

2.3 Damage to Wetlands, Lakes, and Streams Caused by Releases from CKD Management Units

Disposal of CKD at and near sensitive aquatic environments, including wetlands, lakes, and other surface water bodies, has resulted in significant ecological and water quality damages. There are at least six known CKD disposal sites where damage to wetlands and surface water bodies has been demonstrated or the pH of the surface water exceeded the RCRA corrosivity criteria for hazardous waste (12.5 SU). The factors which have contributed to release of CKD constituents to these sensitive environments are summarized in Table 2-6 and include:

- Lack of an engineered cover or bottom liner in the CKD disposal unit (all six cases),

- Waste CKD in contact with shallow ground water with migration of CKD constituents in ground water to nearby seeps and streams (in at least 5 cases), and

- Stormwater run-off transporting CKD from the disposal unit to nearby streams or lakes (in at least 4 cases), and

- Surface water run-off and lake shoreline erosion causing transport of CKD, CKD constituents, and other debris from the waste management unit to the surface water body (National Gypsum site in Alpena, Michigan).

Damages to wetlands and streams from CKD disposal activities are examined in Section 2.3.1. Section 2.3.2 describes the damages that occurred to Lake Huron’s Thunder Bay and Whitefish Bay as a result of CKD disposal by the National Gypsum Company in Alpena, Michigan. The Agency’s evaluation of CKD disposal in wetlands or adjacent to surface water bodies is summarized in Section 2.3.3.

Table 2-5. Factors Contributing to Release of CKD Constituents to Wetlands and Surface Water

Damage Case, City, State (Reference)	Covered Landfill at Time of Release?	Bottom Liner Present?	CKD In Contact with Ground Water or Disposed Below Natural Water Table?	CKD Release Mechanism?	Impacts to Wetlands or Surface Water?
Holnam, Inc., Mason City, IA (USEPA, 1993a and 1997b)	No	No	CKD disposed of in a former quarry which later filled up with rain and ground water	Shallow ground water transport and surface runoff from disposal areas to seeps and Calmus Creek	9/86 fish kill in Calmus Creek; Aquatic community structure dominated by tolerant species
Lehigh, Inc., Mason City, IA (USEPA ,1993a and 1997c)	No	No	CKD disposed of in former quarries which later filled up with rain and ground water	Shallow ground water transport and surface runoff from disposal areas to seeps and Calmus Creek	9/86 fish kill in Calmus Creek; Aquatic community structure dominated by tolerant species
Signal Mountain Cement Co., Chattanooga TN (USEPA, 1997a)	No	No	CKD disposed of in water-filled quarry cavities	Shallow ground water transport and surface runoff from disposal areas to seeps and creeks	Releases with a pH above 12.5 to an unnamed tributary of the Tennessee River; tributary is abiotic
Southdown, Inc., Fairborn, OH (USEPA, 1993a)	Unspecified	No	CKD was landfilled in unlined quarries,	Shallow ground water transport from disposal areas to seeps and creeks	Seeps and surface water with pH up to 13.6
Lehigh Portland Cement Co., Metaline Falls (USEPA, 1997d)	No	No	Lowermost portion of CKD pile below water table	Shallow ground water transport from disposal area to seeps and drainage channels	Seeps and surface water with pH up to 14 downgradient of the disposal area
National Gypsum Co., Alpena, MI (USEPA, 1997a)	No	No	Unspecified	Wave erosion from Lake Huron and surface run-off to Lake Huron	Near shore aquatic community dominated by tolerant species; lake sediments failed toxicity tests
Summary	At least 5 cases involve uncovered CKD waste units	All 6 cases had no bottom liner	At least 5 cases where CKD was in direct contact with ground water	Ground water transport (5 cases); Surface water run-off (4 cases); Lake erosion (1 case)	Seep/Surface water pH >12.5 (3 cases); Altered aquatic community structure (4 cases)

2.3.1 Wetland and Stream Damage From CKD Disposal

The close proximity of the water table to the ground surface in and near wetlands and streams and the mobility of CKD constituents in ground water make these environments susceptible to contamination from unengineered CKD disposal units. Contact of waste CKD with ground water was noted at five of the sites listed in Table 2-6. At the Fairborn, Ohio; Chattanooga, Tennessee; and Mason City, Iowa sites, CKD was disposed of in quarries, which subsequently became filled with water. The ground water table at the Metaline Falls, Washington site was in contact with the CKD pile. At these sites, the migration of ground water, which came in contact CKD, transported CKD constituents to nearby seeps and streams. As shown in Table 2-6, the pH of seeps and surface water near the Metaline Falls, Washington; Chattanooga, Tennessee; and Fairborn, Ohio sites often exceeded the RCRA corrosivity criteria of 12.5 SU for hazardous waste. In addition, at the Fairborn, Ohio site, metals such as arsenic, cadmium, chromium, iron, lead, nickel, and selenium were identified in surface water and shallow ground water above drinking water standards (USEPA, 1993a).

Ecological degradation of Calmus Creek, including a fish kill in September 1986, has been documented near and downgradient of the Lehigh and Holnam facilities in Mason City, Iowa. Aquatic habitat evaluations of Calmus Creek in 1984, 1989 and 1992, indicated that populations of organisms with external gills and benthic taxa were fewer in number downstream of the cement facilities relative to the upstream stations. Species with external gills are sensitive to suspended particulate matter as this matter interferes with the organism’s respiration. The four most abundant species collected (black bullhead, central stoneroller, green sunfish, white sucker) are among the species most tolerant of high turbidity, dissolved oxygen and flow extremes, agricultural siltation, and industrial and domestic pollution. Excessive sedimentation in Calmus Creek was a probable cause for the lack of smallmouth bass. Sedimentation has a profound effect on smallmouth bass habitat, because sedimentation covers suitable spawning areas, suffocates eggs of larval fish, or inhibits sight-feeding activities of bass fry (USEPA, 1997b).

2.3.2 Lake Damage From CKD Disposal

An old, inactive CKD disposal pile, created and owned by the National Gypsum Company is located along the shore of Lake Huron's Thunder Bay in Alpena, Michigan. During a site visit in March 1993, inspectors from the Michigan Department of Natural Resources (MDNR) reported that CKD from the pile was washing into a large erosion ditch (one meter wide by three meters deep) leading to Lake Huron. Other debris, including airbags, drums, kiln brick, and miscellaneous materials co-disposed with the CKD also were being transported in the ditch to the lake. In addition, waves from the lake were reported to be actively eroding the pile along six to nine meter high banks on the south end of the shoreline.

Soil and surface water samples obtained from the pile near the shore of Lake Huron showed evidence of CKD contamination. Arsenic, selenium, lead, and zinc concentrations in grab samples of soil from the beach and upslope from the shore on the CKD pile exceeded State soil cleanup default values. Surface water samples from the erosion ditch and nearby Lake Huron also contain levels of arsenic and lead that exceed State standards.

In July and August 1996, EPA Region V collected data on the fish community structure and function, habitat, and sediment in Thunder Bay and Whitefish Bay. Whitefish Bay is a small embayment north of the CKD pile and receives discharge from the site via an outfall. These data indicate that the ecosystems of both bays have been altered by the filling in of interstitial spaces in the sediment and by the blanketing of sediments by eroded, discharged, and wind-blown ash materials. The absence of trout-perch, burbot, and large smallmouth bass near the CKD pile is contrasted with the presence of tolerant species such as spottail shiner, carp, and large proportion of younger individual smallmouth bass. The dominance of carp near the Lafarge outfall and deep deposits of ash have precluded the use of Whitefish Bay by the representative fauna of Lake Huron and Thunder Bay. Pore water and bulk sediment toxicity test results from Thunder Bay and Whitefish Bay showed chronic toxicity to *Ceriodaphnia*, *Hyallela*, and *Chironomus* (Simon, 1996). The toxicity test results showed toxicity in five out of seven samples with *Chironomus*, in four out of seven samples with *Hyallela*, and in two out of seven samples with *Ceriodaphnia*. The furthest sample from the CKD pile was located about 1000 feet (300 meters) from the CKD pile and indicated toxic conditions with a *Chironomus* survival rate of 29% (Simon, 1998).

Additional EPA Region V observations of the environmental damage in the vicinity of the CKD pile include the following:

> Habitat has been severely altered by the filling in of emergent wetlands, cementing of natural rock substrates, and the washing and erosion of the CKD Pile. The CKD pile appears to have filled in a portion of a wetland near Whitefish Bay and has formed an “unnatural” backwater composed of CKD briquettes. The washing and erosion of the pile has cemented natural substrates and caused a significant portion of the bottom to appear as an underwater cement desert. A milky white haze from wave action has reduced the littoral zone community along the immediate escarpment of the CKD pile. A measurement of pH from water samples showed elevated levels; however, these did not exceed State of Michigan water quality standards (Simon, 1996).

2.3.3 Agency Evaluation of CKD Disposal in Wetlands and Adjacent to Surface Water

The Agency places a high priority on protecting wetlands and surface water bodies from sources of pollution including CKD waste disposal sites. Based on a review of the CKD disposal site damage cases, EPA has determined that wetlands and surface water bodies have been adversely impacted by CKD disposal in and near these environments.   To protect these sensitive environments, EPA is proposing a ban against CKD disposal below the water table and is proposing special design and operational requirements for CKDLF units located in the 100-year floodplain and in wetlands. Good engineering practices require that CKDLF units should be located away from lakes and streams in order to prevent surface water from eroding into the disposal unit and releasing CKD constituents into the environment. Interim and final landfill covers are critical to prevent rainwater infiltration into the CKD waste management unit and to prevent the CKD from contacting stormwater run-off.

As stated in the Agency's Regulatory Determination (60 FR 7366), the Clean Water Act provides sufficient authority to control risks to surface water associated with releases from CKD waste management sites. The Clean Water Act has a number of regulatory mechanisms to protect surface waters including effluent guideline regulations, National Pollutant Discharge Elimination System (NPDES) permits, water quality standards, and storm water permits. EPA's multisector stormwater general permit contains limits to control effluent discharges specific to the cement industry (among other industries) and requires each plant to develop facility-specific pollution prevention plans and demonstrate best management practices. These measures, when implemented at CKD disposal sites, are expected to minimize the potential for contact between stormwater run-off and CKD or else remove CKD before the stormwater is discharged.

2.4 EPA Conclusions Regarding Potential Impacts of CKD to Ground Water

In the Regulatory Determination (60 FR 7366), EPA concluded that additional control of CKD is warranted in order to protect the public from human health risks and to prevent environmental damage. EPA proposed to develop a tailored set of standards for CKD that controls releases to ground water under Subtitle C of RCRA. As discussed in Section 2.1, the existence of at least thirteen CKD disposal sites with ground water contamination indicates that current practices are inadequate to limit contaminant releases. The damage cases show that there is an increased risk to ground water when CKD is land-disposed in karst environments, in quarries below the natural water table, and/or near wetlands and surface water features. In each of these damage cases, water came in contact with CKD resulting in development of alkaline solutions which mobilized metals into the environment. Factors which have contributed the release of CKD contaminants from the waste management unit to ground water include disposal of CKD below the water table in uncovered, unlined pits, and/or with no leachate collection. Based on these damage case findings, EPA has determined that current CKD waste management practices are inadequate and that it is necessary to establish performances standards and default technical design standards for CKD landfills. Proposed CKD landfill design standards are presented in Chapter 5.

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Chapter 3: Evaluation of Options for Technical Design Criteria for CKDLF Units

3.1 Identification and Evaluation of Options for Technical Design Standard

Based on observed environmental damages to ground water resources at CKD disposal sites and the vulnerability of ground water in karst terrain, EPA recognized the need to improve CKD waste management practices and prevent releases of hazardous constituents from CKD into the environment. In response, EPA has evaluated a range of possible landfill design configurations against a range of performance standards. Generally, to evaluate the performance of landfill designs for both Subtitle D and Subtitle C landfills, the EPA uses modeling to first predict the leakage of constituents from the base of the landfill, then to predict ground-water flow and transport of these constituents to a point of concern (POC). If concentrations of constituents of concern are found to be below a specified level of concern (generally, the established maximum contaminant level (MCL) for that constituent), a design is considered to meet the performance standard.

This approach, however, is not appropriate for those CKD landfills that are located in karst hydrogeologic settings. Most ground-water flow models are based on Darcian equations of flow that assume flow through a porous media. Flow through large conduits, such as occurs in karst terrains, is not Darcian flow. Therefore, most ground-water models cannot be used to effectively predict flow, dilution, or attenuation in karst terrains. A few ground-water models have been developed to predict dilution and attenuation in karst terrains, but they are highly dependent on site specific factors such as the maturity of karst or the direction of the flow through the subsurface conduits. This kind of detailed site-specific information is not available to the Agency for the CKD landfill sites under consideration. In addition, a site-specific modeling approach is not appropriate for evaluating performance of a landfill design that may be used in many different hydrogeologic settings.

Based on these limitations, the EPA determined that, for those CKD landfills located in karst terrains, the predicted leakage rate for a particular landfill design would be used to determine the degree of protectiveness of that design. Because contaminant releases to karst aquifers can travel in ground water long distances in a relatively undiluted form, landfill leakage rates can be used as an indicator of landfill performance relative to a standard. The EPA used the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder, et. al., 1994) to predict leakage rates for several landfill designs, including designs derived from the CKD industry proposal, as well as default Subtitle D and Subtitle C landfill designs. The remaining sections of this chapter discuss the development of the particular designs modeled (Section 3.2), an overview of the HELP model (Section 3.3), and the modeling results (Section 3.4).

For CKD landfills located in non-karst terrains, the EPA coupled the HELP model results discussed in this chapter with a subsurface ground water flow model (MULTIMED) to predict potential dilution and attenuation in the subsurface. The results of this effort are discussed in

Chapter 4 of this background document.

3.2 Landfill Design Configurations

As part of this analysis, EPA evaluated a total of five prospective landfill liner design configurations. These design configurations included a "baseline" CKD landfill (to represent an uncontrolled CKD landfill similar to current practices); two configurations intermediate between a baseline and the Subtitle D design; a Subtitle D municipal solid waste design (including a composite liner with leachate collection); and a full Subtitle C hazardous waste design (including a double liner with leachate collection/detection). The two designs between the baseline and the Subtitle D design are based on designs proposed by the cement industry (Alben, et. al., 1993). EPA reviewed the designs proposed by the industry and determined that changes to these designs were necessary, in part because the HELP model predicted unrealistic flow at the surface of these designs (ICF, 1995), and in part to reflect more appropriate engineering practices. The intermediate designs were included in the current evaluation to accommodate industry concerns while still reflecting better design practices. It is recognized that other designs may meet the proposed performance standard for CKD landfills, depending upon site specific conditions. The configurations of the landfill designs evaluated by EPA are summarized in Table 3-1 and discussed in the following sections.

3.2.1 Cement Industry's "Contingent Management Practices" for CKD

In 1993, the Portland Cement Association published a technical report entitled "Detailed Illustration of Contingent Management Practices for Cement Kiln Dust" (Abeln et al., 1993). The report outlined two hypothetical CKD landfill configurations. These two landfill designs are similar to the "Modified CKD Low" and Modified CKD High" designs presented in Table 3-1. The first CKD landfill design proposed by the cement industry focused primarily on the final cap and disposing of a sufficient amount of CKD to prevent CKD over saturation and leakage from the waste management unit. This design included:

- A six-inch vegetative soil layer with a permeability of 1.9×10^{-4} cm/s;
- A one-quarter inch lateral drainage layer with a permeability of 7 cm/s to remove water that has infiltrated through the vegetative layer;
- A geofabric placed above the drainage layer to prevent fines from clogging the drainage layer;
- A two-foot soil barrier with a permeability of 2.5×10^{-5} cm/s under the drainage layer;
- No engineered bottom liner or leachate collection;

Table 3-1. Summary of Landfill Design Configurations

Design Variable	*Baseline CKD Landfill*	*Modified CKD Low*	*Modified CKD High*	*Subtitle D (composite liner; leachate collection)*	*Subtitle C (double liner: leachate collection)*
Cover Layer	Uncompacted CKD (no cover)	0.5 ft top soil 2 ft compacted CKD (k = $2x10^{-5}$ cm/s)	1.0 ft top soil 0.5 ft sand drainage layer (k =$2x10^{-3}$ cm/s) Geotextile support fabric 2 ft compacted CKD	0.5 ft top soil 1.5 ft sand 60 mil HDPE geomembrane 2 ft compacted soil cap	2 ft top soil 1 ft sand 30 mil HDPE geomembrane 2 ft compacted soil cap
Liner Layer	Uncompacted CKD (no liner)	4 ft compacted CKD (k = $2x10^{-5}$ cm/s)	Geotextile filter fabric 1 ft sand (leachate collection layer) Geotextile support fabric 4 ft compacted CKD	1 ft sand (leachate collection layer) 60 mil HDPE geomembrane 2 ft clay	1 ft sand (leachate collection layer) 30 mil HDPE geomembrane 1 ft sand (leachate detection layer) 30 mil HDPE geomembrane 2 ft clay
Slope of Final Cover	NA	NA	2 percent slope	2 percent slope	3 percent slope
Ground Water Monitoring	Yes	Yes	Yes	Yes	Yes
Leachate Collection	No leachate collection	No leachate collection	Yes	Yes (required)	Yes (required)

Source: SAIC 1997. NA means not applicable. K = hydraulic conductivity.

- A 3:1 (3 horizontal to 1 vertical) side slope; and

- The CKD layer, with the minimum total lift according to the climatic setting, and with three values of permeability (1 x 10^{-4} cm/s, 1 x 10^{-5} cm/s, and 1 x 10^{-6} cm/s). These ranges of permeabilities were claimed to occur naturally in uncompacted CKD at some sites and could be achieved with mild to heavy compaction at other sites.

In the PCA report (Abeln et al., 1993), an alternative landfill design included a 4 foot-thick compacted CKD bottom layer (permeability of 10^{-6} cm/s or less) and leachate collection was proposed for sites in wet climates that could not accumulate sufficient CKD to prevent oversaturation in the monofill. The cement industry used EPA's HELP model to calculate the minimum thickness of CKD required to prevent over saturation of the CKD for a one-year active life, and to determine the minimum final CKD height needed to prevent leakage through the capped CKD management unit during a 30-year post-closure period (Abeln et al., 1993). EPA's evaluation of these designs is summarized in Section 3.4.

3.2.2 Baseline, Subtitle D, and Subtitle C Landfill Liner Designs

A study was conducted to determine the incremental effectiveness of RCRA Subtitle D and Subtitle C liners used in a CKD landfill over a baseline CKD landfill (uncompacted CKD in unlined, uncovered landfill) and covers in protecting ground water resources (SAIC 1997)[1]. The baseline landfill, which has minimal engineering control -- no liner or leachate collection system, was evaluated because it represents the current CKD management practice employed at many cement plants that land dispose CKD. The Subtitle C and D designs were evaluated because they represent EPA's default technical standard for hazardous and municipal waste landfill respectively.

Under Subtitle D regulations, municipal solid waste landfills (MSWLFs) must comply with either a design standard or a performance standard for landfill design. The design standard requires a composite liner composed of two feet of soil with a hydraulic conductivity of no more than 1 x 10^{-7} cm/sec overlain by a flexible membrane liner (FML) and a leachate collection system. The performance-based design must demonstrate the capability of maintaining contaminant concentrations below the MCLs at the unit's relevant point of compliance. For the purpose of the HELP modeling evaluation described here, the technical design standard was used.

Under Subtitle C regulations, a hazardous waste landfill must have a liner that is designed, constructed, and installed to prevent any migration of wastes out of the landfill to the adjacent subsurface soil or ground water or surface water at any time during the active life (including

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[1] SAIC, 1997, "HELP Modeling to Assess Incremental Effectiveness of Subtitle C and D Landfill Designs Over a Baseline CKD Landfill", prepared for USEPA OSW under Contract No. 68-W4-0030, WA 215, Task 9 (January 24, 1997).

closure period) of the landfill. Specifically, the owner or operator must install two or more liners and a leachate collection system above and between the liners. The lower liner must be constructed of a least a 3-foot thick layer of recompacted clay or other natural material with a permeability of no more than 1 x 10^{-7} cm/sec (see 40 CFR Part 264.301).

EPA's evaluation of the baseline, Subtitle D, and Subtitle C design configurations for CKDLF units is summarized in Section 3.4.

3.2.3 "Modified CKD Low" and "Modified CKD High" Monofill Designs

EPA established two landfill design configurations intermediate between the baseline and the Subtitle D default for further evaluation and possible use by cement plants in non-karst areas. The designs were known as the "Modified CKD Low" and "Modified CKD High"[2]. Both configurations use compacted CKD and cover materials in their designs.

The Modified CKD Low Design has a post-closure configuration consisting of a cover layer of 0.5 ft top soil and 2 feet of compacted CKD and a liner of 4 feet compacted CKD. No active leachate collection system is assumed. The conditioned compacted CKD is assumed to have a hydraulic conductivity (K) of 2 x 10^{-5} cm/s based on the findings summarized below.

CKD permeability data given in the Report to Congress (RTC) (EPA 1993a), Exhibit 3-16, represent data from laboratory tests using laboratory compaction procedures. The variation in permeability with compaction is shown in the data from the PCA (Todres, et al. 1992) and EPA found that, for soils used in liners, differences between laboratory and field conditions may make it unlikely that hydraulic conductivity values measured in the laboratory on remolded, pre-construction samples are the same as the values achieved during actual liner construction (EPA, 1993b). While several alternative permeability values for CKD have been identified and proposed since publication of the RTC, EPA conducted additional research and identified permeability data for CKD emplaced using current compaction technologies. Data generally meeting these requirements were found in a draft certification report to the New York State Department of Environmental Conservation for the closure of the Independent Cement Corporation (ICC) CKD landfill located in Greene County, New York, about 3.5 miles south of Catskill (Malcolm Pirnie, 1997). As described in the certification, approximately 70,000 cubic yards of weathered and freshly generated CKD were placed to form a 4.5 foot-thick low permeability CKD barrier at the ICC landfill in the period of July through October, 1996. Fifty-eight individual test results for permeability are available showing a range of permeability (in cm/s) from 3.1 x 10^{-7} to 1.1 x 10^{-4}, with an average of 2.76 x 10^{-5} and a median value of 2.1 x 10^{-5}. The PCA report on CKD permeability achieved in the field during tests at the Ash Grove Plant in Chanute, Kansas was consulted for comparison (Todres 1992). In these tests, various compaction equipment were used on test strips. Twelve individual test results for permeability show a range of permeability

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[2] The two designs were adapted from a design proposed in a screening level economic analysis and are similar to those identified by PCA in Abeln, et al. (1993), hence the term "modified".

(in cm/s) from 4.5 x 10^{-6} to 1.51 x 10^{-4}, an average of 3.96 x 10^{-5}, and a median value of 2.27 x 10^{-5}. These results compare well with the ICC data. For the purpose of selecting the best estimated hydraulic conductivity value for compacted CKD, a median value was selected to reflect the special distribution of the test results as representative of how a barrier system might perform as a whole. Based on the above analysis, a CKD permeability value of 2 x 10^{-5} cm/s was selected for use in the HELP modeling of compacted CKD.[3] See Section 6.2 of this background document for additional information on the performance of CKD when used as a landfill liner.

The "Modified CKD High" Design has a post-closure configuration consisting of a cover layer of 1.0 ft top soil, a sand drainage layer of sufficient hydraulic conductivity to allow removal of water during high rainfall events, and a geotextile fabric over compacted CKD. The liner includes an active leachate collection layer between geotextile fabric over compacted CKD. Analysis of the effectiveness and use of the "Modified CKD Low" and "Modified CKD High" designs is provided in Section 3.4 of this document.

3.3 Overview of the HELP Model

The HELP model is a quasi-two dimensional hydrologic model of water movement across, into, through and out of landfills. The model accepts weather, soil, and landfill design data, and uses solution techniques that account for the effects of surface storage, snow melt, runoff, infiltration into the subsurface, evapotranspiration, vegetative growth, soil moisture storage, lateral subsurface drainage, leachate recirculation, unsaturated vertical drainage, and leakage through soil, geomembrane, or composite liners. Landfill systems including various combinations of vegetation, cover soils, waste cells, lateral drainage layers, low permeability barrier soils, and synthetic geomembrane liners may be modeled. The model was developed to conduct water balance analysis of landfills, cover systems, and solid waste disposal and containment facilities. As such, the model facilitates rapid estimation of the amounts of runoff, evapotranspiration, drainage, leachate collection, and liner leakage that may be expected to result from the operation of a wide variety of landfill designs. The primary purpose of the model is to assist in the comparison of design alternatives as judged by their water balances. The model is applicable to open, partially closed, and fully closed sites (Schroeder, et. al., 1994).

HELP is a water-balance model that can predict leakage from a landfill system, but cannot address chemical transformations or transport processes that control the contaminant concentrations at regulatory points of compliance (POCs). As noted in Section 3.1, however, for CKD landfills located in karst terrains, EPA is using the landfill liner leakage rate to estimate the protectiveness offered by the liner design. The model has additional limitations with respect to the arrangement of layers modeled (e.g. a barrier soil layer cannot overlie a lateral drainage layer). However, the landfill designs modeled for the evaluation of CKD landfill designs did not have any of these

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[3] The permeability estimates described here are based on data from the compaction of fresh or weathered CKD. However, the Agency is proposing that prior to compaction, CKD should be moisture-conditioned to improve control of fugitive dust emissions and facilitate bonding of particles to reduce leaching of contaminants from the CKD.

limitations. Certain layer configurations can result in the model predicting very high water accumulation on top of a cover or liner layer, and this results in unexpected predictions for infiltration, but, again, the landfill design configurations modeled in this analysis did not produce this type of result.

One further limitation of this type of modeling lies in the fact that the model inputs (such as landfill area, percent of area from which runoff can occur, SCS curve number, waste layer properties, etc.) represent estimates of national values, not facility-specific values. The EPA is performing this analysis to determine a default landfill design configuration that will be protective in most CKD landfill locations. The leakage rates predicted in this analysis do not represent precise values that can be expected from any one CKD landfill using these designs, but are instead order-of-magnitude estimates of potential leakage from the various designs.

3.4 CKD Landfill Modeling Results

EPA conducted a series of technical analyses to evaluate the various landfill design configurations against proposed performance standards. Because cement manufacturing facilities are located in a wide range of climatic and hydrogeologic settings, it was recognized that a “one-size-fits-all” approach to a developing a technical standard was not appropriate: facilities should be able to develop landfill designs tailored to site-specific climatic and hydrogeologic conditions to achieve the performance standard.

Using the Hydrologic Evaluation of Landfill Performance (HELP) model, EPA estimated landfill leakage rates for the various landfill design configurations summarized in Table 3-1. Each configuration was modeled for a range of climate and rainfall conditions adequate to capture the range of climate conditions and rainfall amounts at cement manufacturing plants in the U.S. and Puerto Rico. Using the HELP model, post-closure leakage rates were predicted for a baseline landfill configuration and for the same size landfill using the “Modified CKD Low”, “Modified CKD High”, Subtitle D, and Subtitle C designs. The modeling results provide a basis for comparing the performance of the various landfill designs (though it is recognized that site-specific landfill designs should be determined after considering site-specific information regarding climate, site hydrogeology, and waste characteristics).

The Subtitle D and Subtitle C designs were modeled using covers with both uncompacted and compacted CKD. Each landfill configuration was modeled using climate conditions from eight locations representing ranges of precipitation (5.81 to 65.33 inches/year) and warm and cold climates for both the operating life and post-closure care period of the landfill. The modeling results for the eight locations are summarized in Table 3-2.

Results for the baseline design showed average post-closure leakage rates between 0.95 and 29.7 in/yr (depending on climate). The average post-closure leakage rates from the “Modified CKD Low” design ranged from 0.011 to 14.9 inches/year and the “Modified CKD High” design ranged from 0.013 to 16.8 inches/year. Results for both Subtitle D and Subtitle C liner and cover configurations showed leakage rates predicted by the model to be on the order of 10^{-6} in/yr, essentially indistinguishable from zero. This result indicates that the Subtitle D design is as effective as the Subtitle C design for reducing leakage from CKD landfills.

EPA then assembled a database of facility-specific information on CKD generation rates, CKD management and disposal practices, hydrogeologic information, and climate to conduct facility-specific design demonstrations. After consideration of the damage cases, the increased risk posed by locating CKD landfills in karst, the post-closure leakage rates estimated for the various landfill configurations, and the limitations of ground water transport models for use in karst hydrogeologic settings, EPA determined that the Subtitle D default technical design standard would be appropriate for CKD landfills located in karst environments. EPA then conducted additional modeling, using the Multimedia Exposure Assessment Model (MULTIMED), to estimate which landfill designs would be appropriate for CKDLF units located in non-karst areas. The results of the MULTIMED analysis are discussed in Chapter 4.

3.5 Conclusions

Based on these results, EPA concluded that the Subtitle D default design would be adequate to control releases to ground water for all CKDLF units including those in karst areas. By minimizing net infiltration by means of a Subtitle D default landfill design, there will be a corresponding low potential for ground water contamination. Note that in areas of unstable ground (such as landslides, sinkholes, poor foundation conditions, etc.), Subtitle D regulations require a demonstration that suitable engineering measures have been incorporated in the landfill design to ensure that the structural components of the landfill will not be disrupted (40 CFR 258.15). Similar requirements are proposed for CKDLF units located in karst hydrogeologic settings. EPA's proposed location restrictions for CKDLF units at karstic and non-karstic sites are further discussed in Chapter 5 of this background document.

Table 3-2. HELP Model Results

Result	Baseline	Modified CKD Low	Modified CKD High	Subtitle D uncompacted CKD	Subtitle D compacted CKD	Subtitle C uncompacted CKD	Subtitle C compacted CKD
Fresno, California							
Peak leakage, post closure (in/yr)	2.8	0.09	0.055	0.000001	0.000001	0.000003	0.000003
Average leakage, post closure (in/yr)	1.2	0.018	0.016	0 See note	0	0	0
Miami, Florida							
Peak leakage, post closure (in/yr)	18.5	17.0	0.18	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	8.5	3.6	0.049	0	0	0	0
Boise, Idaho							
Peak leakage, post closure (in/yr)	1.1	0.069	0.048	0.000002	0.000002	0.000002	0.000002
Average leakage, post closure (in/yr)	0.95	0.011	0.013	0	0	0	0
Duluth, Minnesota							
Peak leakage, post closure (in/yr)	4.4	0.24	0.046	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	1.4	0.056	0.015	0	0	0	0

Table 3-2. HELP Model Results

Result	Baseline	Modified CKD Low	Modified CKD High	Subtitle D uncompacted CKD	Subtitle D compacted CKD	Subtitle C uncompacted CKD	Subtitle C compacted CKD
Raleigh, North Carolina							
Peak leakage, post closure (in/yr)	18.6	17.2	0.42	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	5.97	2.2	0.047	0	0	0	0
Mt. Washington, New Hampshire							
Peak leakage, post closure (in/yr)	49.0	34.8	36.6	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	29.7	14.9	16.8	0	0	0	0
Oklahoma City, Oklahoma							
Peak leakage, post closure (in/yr)	5.68	0.51	0.073	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	1.67	0.063	0.018	0	0	0	0
Salem, Oregon							
Peak leakage, post closure (in/yr)	31.7	29.5	27.4	0.000003	0.000003	0.000003	0.000003
Average leakage, post closure (in/yr)	17.4	11.9	9.3	0	0	0	0

Note: The HELP model reports average leakage rates to 5 decimal places, and reports peak leakage rates to 6 decimal places, therefore average leakage rates may indicate zero even when peak leakage rates are greater than zero.

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Chapter 4: Agency Analysis of Ground Water Controls Required at Cement Manufacturing Facilities

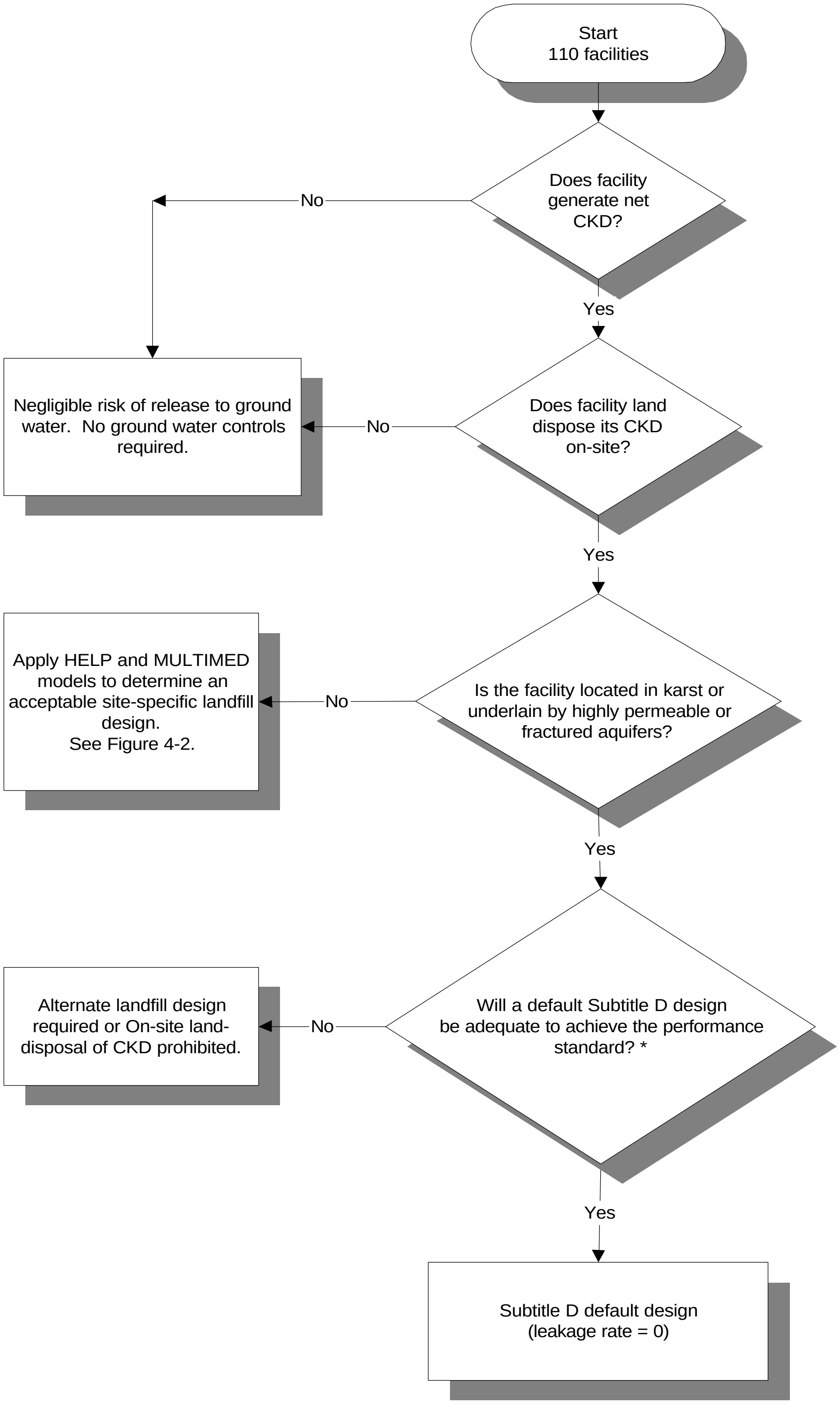
This chapter describes an analysis conducted by EPA to predict the ground water controls, if any, that likely would be employed at each cement plant in the U.S. and Puerto Rico to comply with the proposed ground water protection standards. To conduct this analysis, a four-step process was developed: (1) development of a decision framework, (2) identification and collection of the data required to apply the decision framework, (3) identification of landfill design configurations capable of meeting the performance standard in karst and non-karst areas, and (4) application of the decision framework using information from EPA's cement plant database.

The decision framework was developed so that a landfill design configuration could be assigned to each cement manufacturing facility in the U.S. and Puerto Rico. The decision framework was then applied to each of the 110 cement plants in the Agency's cement plant database to predict the minimum ground water protection measures required to achieve the proposed performance standard for new and actively managed CKDLF units.

4.1 Development of the Decision Framework

The decision framework, presented in Figure 4-1, was designed to establish a rationale for predicting the type of ground water controls required at each cement plant. Accordingly, each "end point" of the decision tree had to represent a waste management scenario or landfill design that could be employed at cement plants, after consideration of facility-specific information. The end points (sometimes referred to as "terminal nodes" in a decision tree) are:

- No ground water controls (e.g., at facilities that beneficially reuse all net CKD);
- Baseline landfill with minimal engineering design (e.g. no liner or leachate collection system);
- "Modified CKD Low" landfill design (see Table 3-1 in Chapter 3 of this background document);
- "Modified CKD High" landfill design (see Table 3-1 in Chapter 3 of this background document);
- Subtitle D default design for CKD landfills in karst areas; and
- On-site land disposal prohibited (e.g., caves or sinkholes present) or an alternative design is required.



* Answer "yes" for cement plants located in karst or highly permeable aquifers (subject to non-Darcy flow).
Answer "no" for cement plants located in mature karst areas with evidence of subsidence, such as sinkholes.

Figure 4-1: Decision Framework

The decision framework consists of a series of questions (represented by "nodes" on a flow chart). Each question relates to a key landfill management standard in the proposed rule related to the landfill design criteria or karst areas. The first question, "Does the facility generate net CKD?" is intended to breakout the population of cement plants into two categories: those potentially subject to the CKD management standards, and those not subject to the standards. Because some facilities transport all of their CKD off site for beneficial use, the question "Does the facility land dispose its CKD on site?" is included to remove those facilities from further evaluation in the decision framework.

To determine the landfill design configuration required, first it is necessary to determine whether the proposed site is in a karst hydrogeologic setting. If the site is in karst, the owner would need to construct a landfill based on the Subtitle D default design (i.e., composite liner with leachate collection) and demonstrate that engineering measures have been incorporated in the CKDLF unit's design to ensure that the integrity of the structural components will not be disrupted. Otherwise, an alternative design would be required or on-site disposal would be prohibited. For the purpose of this analysis, it was assumed that such a demonstration could be made for all karst sites except those with historical evidence of subsidence. All karst sites not subject to subsidence are assigned a "Subtitle D" configuration. If the site is NOT in karst, then a performance-based design demonstration is made using a leachate source model and a ground water transport model (see Section 4.3). For this analysis, two key assumptions are made: (1) the decision framework assumes CKD will no longer be disposed in quarries and that land is available at each facility for a new landfill (or lateral expansion of an existing operating unit) and (2) landfill location and operation will not be restricted by the presence of a shallow water table, flood plains, wetlands, fault areas, or seismic impact zones.

4.2 Data Requirements and Data Collection

Application of the decision framework required facility-specific data such as CKD net generation rates, description of the hydrogeologic setting (i.e., karst or non-karst), the potential for subsidence, facility location, and climate data. All data elements were not required for every cement plant because some cement plants could be categorized quickly with minimal information. For example, facilities that do not land-dispose CKD will not require ground water controls.

The data were drawn from various sources including the following: the 1994 NODA Risk Assessment, Section 2 Ground Water Contamination and Drinking Water Risks from Cement Kiln Dust Managed Over Karst Aquifers (USEPA, 1994); 1990 PCA and 1995 APCA survey results (APCA 1995); and U.S. Geological Survey (USGS) maps and other references documented and summarized in Chapter 2 of this background document (see Chapter 2, Tables 2-3 and 2-4).

4.3 Application of the Decision Framework to the Cement Plant Database

The decision framework (Figure 4-1) enabled the Agency to predict the appropriate landfill design configuration for each of the 110 cement plants in the database. Using facility-specific information, which is summarized in Table 4-1, each cement plant was assigned a waste management scenario or landfill design (e.g., no ground water controls required, baseline landfill, modified CKD low, modified CKD high, Subtitle D default, or alternate design). The results of applying the decision framework to each cement plant also are presented in Table 4-1.

The decision framework was applied as follows: Facilities listed in the database with zero CKD wasted in 1995 were assigned to the category “No Ground Water Controls Required”. Thirty-six out of 110 cement plants fall into this category.

Next, the remaining 74 facilities that waste net CKD were reviewed to determine which ones are located in karst. Fifty-six of the 74 facilities are located in karst settings, and the remaining 18 are located in non-karst settings. The karst underlying these 56 facilities was further categorized based on the maturity of the karst, and the corresponding risk of landfill failure due to sinkholes as evidenced by the presence of sinkholes or other indicators of historical subsidence. Five (5) facilities located in karst with evidence of subsidence were placed in the category “Alternate Design Required or On-Site Land Disposal Prohibited”. The remaining 51 “karst” sites were assigned a “Subtitle D” default design.

Finally, the remaining eighteen (18) facilities that are not located in karst, but do waste net CKD, were assigned a performance-based landfill design after taking into consideration site-specific factors such as site hydrogeology and climate. EPA used the HELP model (described in Chapter 3), coupled with the Multimedia Exposure Assessment Model (MULTIMED) (Sharp-Hansen, S., et al, 1990), to estimate the appropriate landfill design required to meet the performance standard at each cement plant located in a non-karst setting. The modeling approach is outlined in Figure 4-2 and described in detail in the following sections.

Table 4-1. Site Characteristics and Quantity of Net, Beneficially Used, and Wasted CKD, U.S. Cement Manufacturing Facilities

Facility Name	City	State	Does Facility Generate Net CKD? (see Note 1)	Is Some Or All CKD Used For Beneficial Purposes? (see Note 1)	Is Net CKD Wasted? (see Note 1)	Potential for Karst Hydrogeologic Setting (from Table 2-3)	Potential for Subsidence (e.g., mature karst with evidence of sinkholes) (see Table 2-3)	Ground Water Controls Required Based on Decision Framework
Alamo Cement Co.	San Antonio (Cementville)	TX	No	No	No	Yes	No	None (No Net CKD)
Allentown Cement Co. Inc.	Blandon	PA	No	No	No	Yes	No	None (No Net CKD)
Armstrong Cement & Supply Corp.	Cabot	PA	Yes	Yes	No	Yes	No	None (No Waste CKD)
Ash Grove Cement Co.	Chanute	KS	Yes	No	Yes	No	No	Modified CKD High
Ash Grove Cement Co.	Durkee	OR	No	No	No	No	No	None (No Net CKD)
Ash Grove Cement Co.	Foreman	AR	Yes	No	Yes	Yes	No	Subtitle D
Ash Grove Cement Co.	Inkom	ID	Yes	No	Yes	Yes	No	Subtitle D
Ash Grove Cement Co.	Louisville	NE	Yes	No	Yes	No	No	Modified CKD Low
Ash Grove Cement Co.	Montana City	MT	Yes	No	Yes	Yes	No	Subtitle D
Ash Grove Cement Co.	Nephi	UT	No	No	No	Yes	No	None (No Net CKD)
Ash Grove Cement Co.	Seattle	WA	No	No	No	No	No	None (No Net CKD)
Blue Circle Inc.	Atlanta	GA	No	No	No	No	No	None (No Net CKD)
Blue Circle Inc.	Calera	AL	Yes	Yes	Yes	Yes	No	Subtitle D
Blue Circle Inc.	Harleyville	SC	No	No	No	Yes	No	None (No Net CKD)
Blue Circle Inc.	Ravena	NY	Yes	Yes	Yes	Yes	No	Subtitle D
Blue Circle Inc.	Tulsa	OK	Yes	Yes	Yes	Yes	No	Subtitle D
Calaveras Cement Co	Redding	CA	No	No	No	No	No	None (No Net CKD)
Calaveras Cement Co.	Tehachapi	CA	No	No	No	No	No	None (No Net CKD)
Calif. Portland Cement	Colton	CA	Yes	Yes	Yes	No	No	Modified CKD Low
Calif. Portland Cement	Mojave	CA	No	No	No	No	No	None (No Net CKD)
Calif. Portland Cement	Rillito	AZ	No	No	No	No	No	None (No Net CKD)
Capitol Aggregates, Inc.	San Antonio	TX	Yes	No	Yes	Yes	No	Subtitle D
Capitol Cement Corporation	Martinsburg	WV	Yes	Yes	Yes	Yes	No	Subtitle D
Centex	Fernley	NV	No	No	No	No	No	None (No Net CKD)
Centex	Laramie	WY	No	No	No	Yes	No	None (No Net CKD)

Facility Name	City	State	Does Facility Generate Net CKD? (see Note 1)	Is Some Or All CKD Used For Beneficial Purposes? (see Note 1)	Is Net CKD Wasted? (see Note 1)	Potential for Karst Hydrogeologic Setting (from Table 2-3)	Potential for Subsidence (e.g., mature karst with evidence of sinkholes) (see Table 2-3)	Ground Water Controls Required Based on Decision Framework
Centex	La Salle	IL	No	No	No	No	No	None (No Net CKD)
Continental Cement Co., Inc.	Hannibal	MO	Yes	No	Yes	Yes	No	Subtitle D
Dacotah Cement	Rapid City	SD	Yes	No	Yes	Yes	No	Subtitle D
Dixon-Marquette	Dixon	IL	Yes	Yes	Yes	Yes	Yes	Alternative Design Required
Dragon Products Co.	Thomaston	ME	Yes	Yes	Yes	No	No	Subtitle D (based on HELP/MULTIMED Modeling)
ESSROC Materials	Bessemer	PA	Yes	No	Yes	Yes	No	Subtitle D
ESSROC Materials	Frederick	MD	Yes	Yes	Yes	Yes	No	Subtitle D
ESSROC Materials	Logansport	IN	Yes	No	Yes	Yes	No	Subtitle D
ESSROC Materials	Nazareth	PA	No	No	No	Yes	Yes	None (No Net CKD)
ESSROC Materials (Lone Star)	Nazareth	PA	Yes	Yes	Yes	Yes	Yes	Alternative Design Required
ESSROC Materials	Speed	IN	Yes	Yes	Yes	Yes	No	Subtitle D
Florida Crushed Stone	Brooksville	FL	Yes	Yes	No	Yes	Yes	None (No Waste CKD)
Giant Cement Holding, Inc.	Harleyville	SC	Yes	Yes	Yes	Yes	No	Subtitle D
Giant Cement Holding (Keystone)	Bath	PA	Yes	Yes	Yes	Yes	No	Subtitle D
Glens Falls Cement CO., Inc.	Glens Falls	NY	Yes	No	Yes	Yes	No	Subtitle D
Holnam Inc.	Ada	OK	Yes	Yes	Yes	No	No	Modified CKD High
Holnam Inc.	Artesia	MS	Yes	Yes	Yes	Yes	No	Subtitle D
Holnam Inc.	Clarksville	MO	Yes	Yes	Yes	Yes	No	Subtitle D
Holnam Inc.	Dundee	MI	Yes	Yes	No	Yes	No	None (No Waste CKD)
Holnam Inc.	Florence	CO	Yes	Yes	Yes	Yes	No	Subtitle D
Holnam Inc.	Fort Collins	CO	Yes	Yes	Yes	Yes	No	Subtitle D
Holnam Inc.	Holly Hill	SC	Yes	Yes	Yes	Yes	No	Subtitle D
Holnam Inc.	Mason City	IA	No	No	No	Yes	No	None (No Net CKD)
Holnam Inc.	Midlothian	TX	Yes	Yes	No	Yes	No	None (No Waste CKD)

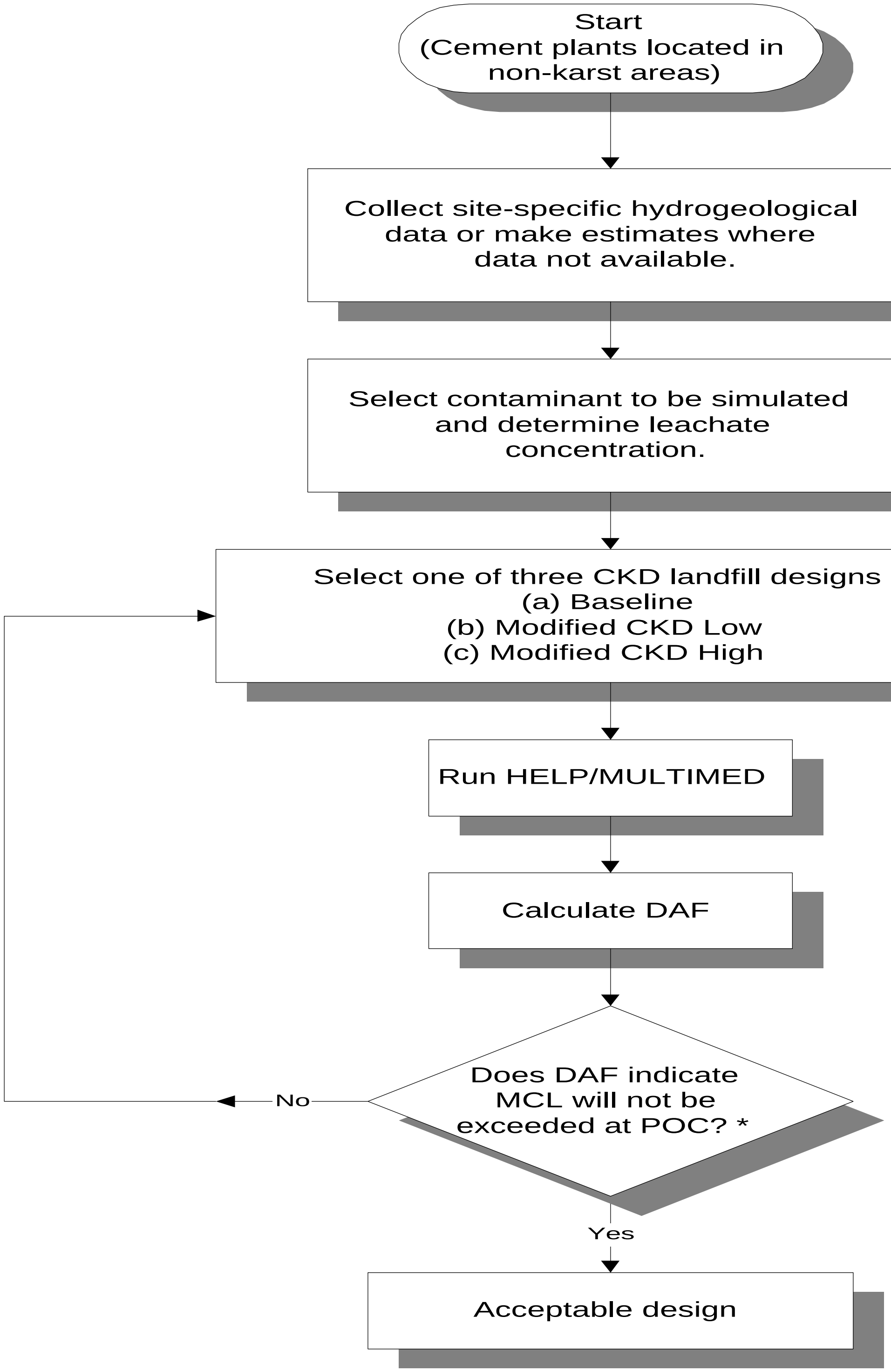
Facility Name	**City**	**State**	**Does Facility Generate Net CKD? (see Note 1)**	**Is Some Or All CKD Used For Beneficial Purposes? (see Note 1)**	**Is Net CKD Wasted? (see Note 1)**	**Potential for Karst Hydrogeologic Setting (from Table 2-3)**	**Potential for Subsidence (e.g., mature karst with evidence of sinkholes) (see Table 2-3)**	**Ground Water Controls Required Based on Decision Framework**
Holnam Inc.	Morgan	UT	Yes	Yes	No	Yes	No	None (No Waste CKD)
Holnam Inc.	Seattle	WA	Yes	Yes	No	No	No	None (No Waste CKD)
Holnam Inc.	Theodore	AL	No	No	No	Yes	No	None (No Net CKD)
Holnam Inc.	Three Forks	MT	Yes	Yes	Yes	Yes	No	Subtitle D
Independent Cement Corp.	Catskill	NY	Yes	Yes	Yes	Yes	No	Subtitle D
Independent Cement Corp.	Hagerstown	MD	Yes	Yes	Yes	Yes	No	Subtitle D
Kaiser Cement Corp.	Permanente	CA	No	No	No	No	No	None (No Net CKD)
Kosmos Cement Co.	Kosmosdale	KY	Yes	Yes	No	Yes	No	None (No Waste CKD)
Kosmos Cement Co.	Pittsburgh	PA	Yes	Yes	No	No	No	None (No Waste CKD)
Lafarge Corporation	Alpena	MI	Yes	No	Yes	No	No	Modified CKD Low
Lafarge Corporation	Buffalo	IA	Yes	Yes	Yes	Yes	No	Subtitle D
Lafarge Corporation	Fredonia	KS	Yes	No	Yes	No	No	Modified CKD High
Lafarge Corporation	Grand Chain	IL	Yes	No	Yes	Yes	No	Subtitle D
Lafarge Corporation	Paulding	OH	Yes	No	Yes	Yes	No	Subtitle D
Lafarge Corporation	Sugar Creek	MO	Yes	Yes	Yes	Yes	No	Subtitle D
Lafarge Corporation	Whitehall	PA	No	No	No	Yes	Yes	None (No Net CKD)
Lehigh Portland Cement	Leeds	AL	No	No	No	Yes	Yes	None (No Net CKD)
Lehigh Portland Cement	Mason City	IA	Yes	Yes	Yes	Yes	No	Subtitle D
Lehigh Portland Cement	Mitchell	IN	Yes	Yes	Yes	Yes	No	Subtitle D
Lehigh Portland Cement	Union Bridge	MD	Yes	Yes	Yes	Yes	No	Subtitle D
Lehigh Portland Cement	Waco	TX	Yes	No	Yes	Yes	No	Subtitle D
Lehigh Portland Cement	York	PA	Yes	Yes	No	Yes	No	None (No Waste CKD)
Lone Star Industries	Cape Girardeau	MO	Yes	No	Yes	Yes	Yes	Alternative Design Required
Lone Star Industries	Greencastle	IN	Yes	No	Yes	Yes	No	Subtitle D
Lone Star Industries	Oglesby	IL	Yes	No	Yes	No	No	Subtitle D (based on HELP/MULTIMED Modeling)
Lone Star Industries	Pryor	OK	Yes	Yes	Yes	Yes	No	Subtitle D

Facility Name	City	State	Does Facility Generate Net CKD? (see Note 1)	Is Some Or All CKD Used For Beneficial Purposes? (see Note 1)	Is Net CKD Wasted? (see Note 1)	Potential for Karst Hydrogeologic Setting (from Table 2-3)	Potential for Subsidence (e.g., mature karst with evidence of sinkholes) (see Table 2-3)	Ground Water Controls Required Based on Decision Framework
Lone Star Industries	Sweetwater	TX	No	No	No	Yes	No	None (No Net CKD)
Medusa Cement Co.	Charlevoix	MI	Yes	Yes	Yes	Yes	No	Subtitle D
Medusa Cement Co.	Clinchfield	GA	No	No	No	Yes	No	None (No Net CKD)
Medusa Cement Co.	Demopolis	AL	Yes	Yes	Yes	Yes	No	Subtitle D
Medusa Cement Co.	Wampum	PA	Yes	Yes	No	Yes	No	None (No Waste CKD)
Mitsubishi Cement Corp.	Lucerne Valley	CA	Yes	No	Yes	No	No	Modified CKD Low
Monarch Cement Co.	Humboldt	KS	Yes	No	Yes	No	No	Modified CKD High
National Cement Co. Of Alabama	Ragland	AL	No	No	No	Yes	No	None (No Net CKD)
National Cement Co. Of California	Lebec	CA	Yes	No	Yes	No	No	Modified CKD Low
North Texas Cement	Midlothian	TX	Yes	Yes	Yes	Yes	No	Subtitle D
Pennsuco Cement Co. (Tarmac)	Medley	FL	Yes	No	Yes	Yes	No	Subtitle D
Phoenix Cement Co.	Clarkdale	AZ	Yes	Yes	No	Yes	No	None (No Waste CKD)
Puerto Rico Cement Co.	Ponce	PR	Yes	Yes	Yes	No	No	Modified CKD High
RC Cement Co. Inc. (Heartland Cement Co.)	Independence	KS	Yes	Yes	Yes	Yes	No	Subtitle D
RC Cement Co. Inc. (Hercules Cement Co.)	Stockertown	PA	Yes	No	Yes	Yes	Yes	Alternative Design Required
RC Cement Co. Inc. (River Cement Co.)	Festus	MO	Yes	No	Yes	Yes	No	Subtitle D
RC Cement Co. Inc. (Signal Mountain Cement Co.)	Chattanooga	TN	Yes	Yes	Yes	Yes	No	Subtitle D
Rinker Portland Cement Corp.	Miami	FL	Yes	No	Yes	Yes	No	Subtitle D
Rio Grande Cement Co. (Holnam Inc.)	Tijeras	NM	Yes	No	Yes	Yes	No	Subtitle D
Riverside Cement Co.	Oro Grande	CA	Yes	Yes	Yes	No	No	Modified CKD Low
Riverside Cement Co.	Riverside	CA	Yes	No	Yes	No	No	Modified CKD Low
RMC Lonestar - Santa Cruz	Davenport	CA	Yes	Yes	Yes	No	No	Modified CKD Low

Facility Name	**City**	**State**	**Does Facility Generate Net CKD? (see Note 1)**	**Is Some Or All CKD Used For Beneficial Purposes? (see Note 1)**	**Is Net CKD Wasted? (see Note 1)**	**Potential for Karst Hydrogeologic Setting (from Table 2-3)**	**Potential for Subsidence (e.g., mature karst with evidence of sinkholes) (see Table 2-3)**	**Ground Water Controls Required Based on Decision Framework**
Roanoke Cement Co.	Cloverdale	VA	Yes	Yes	Yes	Yes	No	Subtitle D
Royal Cement Co., Inc.	Logandale	NV	Yes	No	Yes	No	No	Modified CKD Low
San Juan Cement Co.	Dorado	PR	Yes	No	Yes	No	No	Modified CKD High
Southdown	Brooksville	FL	Yes	No	Yes	Yes	Yes	Alternative Design Required
Southdown	Fairborn	OH	Yes	Yes	No	Yes	No	None (No Waste CKD)
Southdown	Knoxville	TN	Yes	Yes	Yes	Yes	No	Subtitle D
Southdown	Lyons	CO	Yes	Yes	Yes	Yes	No	Subtitle D
Southdown	Odessa	TX	Yes	Yes	Yes	Yes	No	Subtitle D
Southdown	Victorville	CA	Yes	No	Yes	No	No	Modified CKD Low
Sunbelt Cement Corp. (Lafarge Corporation)	New Braunfels	TX	Yes	No	Yes	Yes	No	Subtitle D
Texas Industries	Midlothian	TX	Yes	No	Yes	Yes	No	Subtitle D
Texas Industries (TXI Cement)	New Braunfels	TX	Yes	Yes	Yes	Yes	No	Subtitle D
Texas-Lehigh Cement Co.	Buda	TX	No	No	No	Yes	No	None (No Net CKD)

Notes to Table:

1. Annual CKD generation, disposal, and reuse rates are business confidential and are not shown. Net, beneficially used, and wasted CKD quantities for reporting plants are 1995 quantities from the 1995 CKD Survey (PCA 1995). Quantities from the 1991 CKD Survey were assumed for non-reporting plants. Two plants did not report quantities in either survey (Riverside Cement, Riverside, CA and San Juan Cement, PR) . Quantities for these two plants are based on average net CKD to clinker production ratios by kiln type, which were calculated from reporting plants.



* If none of the three CKD landfill designs are acceptable, then a "Subtitle D" design is selected by default.

Figure 4-2: Procedure for Using MULTIMED to Select Performance-Based Landfill Designs for CKDLF Units Located in Non-Karst Settings

4.3.1 Overview of MULTIMED Modeling Approach

The MULTIMED model simulates the transport and transformation of contaminants released from a waste disposal facility into the multimedia environment. Releases to either air or soil, including the unsaturated and the saturated zones, and possible interception of the subsurface contaminant plume by a surface stream are included in the model. Thus, the model can be used as a technical and quantitative management tool to address the problem of the land disposal of chemicals in the multimedia environment. MULTIMED uses analytical and semi-analytical solution techniques to solve the mathematical equations describing flow and transport. The simplifying assumptions required to obtain the analytical solutions limit the complexity of the systems that can be represented by MULTIMED.[1] The model does not account for site-specific spatial variability, the shape of the land disposal facility, site-specific boundary conditions, or multiple aquifers and pumping wells. Nor can MULTIMED simulate processes, such as flow in fractures and chemical reactions between contaminants, which can have a significant effect on the concentration of contaminants at a site.

MULTIMED can, however, be used as a screening-level model that allows users to obtain an understanding of a transport system, and to make comparisons between transport systems (Sharp-Hansen, et. al., 1990).

As can be seen in the above model descriptions, neither HELP nor MULTIMED alone is sufficient for assessing the potential environmental impacts of releases from CKD landfills. As described is Chapter 3, HELP is a water-balance model that can predict leakage from a landfill system, but cannot address chemical transformations or transport processes that control the contaminant concentrations at regulatory points of compliance (POCs). While MULTIMED can predict constituent concentrations based on attenuation and dilution processes, it does not account for specific landfill properties that control the initial leakage of contaminants into the subsurface. Therefore, as a rule, HELP and MULTIMED (or another equivalent subsurface transport model) are used together to estimate the potential for ground-water contamination from land disposal facilities. This is the methodology adopted in the current analysis of prospective CKD landfill designs. A schematic representation of the coupling of the HELP and MULTIMED

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[1] For the MULTIMED modeling described here, several simplifying assumptions were made, including: steady-state leachate generation (no source term decay); the receptor well is located downgradient of the facility and intercepts the contaminant plume; homogeneous porous aquifer; uniform flow in aquifer; and contaminant concentration is calculated at the top of the aquifer, which will likely result in a “worst-case scenario” evaluation.

models is provided in Figure 4-3.

The approach used in this section to evaluate CKD landfill design requirements follows that recommended by EPA for identifying landfill design requirements under RCRA Subtitle D as described in the "Solid Waste Disposal Facility Criteria, 40 CFR 258, Technical Manual" (USEPA, 1993b). Use of a fate and transport models such as MULTIMED in conjunction with a leachate source model such as HELP can be used for designing solid waste landfills to meet the Subtitle D performance standard. EPA's procedure for using HELP/MULTIMED to design solid waste landfills is summarized in Figure 4-2 and in the following bullets:

- "Collect, site-specific hydrogeologic data, including amount of leachate generated;

- Identify the contaminant(s) to be simulated and the POC;

- Propose a landfill design and determine the corresponding infiltration rate [using the HELP model];

- Run MULTIMED and calculate the dilution attenuation factor (DAF) (i.e., the factor by which the concentration is expected to decrease between the landfill unit and the POC); and

- Multiply the initial contaminant concentration by the DAF and compare the resulting concentrations to the MCLs to determine if the design will meet the [performance] standard" (USEPA, 1993b).

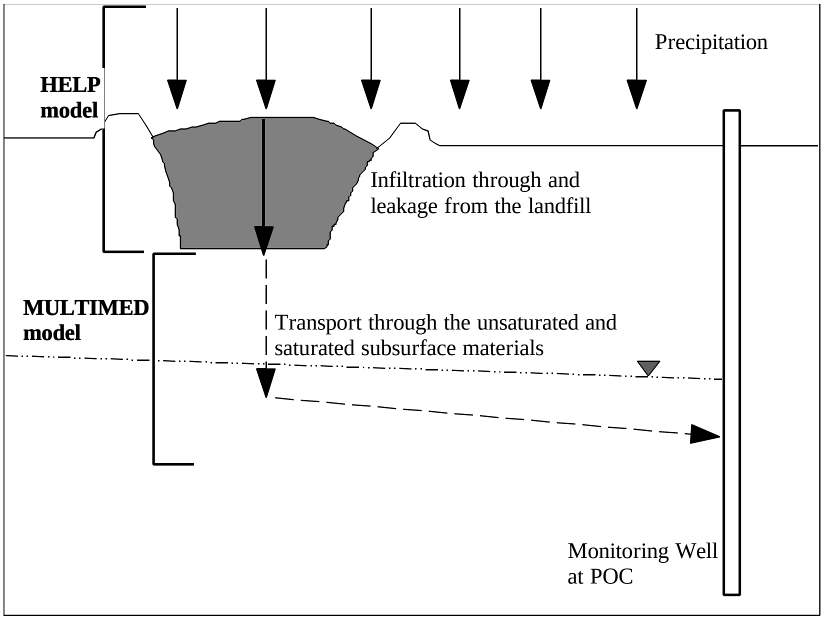

Figure 4-3: Schematic Representation of Coupling the HELP Model and the MULTIMED Model.

As a first step in this evaluation of CKD landfill designs, EPA used the HELP model to estimate leakage rates from a range of landfill designs, as described in Chapter 3. EPA then calculated the impact of this leakage at the hypothetical POCs using a fate and transport model (i.e., MULTIMED). For the landfill designs summarized in Chapter 3, Table 3-1, the MULTIMED model was run in the most conservative mode for this analysis and included a non-karstic limestone setting and no attenuation processes (e.g., no adsorption, no precipitation, and no mineralization of contaminants). The use of a contaminant adsorption term may be appropriate at individual sites, if supported by site-specific data. Comparing the DAFs resulting from the various modeled landfill designs provide an indication of the relative performance of the landfill design (i.e., higher DAFs correspond to better performing landfill designs).

As indicated in Chapter 2, at least nine out of the thirteen ground water damage cases for CKD disposal sites are associated with karst conditions where conduit ground water flow is prevalent. Ground water flow and risk assessments for these areas are difficult to model because of the distribution of the open subsurface fractures and conduits will vary greatly within a particular site as well as from site to site and can not be modeled using MULTIMED. Therefore, landfill performance in karstic areas could not be evaluated using the same approach as for landfills in non-karstic areas.

4.3.2 MULTIMED Modeling to Establish Designs for CKD Landfills in Non-Karst Environments

MULTIMED modeling (combined with the HELP modeling results) was conducted to establish an appropriate design for CKD landfills so that the decision framework could be applied to CKDLF units that will not be located in karst areas. Specifically, the MULTIMED model was used to predict DAFs for various combinations of infiltration rates and rainfall rates taken from the HELP modeling analysis. These DAFs were then applied to the known composition of CKD leachate to determine whether concentrations of constituents of concern will be below their regulatory MCLs at the POC.

For this analysis, two POCs were considered. First, the MULTIMED model was used to predict DAFs at a POC 500 feet (152 meters) immediately hydraulically downgradient of the landfill boundary (i.e., zero degrees off the plume center line). Second, the model was used to predict the dilution factor 3 feet (approximately 1 meter) from the unit boundary, which is the minimum distance permissible in the MULTIMED model. This distance also is consistent with the POC used under Subtitle C for hazardous waste landfills.

Table 4-2 lists the required inputs to the MULTIMED model and the values selected for this analysis. Because few of the required site-specific hydrogeologic data were available for all cement plants, it was necessary to make reasonable estimates for many of the model input parameters.

4.3.3 MULTIMED Results

This Section presents the MULTIMED model results for various combinations of leakage rates and climate settings for the Baseline, Modified CKD Low, and Modified CKD High landfill designs.[2] The precipitation and leakage rates predicted by the HELP model for these designs were reviewed and it was determined that they could be grouped together such that each landfill configuration can be assigned an approximate leakage rate (predicted by the HELP model) of 0.01 inches per year (in/yr), 0.05 in/yr, 1 in/yr, 5 in/yr, 10 in/yr, or 15 in/yr.

As shown in Table 4-3, the average annual precipitation at a particular site is a critical factor in causing leakage for these three landfill designs. For most precipitation rates, the average temperature (warm vs. cold) was not an important factor affecting the predicted infiltration rate. However, for precipitation greater than 40 inches per year, leakage rates, and therefore DAFs, are affected by climate. A review of the HELP model results indicates that the largest difference in water balance between these locations lies in the evapotranspiration amount. That is, more of the incoming precipitation evaporates in warmer climates than in cold, resulting in less infiltration into the top of the landfill, and less leakage through the liner. While differences in evaporation also occur between warm and cold climates with lower precipitation, differences are not seen in the leakage rates. In climates with less rainfall, it is likely that evaporation forms a significant portion of the overall water balance in both warm and cold climates simply because the total precipitation is small. Therefore, the net infiltration into the landfill is similar.

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[2] Because the leakage rate predicted for a Subtitle D design approached zero inches per year, it was not necessary to conduct MULTIMED modeling for sites with this design. It is assumed the performance standard will be met at sites using a Subtitle D or equivalent design.

Table 4-2: MULTIMED Model Input Parameters

Parameter	Value	Reference
Aquifer Particle Diameter (mm)	0.004	Value for coarse clay/fine silt from Sharp-Hansen et al., 1990
Aquifer Bulk Density (g/cc)	1.67	SAIC, 1992
Depth of Aquifer (m)	78.6	SAIC, 1992
Aquifer Hydraulic Conductivity (cm/s)	10^{-5}	Mid-range value for unfractured limestone and dolomite (Freeze and Cherry, 1979)
Aquifer Hydraulic Gradient (unitless)	0.0309	SAIC, 1992
Aquifer Temperature °C	14.4	SAIC, 1992
pH of Aquifer (SU)	6.2	SAIC, 1992
Organic Carbon Content (fraction)	0.000001	SAIC, 1992
Radial distance from unit boundary to POC (m)	1 or 152	Proposed performance standard
Infiltration Rate (Landfill Leakage Rate) (m/yr)	See Table 4-3	Results of HELP model
Landfill Area (acres)	25	Same as input to HELP model
Recharge Rate (Total Precipitation) (m/yr)	See Table 4-3	Same as input to HELP model

Table 4-3. Estimated DAFs for POC at 1 Meter and 152 Meters (From SAIC, 1997)

Climate Conditions Modeled with HELP Model: Precipitation (in/yr) and Temperature	**Cement Plant Locations Matched to Modeled Climate Conditions** (Facility Name, City, State, and Annual Precipitation (in/yr))	**HELP and MULTIMED Results for CKDLF Configurations in Non-Karst Settings**					
		Baseline Design		Modified CKD Low Design		Modified CKD High Design	
		Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED	Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED	Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED
10 Warm and Cold Climates	California Portland Cement, Colton, CA (9.58) Mitsubishi Cement, Lucerne Valley, CA (15.42) Riverside Cement Co., Oro Grande, CA (6.58) National Cement, Lebec, CA (12.68) Riverside Cement Co., Riverside, CA (15.63) Royal Cement, Logandale, NV (5.81) Southdown, Victorville, CA (5.51)	1	<1[a] where POC = 152 m <1[a] where POC = 1 m	0.01	800 where POC = 152 m 18 where POC = 1 m	0.01	800 where POC = 152 m 18 where POC = 1 m
29 Warm and Cold Climates	Ash Grove Cement Co, Louisville, NE (30.13) Lafarge, Alpena, MI (28.83) RMC Lonestar, Davenport, CA (28.99)	1	<1[a] where POC = 152 m <1[a] where POC = 1 m	0.05	13,700 where POC = 152 m 4 where POC = 1 m	0.01	62,500 where POC = 152 m 19 where POC = 1 m
40 Warm Climate	Ash Grove Cement, Chanute, KS (41.9) Holnam Inc., Ada, OK (38.9) Lafarge, Fredonia, KS (38.78) Monarch Cement Co., Humboldt, KS (40.28) Puerto Rico Cement Co., Ponce, PR (40.98)	5	<1[a] where POC = 152 m <1[a] where POC = 1 m	1	<1[a] where POC = 152 m <1[a] where POC = 1 m	0.05	100,000 where POC = 152 m 4 where POC = 1 m

Climate Conditions Modeled with HELP Model: Precipitation (in/yr) and Temperature	**Cement Plant Locations Matched to Modeled Climate Conditions** (Facility Name, City, State, and Annual Precipitation (in/yr))	**HELP and MULTIMED Results for CKDLF Configurations in Non-Karst Settings**					
		Baseline Design		Modified CKD Low Design		Modified CKD High Design	
		Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED	Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED	Approximate Post-Closure Leakage Rate predicted by HELP (in/yr)	DAF predicted by MULTIMED
40[b] Cold Climate	Dragon Products, Thomaston, ME (45.77) Lone Star Industries, Oglesby, IL (37.24)	15	<1[a] where POC = 152 m <1[a] where POC = 1 m	10	<1[a] where POC = 152 m <1[a] where POC = 1 m	10	3 where POC = 152 m 2 where POC = 1 m
55 Warm and Cold Climates	San Juan Cement, Dorado, PR (65.33)	10	<1[a] where POC = 152 m <1[a] where POC = 1 m	5	<1[a] where POC = 152 m <1[a] where POC = 1 m	0.05	1,000,000 where POC = 152 m 5 where POC = 1 m

[a] Landfill configurations that resulted in leakage rates of 1 inch or more per year caused the MULTIMED model to predict that the aquifer could not remove the infiltrating leachate rapidly enough to accommodate the leachate and resulted in a DAF calculation of less than 1. This implies that any landfill design that results in 1 inch or more of leakage per year would not be appropriate for sites overlying aquifers with hydraulic conductivities of 10^{-5} cm/s.

[b] Landfill leakage rates at locations with approximately 40 inches per year are sensitive to the evapotranspiration rate. Leakage rates are consistently higher for sites modeled in colder climates (i.e., low evapotranspiration (ET)) than for the sites modeled in warmer climates (i.e., high ET). For other rainfall amounts, approximate leakage rates did not vary significantly with temperature and ET.

Five climate scenarios were modeled using MULTIMED based on the approximate HELP leakage rates predicted for eight climate scenarios. The warm and cold climate scenarios with average precipitations of 10, 29 and 55 inches/year were combined based on their similar leakage rates for the three landfill designs. Two POCs located at 1 and 152 meters (3 and 500 feet) downgradient from the landfill were evaluated in the MULTIMED simulations. Because MULTIMED is a steady state model and no adsorption is assumed, the depth to ground water is not a factor in computing leachate attenuation at the POC. The model assumes that hydrodynamic dispersion (i.e., dilution) in the saturated ground water system is the only physical process resulting in contaminant attenuation. The DAFs resulting from these simulations are presented in Table 4-3. As a point of reference, cement plants that waste net CKD and are located in non-karst areas are matched in this table according to the appropriate climate.

As described in the following section, the DAFs predicted by MULTIMED can be applied to known leachate constituent concentrations in order to determine whether the MCLs for these contaminants will be exceeded at a POC.

4.3.4 Using MULTIMED DAFs to Evaluate CKDLF Designs Relative to the Performance Standard in Non-Karst Hydrogeologic Settings

Using the DAFs calculated by MULTIMED, an analysis was performed to determine which (if any) of the three landfill design configurations (Baseline, Modified CKD Low, or Modified CKD High) can be expected to meet the performance standard, assuming the landfill is constructed in a hydrogeologic environment in which Darcy’s law is valid. To estimate the concentration of the constituent of concern in the receptor or POC well (C_{RW}), the leachate concentration (C_L) is divided by the DAF for the landfill design being evaluated:

$$C_{RW} = C_L / DAF \quad \text{(Equation 4.1)}$$

The result is then compared to the MCL to determine whether the performance standard can be achieved. Alternatively, one could estimate the minimum DAF required to meet the performance standard by setting the receptor well concentration equal to the MCL and rearrange Equation 4.1 to:

$$DAF = C_L / MCL \quad \text{(Equation 4.2)}$$

Next, a contaminant was selected along with an assumed leachate concentration. To select a contaminant, TCLP data were reviewed from the 1994 Notice of Data Availability (NODA) “Human Health and Environmental Risk Assessment in Support of the Report to Congress on Cement Kiln Dust” (USEPA, 1994). The report includes a composite of “as managed” TCLP results from three data sources: (1) EPA's 1992 and 1993 sampling analyses, (2) the 1990 PCA survey responses, and (3) EPA's 1992 request for additional information under Section 3007 of the Resource Conservation and Recovery Act (RCRA). Upper 95th percentile levels derived from the above-referenced data were reported as follows: antimony concentrations at 17 times the MCL, lead at 109 times the MCL, and thallium at 650 times the MCL. Upper 95th percentile data were used to generate an **upper-bound** estimate of the DAF required for a landfill design to meet the proposed performance standard in non-karst environments.

Thallium was selected as the constituent of concern because it has the highest upper 95th percentile TCLP leachate concentration relative to its MCL. Using Equation 4.2, a DAF of 650 is required to meet the performance standard. Landfill designs with predicted DAFs greater than 650 should be capable of achieving a performance standard of no exceedance of MCLs at 150 meters downgradient of the CKD landfill for all constituents of concern. Designs which yield a DAF of less than 650 are considered unacceptable under the stated assumptions.

Using the data presented in Table 4-3, each of the 18 “non-karst” facilities in the table was assigned a landfill design capable of yielding a DAF of 650 or greater. If one of the three alternative designs (i.e., Baseline, Modified CKD High, Modified CKD Low) could not achieve a DAF of at least 650 at the POC, then the Subtitle D design was assigned by default. The results of this analysis are summarized in Table 4-4.

4.3.5 Summary Results of Application of the Decision Framework to the Cement Plant Database

The results of the application of the decision framework to the cement plant database are summarized in Table 4-5.

Table 4-4. Results of Landfill Evaluation for Cement Plants in Non-Karst Areas (Assuming a Minimum DAF of 650 is Required to Meet the Performance Standard -- see Sec. 4.3.4)

Cement Plant Name/Location	**Baseline Design**		**Modified CKD Low Design**		**Modified CKD High Design**		**Landfill Design Selected**
	POC=152 m	POC=1 m	POC=152 m	POC=1 m	POC=152 m	POC=1 m	
Ash Grove Cement Co, Louisville, NE	✖	✖	✔	✖	✔	✖	CKD Low
Ash Grove Cement, Chanute, KS	✖	✖	✖	✖	✔	✖	CKD High
California Portland Cement, Colton, CA	✖	✖	✔	✖	✔	✖	CKD Low
Dragon Products, Thomaston, ME	✖	✖	✖	✖	✖	✖	Subtitle D[a]
Holnam Inc., Ada, OK	✖	✖	✖	✖	✔	✖	CKD High
Lafarge, Alpena, MI	✖	✖	✔	✖	✔	✖	CKD Low
Lafarge, Fredonia, KS	✖	✖	✖	✖	✔	✖	CKD High
Lone Star Industries, Oglesby, IL	✖	✖	✖	✖	✖	✖	Subtitle D[a]
Mitsubishi Cement, Lucerne Valley, CA	✖	✖	✔	✖	✔	✖	CKD Low
Monarch Cement Co., Humboldt, KS	✖	✖	✖	✖	✔	✖	CKD High
National Cement, Lebec, CA	✖	✖	✔	✖	✔	✖	CKD Low
Puerto Rico Cement Co., Ponce, PR	✖	✖	✖	✖	✔	✖	CKD High
Riverside Cement Co., Riverside, CA	✖	✖	✔	✖	✔	✖	CKD Low
Riverside Cement Co., Oro Grande, CA	✖	✖	✔	✖	✔	✖	CKD Low
RMC Lonestar, Davenport, CA	✖	✖	✔	✖	✔	✖	CKD Low
Royal Cement, Logandale, NV	✖	✖	✔	✖	✔	✖	CKD Low
San Juan Cement, Dorado, PR	✖	✖	✖	✖	✔	✖	CKD High
Southdown, Victorville, CA	✖	✖	✔	✖	✔	✖	CKD Low

POC = “point of compliance”, ✖ = Unacceptable design based on MULTIMED DAF, ✔ = Acceptable design based on MULTIMED DAF.

[a] None of the proposed landfill designs (Baseline, Modified CKD Low, or Modified CKD High) were found acceptable for this facility, therefore, a default Subtitle D design was recommended.

Table 4-5. Predicted Ground water Controls Required at Cement Plants

Predicted Ground Water Controls		Number of Facilities	Percent of Total
1.	No Ground Water Controls Required	36	32.7
2.	Baseline Landfill (see note)	0	0.0
3.	Modified CKD Low Landfill Design (see note)	10	9.1
4.	Modified CKD High Landfill Design (see note)	6	5.5
5.	Subtitle D Default Landfill Design	53	48.2
6.	Alternative Landfill Design Required (per proposed §259.30(g)) or On-site Land Disposal Prohibited	5	4.5
Total		**110**	**100.0**

Note: Assumes a point of compliance (POC) at 150 meters (500 ft.) downgradient of the CKD management unit.

4.3.6 Assumptions and Limitations

The decision framework assumes facilities that currently land dispose CKD will continue to do so after the CKD rule is implemented. Due to the additional costs associated with the design and operation of a new landfill, it is possible that some (and possibly most) facilities will attempt to implement recycling and/or reuse measures as a means to avoid or minimize land disposal of CKD. The decision framework, as currently structured, does not account for this possibility. Accordingly, the decision framework might overestimate the number of facilities that will continue to land-dispose CKD and will require ground water controls.

4.4 Summary and Conclusions

As part of the rulemaking effort, EPA requires estimates of the ground-water controls likely to be implemented at cement plants in response to the regulation. To predict the ground-water controls, if any, that will be required at each cement plant in the U.S., a decision framework was developed based on the ground-water controls currently under consideration by EPA for inclusion in the proposed rule for management of CKD. A range of possible ground-water controls was then established, each of which could be an end point upon application of the decision framework. The ground water controls include: (1) no landfill required for facilities that do not land dispose CKD; (2) a baseline landfill; (3) a modified CKD Low design (4) a modified CKD High design; (5) the Subtitle D default design; and (6) alternative landfill design or off-site land disposal of CKD for facilities located in mature karst areas subject to subsidence. Engineering analyses, HELP modeling, and MULTIMED modeling were conducted to assess the adequacy of the proposed designs. The cement plant database was updated to include new information on CKD generation rates, CKD management practices, and site-specific hydrogeologic information. The decision framework was then applied to the database to predict the ground-water protection measures required at each of the 110 cement plants in the database.

The results of the analysis indicate that 36 cement plants (33%) will not require any ground water controls because they do not waste net CKD. Fifty-three cement plants (48%) are likely to require the Subtitle D default design for their CKD landfills because they land-dispose CKD and they are located in areas of karst or in climate settings that might allow CKD leachate to enter the ground water with inadequate dilution and attenuation. Sixteen cement plants that land-dispose CKD will require either a “Modified CKD Low” or “Modified CKD High” design. MULTIMED modeling results indicate the Baseline CKD landfill configuration (which represents current industry practice) is not acceptable for use at any cement plant under the assumptions stated in the analysis. At five (5) cement plants (4.5%), an alternative landfill design will be required or on-site land disposal likely will not be feasible due to the presence of mature karst features and the high potential for subsidence and/or landfill failure.

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Chapter 5: Summary of Proposed CKD Waste Management Standards for Protection of Ground Water Resources

This chapter provides a summary of EPA's proposed standards for the design and operation of CKDLF units. A CKDLF unit is defined in the proposed rule as a discrete area of land or an excavation that receives CKD waste, and that is not a land application unit, surface impoundment, injection well, or waste pile[1]. A CKDLF unit may receive other types of non-hazardous industrial wastes, such as kiln brick, construction debris, mining overburden or other industrial waste. A CKDLF unit may be a new CKDLF unit, an existing CKDLF unit[2] or a lateral or vertical expansion of an existing unit. The standards to control releases to ground water at CKDLF units include location restrictions (Section 5.1), performance standards for landfill liners (Section 5.2), a default technical design criteria for CKDLF units (Section 5.3), and technical requirements for ground water monitoring and corrective actions (Section 5.4).

5.1 Location Restrictions

The Agency is proposing six location restrictions applicable to CKDLF units. The proposed restrictions include: a prohibition on disposal of CKD below the natural water table (Section 5.1.1); restrictions on placement of CKDLF units in floodplains (Section 5.1.2), wetlands (Section 5.1.3), fault areas (Section 5.1.4), seismic impact zones (Section 5.1.5), and unstable areas, particularly unstable areas in karst terrain (Section 5.1.6). With one exception (i.e., the prohibition against disposal of CKD below the water), the Agency is not proposing an absolute prohibition against siting CKDLFs at these locations; however, all of the proposed locations restrictions require the owner or operator to demonstrate to the State (or in unauthorized States, the EPA Regional Administrator) that they meet specific criteria. In absence of evidence of information to the contrary, EPA is proposing location standards for floodplains, fault areas, seismic impact zones, and unstable areas that are similar to those specified under RCRA Subtitle C for hazardous waste facilities. Because EPA has found increased risks to human health and the environment from CKD disposal at karstic sites, additional standards have been proposed for CKDLF units located in karst terrain (see Section 5.1.6). Nothing in the proposed rule is intended to affect any requirements that facilities may have to comply with under other programs, such as §404 of the Clean Water Act which affects disposal in wetlands.

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[1] Land application units are facilities at which waste is applied onto or incorporated into the surface soil; surface impoundment are facilities designed to hold an accumulation of liquid wastes or liquids containing free liquids; injection wells are wells into which fluids are injected.

[2] An existing CKDLF unit means any CKD waste landfill unit that is receiving CKD as of 90 after promulgation of the proposed rule.

5.1.1 Prohibition of CKD Disposal Below the Natural Water Table

EPA is proposing to ban disposal of CKD in units below the natural water table. The natural water table is defined as the natural level at which water stands in a shallow ground water well open along its length and penetrating the surficial deposits just deeply enough to encounter standing water at the bottom. For the purpose of this standard, this level is uninfluenced by ground water pumping or other engineered activities. At some CKDLF units, the Agency has observed that facility owners artificially lower the natural water table to minimize contact of CKD with ground water. In the case where a site is dewatered (i.e., the water table is artificially lowered) and CKD is disposed below the natural water table, ground water could rise and flow into the CKD disposal unit if the site were abandoned and pumping discontinued. Financial assurances for unit closure would not be sufficient to maintain site dewatering activities indefinitely or would be inadequate to prevent contact of ground water with CKD waste. This would represent an increased risk to human health and the environment due to the subsequent mobilization of CKD constituents within the ground water system. Accordingly, the Agency is proposing to prohibit disposal of CKD below the natural water table.

The Agency has identified at least seven incidents where direct CKD contact with ground water has resulted in degradation of ground water. These incidents are summarized in Table 5-1. At these sites, ground water appears to have saturated portions of waste CKD disposed below the natural water table, mobilized CKD contaminants into the aqueous phase, and transported these contaminants to downgradient areas. The Agency's proposed prohibition against CKD disposal below the natural water table minimizes releases to ground water caused by direct contact of CKD with ground water. CKD contaminants will be less likely to migrate off-site if there is no potential for the CKD waste to contact the saturated ground water system.

Table 5-1. Damage Cases due to CKD Disposal Below the Natural Water Table

CKD Site, Location	CKD Disposal Practice	Environmental Impact
Holnam, Inc., Mason City, Iowa	CKD was disposed of in a former limestone quarry (West Quarry) which was about 40 feet deep and 150 acres in size.	The quarry became filled with ground water and rain water subsequent to the suspension of quarrying operations. Ground water flow in the CKD fill and fractured bedrock transported CKD constituents (Cd, total alkalinity, SO_4, Na, K, and high pH) from the quarry and resulted in a fish kill in Calmus Creek. Maximum concentrations of Sb, Cd, Cr, Pb, Ni in ground water exceeded federal drinking water standards (USEPA, 1997a).

CKD Site, Location	CKD Disposal Practice	Environmental Impact
Lehigh Portland Cement Co., Mason City, Iowa	CKD was disposed of in former limestone quarries (Arch Pond, Blue Waters Pond, Area C Pond).	Quarries became filled with ground water and rainwater following the suspension of excavation operations. Conduit ground water flow in the CKD fill and fractured bedrock transported CKD constituents (As, Pb, SO_4, Na, K, and high pH) into the shallow ground water system (USEPA, 1997b).
Lehigh Portland Cement Co., Metaline Falls, Washington	CKD was disposed of in an unlined waste pile covering about 7.2 acres located in the Sullivan Creek floodplain	Subsequent to disposal ground water levels rose up into the CKD and mobilized waste CKD constituents (As, Cd, Cr, Ni, Pb, Tl, and high pH) into the underlying ground water system and/or adjacent seeps and drainages. Percolation of storm water run-on through the pile was also a factor in mobilizing CKD constituents in ground water (USEPA, 1997c).
Medusa Cement Co., Charelvoix, Michigan	Since 1967, CKD has been disposed of in nine piles which are less than 0.5 miles from Lake Michigan.	The lower portions of CKD Piles 2, 4, and 9 appear to lie within the ground water table. Ground water seeps adjacent to Lake Michigan contained elevated levels of pH (up to 12.1 SU) and specific electrical conductance (up to 5750 umhos/cm). In spite of site dewatering activities, ground water flows through the piles toward Lake Michigan have resulted in CKD contaminated waters emerging as shoreline seeps (RTM 1996).
Portland Cement Co., Salt Lake City, Utah	CKD and chromium-bearing refractory bricks were dumped as fill material on a 70-acre site in a floodplain adjacent to the Jordan River Surplus Canal in order to improve site drainage.	Subsequent to disposal ground water levels rose up into the CKD and mobilized CKD waste constituents (As, Cd, Cr, Pb, Mo, and high pH) into the underlying ground water system (USEPA, 1997d).
Signal Mountain Cement Co., Chattanooga, Tennessee	CKD was landfilled on-site in an old abandoned limestone quarry and adjacent wall cavities connected to underground caverns beneath Signal Mountain.	Ground water (pH levels in excess of the Federal Secondary Drinking Water Standard) flowed through the caverns and combined with landfill surface runoff (pH levels in excess of the RCRA hazardous characteristic of corrosivity) to discharge into a tributary of the Tennessee River. Measurements of pH in ground water from the quarry cavities were ranged from 12.0 to 12.27 SU (USEPA, 1997e).

CKD Site, Location	CKD Disposal Practice	Environmental Impact
Southdown, Inc., Fairborn Ohio	CKD and chromium-bearing refractory bricks were disposed of in former limestone quarries and in unlined landfills adjacent to wetlands and the Mud Run.	A ground water seep located at the toe of Landfill #6 contained CKD constituents (As, Fe, Hg, Ni, Se, Zn, and pH) above drinking water standards. The uppermost aquifer, which consists of gravelly glacial deposits, is an important drinking water aquifer for the City of Fairborn (USEPA, 1993a).

5.1.2 Floodplains

EPA is proposing a restriction on the placement of CKDLF units in a 100-year floodplain. Under the proposed standard, the CKDLF unit must not restrict flow of the 100-year flood, reduce the temporary water storage capacity of the floodplain, or during flooding, have solid waste washout resulting in a hazard to human health and the environment. A floodplain is defined as the lowland and relatively flat areas adjoining inland and coastal waters, including flood-prone areas of offshore islands, that are inundated by the 100-year flood. A 100-year flood means a flood that has a 1-percent or greater chance of recurring in any given year or a flood of a magnitude equaled or exceeded once in 100 years on the average over a significantly long period. To determine whether a CKDLF is in the 100-year floodplain, owners and operators should use flood insurance rate maps (FIRMS) developed by the Federal Emergency Management Agency. If a new or existing CKDLF unit is located in a 100-year floodplain, it must be designed and operated to prevent potential flooding damages including: (1) rapid transport of hazardous constituents by floodwater resulting in degradation of water quality downstream: (2) restriction of floodwater flow, causing greater flooding upstream; and (3) reduction of the storage capacity of the floodplain, since this may cause more rapid movement of floodwater downstream, resulting in higher flood levels and greater flood damages downstream. Site-specific information should be used to evaluate whether a facility has met this standard. The owner or operator must place a demonstration that the facility has met this standard in the operating record and notify the State Director that the demonstration has been placed in the operating record.

5.1.3 Wetlands

The Agency is proposing that no new CKDLF unit can be placed in wetlands unless the owner or operator makes specific demonstrations to the State or (in unauthorized States) to the EPA Regional Administrator, that the new unit: (1) will not result in “significant degradation” of the wetland as defined in the Clean Water Act §404(b)(1) guidelines and published at 40 CFR Part 230; and (2) will meet other requirements derived from the §401(b)(1) guidelines. Wetlands are defined by 40 CFR §232.2(r) as: “..areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas."

Before siting a CKDLF unit in a wetland, the owner or operator must meet five requirements to qualify for a waiver to the ban. These requirements involve:

- conducting a test which shows that there are no practicable alternatives to siting the proposed landfill in the wetland (§230.10(a));

- performing an assessment of compliance with other applicable laws (§230.10(b)). Specifically, the owner or operator will be required to show that the construction and operation of the CKDLF unit will not:
  (i) cause or contribute to violations of any applicable State water quality standard,
  (ii) violate any applicable toxic effluent standard or prohibition under Section 307 of the Clean Water Act,
  (iii) jeopardize the continued existence of endangered or threatened species or result in the destruction or adverse modification of a critical habitat, protected under the Endangered Species Act of 1973, and
  (iv) violate any requirement under the Marine Protection, Research, and Sanctuaries Act of 1972 for the protection of a marine sanctuary.

- performing an assessment of aquatic degradation (§230.10(c)) to establish that the CKDLF unit will not cause or contribute to significant degradation of wetlands;

- evaluating steps taken to minimize the adverse effects of discharge (§230.10(d)) to prevent a net loss of wetlands; and

- assessing whether sufficient information is available to determine if the first four requirements are met.

The guiding principle is that discharges should not be allowed unless the owner or operator can demonstrate that such discharges are unavoidable and will not cause or contribute to significant degradation of wetlands.

5.1.4 Fault Areas

EPA proposes that no new CKDLF units can be sited within 60 meters (200 feet) of a fault that has experienced displacement in Holocene time (within the last 10,000 to 12,000 years), unless a demonstration is made to the State or (in unauthorized States) to the EPA Regional Administrator that an alternative setback distance of less than 60 meters will prevent damage to the structural integrity of the CKDLF unit, and will be protective of human health and the environment. A fault is a fracture or a zone of fractures in any material along which movement has occurred and strata on each side have been displaced relative to each other. EPA believes that motion along faults, as well as secondary effects of shaking such as ground or soil failure, may adversely affect the structural integrity of CKDLF units, and that a 60-meter buffer zone is necessary to protect engineered structures from seismic damages. Regional geologic maps of Holocene age faults are published by the U.S. Geological Survey (USGS, 1978).

For locations where a fault zone has been subject to movement since the USGS maps were published in 1978, a geological reconnaissance of the site and surrounding areas may be required to map fault traces and to determine the faults along which movement has occurred in Holocene time. Site fault characterization studies may be necessary to support a demonstration for a setback of less than 200 feet. Site fault characterization studies would include obtaining information on any lineaments (linear features) that suggest the presence of faults within a 3,000-foot radius. This information could be based on:

- A review of available maps, logs, reports, scientific literature, or insurance claim reports;
- An aerial reconnaissance of the area within a five-mile radius of the site, including aerial photo analysis; or
- A field reconnaissance that includes walking portions of the area within 3,000 feet of the site.

A more detailed site investigation including exploratory trenching is warranted if the site characterization study indicates that a fault or set of faults is situated within 3,000 of the proposed unit. Guidance for conducting detailed fault investigations is found in “Solid Waste Disposal Facility Criteria, Technical Manual” (USEPA, 1993b) and “Guidance Document, Seismic Considerations, Hazardous Waste Management Facilities” (MITRE, 1980).

5.1.5 Seismic Impact Zones

The Agency proposes that any new CKDLF unit located in a seismic impact zone be designed to resist the maximum horizontal acceleration in lithified material for the site. The design features affected include all containment structures (i.e., liners, leachate collection systems, final landfill cover systems, and surface water control systems). Seismic impact zones are defined as areas having a ten percent or greater probability that the maximum expected horizontal acceleration in lithified material for the site, expressed as a percentage of the earth’s gravitational pull (g), will exceed 0.10 g in 250 years. The term ‘lithified material’ refers to any consolidated or coherent, relatively hard, naturally occurring aggregate composed of one or more minerals (e.g., granite, shale, marble, sandstone, limestone, etc.). This definition explicitly excludes loose, incoherent masses such as soils or regolith, and man-made materials such as fill, concrete or asphalt. Maps depicting the potential seismic activity across the United States at a constant probability level have been prepared by the United States Geological Survey (Algermissen et al., 1976).

To determine the maximum horizontal acceleration of the lithified earth materials for the site, owners or operators should review the seismic 250-year interval maps in “Probabilistic Earthquake Acceleration and Velocity Maps for the United States and Puerto Rico” (Algermissen et al., 1991). Information on the location of earthquake epicenters and intensities may be available through State Geologic Surveys or the National Earthquake Information Center, located at the Colorado School of Mines in Golden, Colorado.

Studies indicate that during earthquakes, limited downslope movement of cover soils, cracking, and differential displacements tend to be produced at landfills rather than massive slope failures (Anderson and Kavazanjian, 1995). Stresses created by surficial failures can affect the liner and final cover systems as well as the leachate and gas collection and removal systems. Tensional stresses within the liner can result in fracturing of the soil liner and/or tearing of the flexible membrane liner. If due to a lack of suitable alternatives a site is chosen that is located in a seismic impact zone, a demonstration must be made to the Director that the design of the unit’s structural components (e.g., liners, leachate collection, final covers, run-on and run-off systems) will resist the maximum horizontal acceleration in lithified materials at the site. As part of the demonstration owners/operators must:

- Determine the expected peak ground acceleration from a maximum strength earthquake that could occur in the area,

- Determine the site-specific seismic hazards such as soil settlement, and

- Design the facility to withstand the expected peak ground acceleration.

The design of slopes, leachate collection system, and other structural components should have built-in conservative design factors. Additional, redundant precautionary measures should be designed and built into various landfill systems. In determining the potential effects of seismic activity on a structure, an engineering evaluation should examine soil behavior with respect to earthquake intensity. Guidance for conducting such an evaluation is found in “Solid Waste Disposal Facility Criteria, Technical Manual” (USEPA, 1993b).

5.1.6 Unstable Areas Including Karst Terrains

EPA is also proposing that owners and operators of new and existing CKDLF units located in unstable areas must demonstrate to the State (or, in unauthorized States, the EPA administrator) the structural integrity of the unit. This demonstration must show that engineering measures have been incorporated into the unit's design to mitigate the potential adverse structural impacts on the structural components of the unit that may result from subsidence, slope failure, or other mass movements in unstable areas. For purposes of this section, structural components include liners, leachate collection systems, and final covers.

The EPA is particularly concerned with CKDLF units located in areas of karst terrain. More than one half of all cement plant sites are estimated to be located in karst terrains with a potential to be underlain by karst aquifers with conduit flow characteristics. The potential for off-site CKD leachate migration in karst aquifers with a strong component for conduit flow is high. As a result, owners or operators of a new or existing CKDLF unit, or a lateral expansion located in a karst hydrogeologic setting must demonstrate that engineering measures have been incorporated into the landfill unit's design to ensure that the integrity of the structural components of the unit will not be disrupted. These structural components include liners, leachate collection systems, final covers, run-on/run-off systems, and any other component used in the construction and operation of the CKD landfill unit that is necessary for the protection of human health and the environment.

Before construction of a CKD in carbonate terrain, the owner/operator shall be required to verify and certify whether the facility is situated in a karst terrain. Verification of a karst terrain may include a review of the available literature, and if the literature review is inconclusive, a basin-wide field study. This field study is required to compile an inventory of karst features and identify all potential springs from which ground water passing beneath the CKD landfill unit may discharge even if the discharge points of the basin extend beyond the facility boundary. Factors to be considered during the inventory include:

- on-site or local geologic or geomorphologic features, especially those features indicative of a karst hydrogeologic setting; and

- on-site or local soil conditions that may result in significant differential settling, collapse, or puncture of the landfill liner, and

- on-site or local anthropogenic features or events (both surface and subsurface) that may impact the integrity of the CKDLF unit or ground water flow from the site.

To conduct the site characterization field study, the facility must locate background and intermediate sampling locations, and downgradient springs or ground water monitoring wells. If the site is certified to be located in karst terrain by an independent professional ground water scientist, data collected from these locations must be incorporated into a determination of on-site hydrology, including the character and direction of ground water flow and points of discharge for the karst ground water basin the facility may affect. Such a determination will require:

- tracer studies to verify ground water flow path,

- the regular monitoring of chemographs and hydrographs of springs and monitoring wells, and

- the development of a sampling strategy capable of detecting releases from the CKDLF unit. The sampling strategy must be based on the unique fate and transport characteristics of the toxic constituents in CKD and the hydrology of the karst aquifer.

The requirement for a karst ground water investigation may be suspended if the owner or operator of the facility can demonstrate that there is no potential for migration of hazardous constituents from the CKD landfill unit to the uppermost aquifer during the active life of the unit and the post-closure care period (proposed 40 CFR 259.30(b)). This demonstration must be certified by a qualified ground water scientist, approved by the State and based upon:

- site-specific field collected measurements, sampling, and analysis of physical, chemical, and biological processes affecting contaminant fate and transport, and
- contaminant fate and transport predictions that maximize contaminant migration and consider impacts on human health and the environment.

5.2 Performance-Based Standard for Protection of Ground Water

After evaluating a range of possible performance standards as discussed in Chapters 3 and 4, and considering the need for a tailored and flexible approach for the protection of ground water, the Agency is proposing a performance-based design standard that is similar to the RCRA Subtitle D performance standard found in 40 CFR 258.30(c)(1). This performance-based standard would apply to the metal constituents (antimony, arsenic, barium, beryllium, cadmium, chromium (total), lead, mercury, nickel, selenium, silver, thallium, and vanadium). For each constituent, the standard would be as follows: (1) if available, the maximum contaminant level (MCL) established under § 1412 of the Safe Drinking Water Act (See 40 CFR Part 141); (2) for constituents with concentration levels lower than background, the background level; and (3) for constituents with no MCLs, an alternative risk-based number or appropriate level established by the EPA Regional Administrator.

MCLs would be measured in ground water from the uppermost aquifer at the point of compliance, defined as the closest practical distance from the unit boundary, or at an alternative point chosen by the State. The alternative point of compliance must be on facility property and be no more than 150 meters from the unit boundary (proposed 40 CFR 259.30(f)). In allowing for an alternative point of compliance, the Agency's rationale is to allow greater flexibility for a State to set design requirements based on site-specific factors. In determining the relevant POC, the following factors shall be considered:

- the hydrogeologic characteristics of the facility and surrounding land;

- the volume and physical and chemical characteristics of the leachate;

- the quantity, quality, and direction of flow of ground water;

- the proximity and withdrawal rate of ground water users;

- the availability of alternative drinking water supplies;

- the existing quality of the ground water, including other sources of contamination and their cumulative impacts on the ground water, and whether the ground water is currently used or reasonably expected to be used for drinking water; and

- public health and safety effects (proposed 40 CFR 259.30 (f)).

5.3 Default Technical Design Criteria for CKDLF Units

EPA is proposing that design criteria similar to that for municipal solid waste landfills (MSWLFs) under the Subtitle D program (Solid Waste Disposal Facility Criteria, 56 FR 50978, October 9, 1991) be adopted for CKDLF units with modifications for ground water monitoring (see section 5.4.1) and remediation. As EPA demonstrated using the HELP model (See Chapter 3) and studying management of waste similar to CKD (See Chapter 6), these default design criteria are considered sufficient to meet the CKDLF performance standards discussed in Section 5.2. It is recognized that for some sites alternative designs can be demonstrated to meet the performance based standards. In the absence of an approved alternative design, the default design criteria would apply to any new CKD waste management unit or lateral extension. The default technical design criteria for CKDLF units require a composite bottom liner and a leachate collection and removal system (LCS) that is designed and constructed to maintain less than a 30 cm depth of leachate over the liner. The composite liner must consist of two components: an upper flexible membrane liner (FML) with a minimum thickness of 30-mil, and a lower component consisting of at least two feet of compacted clay with a hydraulic conductivity of no more than 1×10^{-7} cm/sec. FML components consisting of high density polyethylene (HDPE) shall be at least 60-mil thick, and must be installed in direct and uniform contact with the compacted soil component (proposed 40 CFR 259).

The Agency believes that this proposed default design criteria will be protective of ground water resources. Liners will prevent leachate from seeping from the landfill and entering the aquifer. Functionally, both the FML and lower clay component are necessary to retard the migration of contaminants; the FML would impede the flow of leachate into subsoil, and the compacted clay component would adsorb and attenuate pollutants. A LCS is necessary to relieve the hydraulic pressure within the landfill which could drive leachate migration through the base of the landfill.

When designing a CKD landfill unit, in addition to the proposed design criteria, the owner or operator shall consider at least the following factors:

- the hydrogeologic characteristics of the facility and surrounding land, especially the presence of karst terrain (see section 5.1.2);
- the climatic factors of the area; and
- the volume and physical and chemical characteristics of the leachate (proposed 40 CFR 259.30 (e)).

5.4 Proposed Technical Requirements For Ground Water Monitoring

The proposed technical requirements for ground water monitoring at CKD disposal units are based on those already promulgated under 40 CFR Part 258 (for MSWLFs) and 40 CFR Part 264 (for hazardous waste management units). In developing these standards, EPA also considered a draft proposal submitted to the Agency from the cement industry entitled *Cement Kiln Dust Management Practices* (Portland Cement Association, 1995). The proposed requirements have been tailored to address the characteristics of CKD and provide sufficient flexibility to allow effective implementation by States. EPA's proposed standards for ground water monitoring at CKDLFs include provisions for:

- ground water monitoring well design, construction and development (Section 5.4.1),
- ground water sampling and analysis requirements (Section 5.4.2),
- statistical analysis of ground water monitoring data (Section 5.4.3),
- detection monitoring (Section 5.4.4),
- assessment monitoring (Section 5.4.5),
- assessment of corrective measures (Section 5.4.6),
- selection of remedy (Section 5.4.7), and
- implementation of corrective action (Section 5.4.8).

All owners and operators of new or existing CKDLF units or lateral expansions are required to comply with these standards. However, limited waivers may be granted to owners or operators who can demonstrate that a waste management unit is located above a hydrogeologic setting that will prevent the migration of CKD constituents of concern to ground water during the active life and closure and post-closure periods of the unit.

5.4.1 Ground Water Monitoring Well Design and Construction

As a part of the performance standard for new and actively managed CKDLF units, and lateral expansions, the EPA proposes the installation of ground water monitoring systems similar to those described in 40 CFR 258.51 for MSWLFs. These ground water monitoring systems shall be used throughout the active, closure, and post-closure periods of the unit.

The proposed standards require that implementation of a ground water monitoring program would be required for new CKDLF units prior to accepting CKD waste. Ground water monitoring wells are required to be designed according to the following criteria:

- The ground water monitoring system must include, at a minimum, one up-gradient and three down-gradient wells.

- The relevant point of compliance for down-gradient wells must be on the property of the CKDLF unit owner. If obstructed by physical barriers from being located on-site, the ground water monitoring system shall be installed at the hydraulic down-gradient position closest to the point of compliance where contaminated ground water in the uppermost aquifer can be detected.

- The ground water monitoring system must be capable of ascertaining the quality of background ground water that has not been affected by leakage from the unit, and assessing the quality of ground water passing the relevant point of compliance. As discussed in Section 8.1.2, this may be a formidable task in karst terrain.

- The number, spacing and depths of monitoring systems shall be dependant on aquifer thickness, ground water flow rate, ground water flow direction including seasonal and temporal fluctuations in ground water flow. Other factors to be considered include: the thicknesses, stratigraphy, lithology, hydraulic conductivities, porosities, and effective porosities of saturated and unsaturated geologic units, and fill comprising the uppermost aquifer and the confining unit forming the lower boundary of the uppermost aquifer;

- Where the facility has several units, the owner or operator may install a multi-unit ground water monitoring system instead of separate ground water monitoring systems for each CKD landfill unit.

- Each ground water monitoring system be certified as adequate by a qualified ground water scientist or approved by the State;

Monitoring wells must be constructed in a manner that maintains the integrity of the monitoring well bore hole. The casing must be screened or perforated and packed with gravel or sand, where necessary, to enable collection of ground water samples. The annular space above the sampling depth must be sealed to prevent contamination of samples and the ground water. Ground water monitoring plans, monitoring well locations, and points of compliance for CKDLF units must be approved by the State Director prior to implementation.

5.4.2 Ground Water Sampling and Analysis Requirements

The Agency is proposing requirements for ground water sampling and analysis at CKDLF units similar to those established under 40 CFR 258.53 for MSWLFs. The proposed rule allows the State to develop an alternative sampling procedure if necessary to protect human health and the environment. For all CKDLF units, the owner or operator must develop a sampling and analysis plan for monitoring releases to ground water. The State Director must be notified that the sampling and analysis program documentation has been placed in the operating record.

Ground water sampling and analysis procedures are designed to ensure consistency and obtain accurate ground water quality data at (a) hydraulically-upgradient background wells, and (b) downgradient wells at the point of compliance. As stated in the previous subsection, downgradient monitoring wells must be designed and constructed to detect potentially contaminated ground water from the CKDLF unit. For facilities located in karst terrain, EPA is also proposing that a ground water monitoring strategy include, where necessary, monitoring of springs which are the ultimate discharge points of the karst ground water basin in which the facility is located. Additional information on the use of springs in a ground water monitoring strategy is provided in Section 7.1. Records of the sampling and analysis program shall include procedures and techniques used for sample collection; sample preservation and shipment; analytical procedures; chain of custody control; and quality assurance and quality control. The ground water monitoring program must include sampling and analytical methods that are appropriate for ground water sampling and that accurately measure hazardous constituents and other monitoring parameters in ground water samples. Ground water samples shall not be field-filtered prior to laboratory analysis. Owners and operators of a CKDLF shall be required to establish background concentrations in a hydraulically upgradient well or background well(s), and if in karst terrain, in springs for each of the monitoring parameters or constituents required in the ground water monitoring program. Ground water sampling procedures and frequency must be protective of human health and the environment during the active life, closure and post-closure periods of the CKD disposal site.

Ground water elevations must be measured in each well immediately prior to purging for each ground water sample. In addition, the owner or operator must determine the rate and direction of ground water flow each time ground water is sampled. Ground water elevations in wells which monitor the same waste management area must be measured within a period of time short enough to avoid temporal variations (e.g., pumping well effects and climatic conditions) in ground water flow which could preclude accurate determination of ground water flow rate and direction.

The number of samples collected to establish ground water quality must be consistent with the appropriate statistical procedures described in section 5.4.3.

5.4.3 Statistical Analysis of Ground Water Monitoring Data

The Agency is proposing performance standards and technical procedures for the statistical analysis of ground water monitoring data at CKDLF units. The standards and procedures are similar to those already established for ground water monitoring conducted under 40 CFR Part 258 (for MSWLF units) and 40 CFR Part 264 (for land-based hazardous waste management units)[3], however, the requirements can be tailored to address the characteristics of CKD and provide sufficient flexibility to allow effective implementation by facilities and States.

The statistical analysis requirements will be applicable to all new and actively managed CKDLF units. The use of statistical procedures to evaluate ground water monitoring data shall be used for the duration of the monitoring program, including the post-closure care period.

The proposed requirements provide that the owner or operator of a CKDLF units must select an appropriate statistical procedure to determine if samples taken from downgradient monitoring wells represent a statistically significant increase over background values for each parameter or constituent that occurs in the downgradient sample. The proposed rule requires the owner or operator to employ one of four statistical procedures or an alternative procedure that would protect human health and the environment and meet the proposed ground water protection standard. The four statistical procedures proposed by EPA include:

1) A parametric analysis of variance (ANOVA) followed by multiple comparisons procedures to identify statistically significant evidence of contamination,

2) An analysis of variance based on ranks followed by multiple comparisons procedures to identify statistically significant evidence of contamination,

3) A tolerance or prediction interval procedure; and

4) A control chart approach.

The proposed rule also will allow the State to develop an alternative sampling procedure and statistical test if necessary to protect human health and the environment. In establishing an

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[3] See 52 FR 31948 Statistical Methods for Evaluating Ground water Monitoring Data from Hazardous Waste Facilities and 56 FR 50978 Solid Waste Disposal Criteria; Final Rule.

alternative statistical method, the State should consider the performance standards for the statistical analysis methods. The performance standards for the statistical analysis of ground water monitoring data at CKDLFs are based on those already promulgated under 40 CFR Part 258.53(h) for MSWLFs. The performance standards include the following:

1) The method must be appropriate for the observed distribution of the data

2) Individual well comparisons to background ground water quality or a ground water protection standard shall be done at a Type I error level of no less than 0.01 or, if the multiple comparisons procedure is used, the experiment-wise error rate for each testing period shall be no less than 0.05

3) If a control chart is used, the type of chart and associated parameter values shall be protective of human health and the environment

4) The level of confidence and percentage of the population contained in an interval shall be protective of human health and the environment

5) The method must account for the data below the limit of detection (less than the PQL) in a manner that is protective of human health and the environment

6) The method must account for seasonal and spatial variability and temporal correlation of the data, if necessary.

The performance standards provide means to limit the possibility of making false conclusions from the monitoring data.

5.4.4 Detection Monitoring

A detection monitoring program similar to that used under 40 CFR 258.54 is proposed for all new and actively managed CKDLF units. The proposed rule allows the State to develop an alternative monitoring program if necessary to protect human health and the environment.

Detection monitoring shall be implemented at all ground water monitoring wells and springs included in the ground water monitoring system. The detection monitoring program must include sampling for the indicator parameters identified in Table 5-2 to establish background. These detection parameters have been proposed to the Agency by the cement industry as constituents that are easily measured and provide a reliable indication of inorganic releases from the CKD waste management unit to ground water (PCA, 1995).

Table 5-2. Indicator Parameters for Detection Monitoring

Constituents/Parameters
Chloride
Potassium
Sodium
Sulfate
pH
Conductivity
Total dissolved solids

Monitoring shall be conducted at least semi-annually during the active life, the closure and post-closure periods of a CKDLF unit to determine whether there has been a statistically significant increase over background. At least four independent samples from each well (or in the case of downgradient locations, wells and springs) must be collected and analyzed for constituents listed in Table 5-2 or an approved alternative list during the first semiannual sampling event.

At least one sample must be collected from each well and spring (background and downgradient) and analyzed during subsequent semiannual sampling events. The State Director may specify an appropriate alternative frequency for repeated sampling and analysis for Table 5-2 constituents, or an approved alternative list during the active life (including closure) and post-closure care period.

When detection monitoring parameters are identified at statistically significant levels over established background concentrations at any monitoring well or spring at the waste management unit boundary, assessment monitoring must be initiated.

5.4.5 Assessment Monitoring

The EPA proposes that assessment monitoring be required at a CKDLF unit whenever a statistically significant increase over background is detected for one or more of the constituents listed in Table 5-2. The assessment monitoring program for CKDLFs is similar to the assessment monitoring approach used under 40 CFR 258.55 for MSWLFs.

Owners and operators shall begin to sample and analyze for constituents listed in Table 5-3 (antimony, arsenic, barium, beryllium, cadmium, chromium (total), lead, mercury, nickel, selenium, silver, thallium, and vanadium) within 90 days of the detection monitoring event indicating the occurrence of a contaminant release. Subsequent assessment monitoring shall be conducted semi-annually after the first round of assessment sampling is conducted. A minimum of one sample from each downgradient well and spring must be collected and analyzed during each sampling event.

Table 5-3.Constituents and MCLs for Assessment Monitoring

Constituents/Parameters	MCL (mg/L)
Antimony	0.006
Arsenic	0.05
Barium	2.0
Beryllium	0.004
Cadmium	0.005
Chromium (total)	0.1
Lead	0.015
Mercury	0.002
Nickel	Remanded 6/95
Selenium	0.05
Silver*	0.1
Thallium	0.002
Vanadium	No MCL

Source: EPA Drinking Water Hotline (6/10/98)

* Secondary drinking water standard for silver shown. All other MCLs shown are primary drinking water standards.

The constituents of concern identified in Table 5-3 are those constituents reasonably expected to be in, or result from, CKD disposed in landfills or other land-based management units. In addition, the constituents have been found at elevated concentrations in ground water in the vicinity of CKD landfills as documented in EPA's damage case summaries (see Table 2-1 in Chapter 2).

The Agency proposes a ground water protection standard for constituents of concern listed in Table 5-3. As discussed in Section 5.2, the protection standard shall be the MCL, or the background concentration of that parameter for the site. If the background level is higher than the MCL for a constituent, the background level must be used as the ground water protection standard.

If one or more of the constituents listed in Table 5-3 are detected at statistically significant levels above the ground water protection standard in any sampling event, the owner or operator must:

- characterize the nature and extent of the release by installing additional monitoring wells if necessary;
- install at least one additional monitoring well at the facility boundary in the direction of contaminant migration and sample this well;
- notify all persons who own land or reside on land that directly overlies any part of the plume of contamination if contaminants have migrated off-site; and
- initiate an assessment of corrective measures within 90 days.

5.4.6 Assessment of Corrective Measures

EPA is proposing requirements for an assessment of corrective measures similar to those promulgated under 40 CFR 258.56 for MSWLFs. An assessment of corrective measures shall begin within 90 days of detecting constituents at statistically significant levels above ground water protection standards (Section 5.4.5). Such an assessment must be completed within a reasonable period of time.

The owner/operator shall be required to continue to monitor in accordance with the monitoring assessment program. The assessment of corrective measures shall include an analysis of the effectiveness of potential corrective measures and address at least the following:

- the performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;
- the time required to begin and complete the remedy;
- the costs of remedy implementation; and
- the institutional requirements such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

Prior to selection of the remedy, the owner/operator must discuss the results of the corrective measures assessment in a public meeting with interested and affected parties.

5.4.7 Selection of a Remedy

After conducting the assessment of corrective action, the owner or operator shall select a course of action that is similar to 40 CFR 258.57, and at a minimum,

- protects human health and the environment,
- achieves the ground water protection standard specified in Section 5.4.5,
- controls contaminant releases in order to reduce or prevent further releases which may threaten human health or the environment, and
- enables compliance with any RCRA requirements to be achieved.

In addition, the owner or operator shall include with the specified remedy a schedule or schedules for beginning and completing remedial activities.

5.4.8 Implementation of Corrective Action

Upon selecting the schedule of remedial activities, the owner or operator shall establish a corrective action ground water monitoring program that shall at least:

- meet the requirements of an assessment monitoring program;
- indicate the effectiveness of the corrective action remedy; and
- demonstrate compliance with ground water protection standards specified in Section 5.4.5.

The owner/operator also is required to implement the selected corrective action remedy and take any interim measures necessary to ensure the protection of human health and the environment. Interim measures should, to the greatest extent practicable, be consistent with the objectives of and contribute to the performance of any remedy that may be required in Section 5.4.7.

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Chapter 6: Effectiveness of Proposed CKD Landfill Design Elements

Current baseline designs and practices at CKDLF units are inadequate to protect ground water resources as evidenced by the damage cases discussed in Section 2.1.1. The Agency evaluated a range of possible landfill design configurations and performance standards (see Chapter 3) and generated upper bound estimates of the types of controls that might be required at new CKDLF units in the U.S. and Puerto Rico (see Chapter 4). A summary of the proposed standards and rationale to protect ground water resources at CKDLF units is provided Chapter 5. The proposed standards are intended to improve upon baseline CKD landfill designs and practices. To evaluate the expected performance of the proposed management standards, the Agency also studied the performance of landfills that manage waste similar to CKD and evaluated the effectiveness of CKD when used as a landfill liner or cap material. To evaluate the performance of landfills managing waste similar to CKD, EPA analyzed information from several coal ash landfills and CKD disposal sites. Besides the use of liners, coal ash landfills may install leachate collection and ground water monitoring systems and pre-treat wastes before disposal to improve ease of handling and obtain the consistency suitable for landfill disposal. A more detailed evaluation of coal ash landfills can be found in a background report entitled *Technical Background Document on the Efficiency and Effectiveness of CKD Landfill Design Elements - Draft Report* (USEPA, 1997a).

Section 6.1 presents landfill design and operating information on coal ash disposal sites associated with two coal-fired power plants in Pennsylvania. In Section 6.2, the performance of these landfills with respect to preventing ground water contamination is compared with the proposed CKD landfill standards. In Section 6.3, the performance of the ground water monitoring systems at these landfills is compared with the proposed CKD landfill standards. Landfill performance data were evaluated for these Pennsylvania coal ash landfills in a technical background document prepared in support of EPA's CKD rule making efforts (USEPA, 1997a).

Several CKD disposal facilities have proposed or used conditioned CKD as a cover or bottom liner material for a CKD landfill. The effectiveness of conditioned CKD as an engineered component in a landfill design is evaluated in Section 6.4.

6.1 Coal Ash Disposal at Selected Landfills in Pennsylvania

This section draws on the operating and landfill performance data at coal utility plants for disposing large quantities of fly ash to validate the proposed CKD disposal standards presented in Section 5.2. Coal fly ash has many characteristics similar to CKD including a fine grain size, and elevated concentrations of certain toxic metals including arsenic, chromium and lead. TCLP analysis of 12 fly ash and 13 bottom ash samples found no results above the RCRA toxicity limits. Extraction Procedure (EP) analyses found that 2 out of 78 fly ash samples exceeded the RCRA toxicity limits for arsenic or chromium (by a factor of 3.3 or 1.7, respectively) (USEPA, 1993a). CKD and coal combustion wastes are generally alkaline and have very low concentrations of organic compounds. pH values for CKD leachate range from 6.11 to 12.98 standard units (USEPA, 1993b), and a study of ash derived from bituminous, sub-bituminous, and lignite coals reports pH values of 8.2, 10.8 and 9.2 standard units, respectively (Adriano, et al., 1980).

Coal combustion wastes may be managed in impoundments, landfills, mines and quarries or other facilities. Approximately 45 percent of all the coal ash disposal units in the United States are landfills. Old utility ash landfills and surface impoundments are generally simple, unlined systems. After 1975, over 40 percent of all generating units managed their wastes in lined facilities using one or more layers of low permeability clays or synthetic liners, or a combination of both. Fly ash has been incorporated in some clay liners since it is cohesive and fairly impermeable when properly compacted. However, variabilities in its chemical composition and changes in its permeability and shear strength over time limit its use (USEPA, 1988). Flue gas desulfurization (FGD) waste from air pollution abatement equipment (i.e., scrubbers) is often co-disposed with fly ash. FGD waste consists of primarily of calcium sulfate (i.e., gypsum) which dissolves in water and has no shear strength under high moisture conditions. FGD waste is not disposed at the Montour and Titus/Beagle Club ash landfills.

6.1.1 Montour Generating Station/Ash Storage Sites 2 and 3

The Montour Steam Electric Station, owned by the Pennsylvania Power & Light Company (PP&LC), is located on the Chillisquaque Creek in Derry Township, Montour County, Pennsylvania. It first started producing electricity in 1972 and currently has an electric generating capacity of 1500 MW. Montour has two coal ash disposal landfills with a bottom liner design similar to that required under Subtitle D for municipal landfills including a low permeability bottom layer (geomembrane or clay <10^{-7} cm/s permeability) with leachate collection, and 1 or 2 ft thick compacted bottom ash drainage blanket with perforated pipe for leachate collection. Both landfills have an underdrain below the landfill bottom liner to prevent upgradient surface run-off and ground water from flowing into the landfill.

Operations in Ash Storage Area 2 began in 1982 and lasted until 1989 when ash disposal activities began in Ash Storage Area 3. In 1982, fly ash waste management practices changed from sluicing to Ash Basin 1 to pneumatically transporting fly ash to silos for temporary storage. The fly ash is then conditioned with water and either sold off-site for beneficial uses or disposed of on site. Montour is able to sell most of the fly and bottom ash that is generated, primarily as light weight construction fill. Ash Storage Area 2 is permitted to cover 34 acres and is lined either with 20-mil PVC (where depth to ground water is less than 2 feet) or with two feet of clay soil with a maximum permeability of 10^{-7} cm/s. Ash Storage Area 3 is permitted to cover 64 acres and is underlain by a 30-mil PVC bottom liner.

The conditioned fly ash is compacted to a minimum of 90 percent of Standard Proctor (ASTM, D698) maximum density with a smooth wheel vibratory roller during disposal. Fly ash surfaces that are completed but not at final grade are sprayed with water or a dust control agent or covered with bottom ash if the ash surface begins to dust (PP&LC, 1981). Permit conditions require a one-foot thick final clay cover for Ash Storage Area 2 and a two-foot thick final clay cover for Ash Storage Area 3. Storm water run-off and landfill leachate is collected in surge ponds adjacent to the landfills, routed to the plant's Miscellaneous Plant Waste Basin for treatment with other plant waste waters and discharged under a NPDES permit. Ground water monitoring has identified some evidence of downgradient contamination due to oxidation of naturally occurring pyrite in the bedrock shale formation. Recent repairs made to Area 3 surge basin overflow spillway may have caused elevated levels of sulfate, calcium, and specific conductivity in downgradient monitoring well MW-3-3 relative to pre-1996 monitoring results (PP&LC, 1997).

6.1.2 Titus Generating Station/Beagle Club Ash Disposal Site

The Titus Generating Station is a steam electric generating plant located on the Schuylkill River in Cumru Township, Berks County, Pennsylvania. It began producing energy in 1951, has a generating capacity of 240 MW, and is operated by Metropolitan Edison Company (Met-Ed)/ GPU Genco. The Beagle Club Ash Disposal Site is located about 1 mile south of the City of Reading, adjacent to Highway 422, and immediately across the Schuylkill River from the Titus Generating Station. Disposal operations at the Beagle Club Ash Disposal Site began when it was permitted as a new ash disposal site in 1978. Major permit modifications were issued to the facility in 1984 to construct a leachate collection system under the landfill and to install leachate/run-off treatment ponds and in 1991 to install a 50-mil PVC bottom liner under new portions of the facility. Because the 1984 permit prohibited new ash disposal over the old ash fill with out leachate collection, the pre-1984 ash landfill was excavated, stockpiled and then reburied. A leachate collection system was installed under the entire landfill. A minimum 2-foot-thick native clay layer is present under 9 acres of the landfill associated with pre-1991 ash disposal. Since 1991, a 50-mil-thick PVC bottom liner has been used for the remaining 10.7 acres of this landfill. An additional 18 acres has been permitted to provide support for the disposal area including leachate/run-off pond system, soil stockpiles and access roads (CEC, 1992).

The fly ash generated at the station is collected in hoppers, conditioned with water, trucked to the disposal site, spread in one foot lifts and compacted. Sludge from an ash sedimentation pond associated with the fly ash loading area and bottom ash is periodically removed and disposed at the disposal facility. Fly ash surfaces that are completed but not at final grade are sprayed with water or covered with bottom ash if the ash surface begins to dust. Portions of the landfill, which have been built up to the final grade, have been capped with a one-foot-thick clay layer (maximum permeability is 10^{-7} cm/s) (Gilbert/Commonwealth, 1994). Landfill leachate and dirty storm run-off are collected in ponds adjacent to the landfill and discharged under a NPDES permit to the Schuylkill River. Based on analytical results to date, no treatment has been required for this water.

Ground water degradation (i.e., sulfate and total dissolved solids (TDS) concentrations above secondary drinking water limits in downgradient wells but not in background wells) due to coal ash disposal has been observed at the Titus landfill. The leakage rate estimated by HELP model analysis for the 9 acre unlined portion of the landfill ranged from a maximum monthly flow rate of 1.6 gpm (0.3 inches/month) in 1994 to less than 0.1 gpm (0.02 inches/month) following site closure, projected in 2008 (Gilbert/Commonwealth, 1994).

6.2 Comparison of Coal Ash Landfill Performance with Proposed CKD Landfill Standards

This section summarizes the effectiveness of the landfills described in Sections 6.1.1 and 6.1.2 in protecting ground water resources and projects how effective these design elements would function at CKD landfills. Annual rainfall at both the Montour and Titus/Beagle Club locations is about 40 inches (Sterner, 1994). Therefore, based on EPA's modeling and evaluation of CKD landfill designs summarized in Section 4.4, the Subtitle D technical default standard would be expected to perform acceptably, but the "Modified CKD High" and "Modified CKD Low" design would not perform as well.

6.2.1 Composite Bottom Liner

Of the three landfills, only the Montour Ash Storage Area 3 used a modified composite bottom liner design where the landfill is entirely underlain by a plastic (e.g., PVC) bottom liner. However, the requirements for the clay portion of the composite liner for these landfills was less stringent than the 2 feet of clay with a permeability less than 10^{-7} cm/s, specified in the RCRA Subtitle D regulations (40 CFR 258.40(a)(2)). No minimum permeability (other than that resulting from site clearing, grubbing and rolling soil flat) was required for the subbase material of the Montour landfill. An underdrain was constructed at the Montour Area 3 landfill to drain upgradient surface water and/or shallow ground water and to prevent excessive pressure heads under the landfill. A leachate collection system consisting of bottom ash and perforated PVC pipes was installed throughout the landfill immediately overlying the bottom liner.

Ground water monitoring results at the Montour facility indicate the presence of pre-existing, poor quality ground water under these landfills. As discussed in Section 6.1.1, this pre-existing, poor quality ground water makes it difficult to evaluate the potential for leakage through the landfill bottom liners.

EPA is considering using the RCRA Subtitle D composite liner design as the technical default standard for CKD landfills. EPA's evaluation of the Subtitle D composite liner design indicates that the expected leakage from this design is very small and would be protective of human health and ground water resources (see Section 4.4). In designing a bottom liner for CKD landfills in non-karstic areas, EPA is considering a performance-based design standard that is based on the RCRA Subtitle D performance standard found in 40 CFR 258.40(a)(1). This standard would allow the use of a modified bottom liner design, such as those found at the coal ash landfill sites, as long as there is no exceedance of EPA's maximum contaminant levels (MCLs) for drinking water (or background, for constituent for which no MCL has been established) for arsenic, antimony, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and thallium in the uppermost aquifer at the relevant point of compliance (POC).

6.2.2 Alternative Bottom Liner Designs

Portions of the Montour Area 2 and Titus/Beagle Club landfills do not have a plastic bottom liner, but instead use compacted native clay as a bottom liner. At the Montour Area 2 facility, a plastic liner was only used in areas where the depth to water was less than 0.6 meters (2 feet), otherwise the bottom liner consisted of a 2-foot-thick native clay with a maximum permeability of 10^{-7} cm/s (PP&LC, 1981). A 2-foot-thick native clay with no permeability requirement was used a bottom liner for the Titus/Beagle Club landfill prior to 1991. From 1978 to 1984, the Titus/Beagle Club landfill operated without a leachate collection system. In 1984 and 1985 this landfill was excavated and stockpiled until redisposed on site in a landfill with a leachate collection system. After 1991, a PVC bottom liner was installed at the Titus/Beagle Club landfill (Gilbert/Commonwealth, 1994).

Ground water degradation downgradient of the Montour Area 2 and Titus/Beagle Club facilities has been identified from the ground water monitoring data. Evaluation of trace element concentrations in downgradient ground water at the Montour Area 2 facility indicates that no leakage has been confirmed because the degradation appears to be related to oxidation of naturally-occurring pyrite in the shale bedrock rather than fly ash constituents (PP&LC, 1987). HELP modeling of the Titus landfill has predicted a current maximum leakage rate of 1.6 gpm (0.3 inches/month) from the 9 acre portion of the landfill without a plastic liner (Gilbert/Commonwealth, 1994). Higher landfill leakage rates and ground water degradation probably occurred prior to 1984 when no leachate collection was performed. Based on these observations, it appears that alternative bottom liner designs, such as that at Montour Area 2, which do not use synthetic liners may be appropriate for some CKD landfills depending upon site-specific conditions.

6.2.3 Compaction of Fly Ash Waste

Measures were taken at the Montour and Titus/Beagle Club power plants to condition the fly ash with water and to compact it during disposal. This appears to have provided greater control over fugitive dust emissions as well as extending the capacity of these landfills. Hoppers or silos also were used at all of the utility plants to temporarily store the fly ash as it was being generated and until it was transported to the landfill for disposal.

These dust control measures could be effectively applied at CKD disposal sites. Care must be taken to not over apply water to CKD due to the potential caustic quality of the run-off that may be generated and because this may result in failure to achieve the desired in-place density during compaction. Conditioning CKD with water and compacting it during disposal is expected to help control fugitive dust emissions and releases of CKD constituents to ground water. Conditioned and compacted CKD has a higher density, higher strength, and lower permeability than unconditioned CKD. Landfilling of conditioned and compacted CKD is expected to result in the production of less leachate and a more structurally stable landfill design relative to landfilling of unconditioned CKD.

6.2.4 Landfill Closure and Post-Closure Measures

The Montour Area 2 facility was closed in 1989. Closure activities consisted of completing installation of a final 1-foot-thick clay cover over the landfill, allowing it to become vegetated, and continuing with the ground water monitoring program during a 30-year post-closure period. Pennsylvania Department of Environmental Protection (PDEP) granted a variance for the 1-foot-thick clay cover based on the results from demonstration plot tests of 1-foot-thick and 2-foot-thick clay covers performed at the Montour site. A recent inspection of the Montour Area 2 landfill has found that erosion has exposed waste ash in one corner of the landfill where vegetation did not become sufficiently established. PDEP staff attributes the poorer than expected performance of the final cover to unfavorable growing conditions (i.e., soil removed by erosion, lack of moisture, and excessive wind) at this exposed location. The performance of vegetation growth in a relatively small test plot, however, may not be directly extrapolated for a large landfill (Stevens, 1997).

EPA is considering standards for landfill closure and post-closure requirements based on the RCRA Subtitle D regulations (40 CFR 258.60-61). The cover must have a permeability less than or equal to the bottom liner or natural subsoils or have a permeability no greater than 10^{-5} cm/sec, whichever is less. The cover must minimize infiltration by using an infiltration layer that contains at least 18 inches of earthen material. The cover must minimize erosion by using an erosion layer that contains at least 6 inches of earthen material that is capable of sustaining native plant growth. Similar to the PDEP approach (Section 288.234 of the Pennsylvania Residual Waste Regulations), an alternative landfill final cover design may be approved as long as it provides an equivalent degree of infiltration and erosion protection.

6.3 Comparison of Coal Ash Landfill Performance with Proposed CKD Landfill Ground Water Monitoring Requirements

This section evaluates the effectiveness of the ground water monitoring programs which were implemented for the landfills described in Sections 6.1.1 and 6.1.2 with respect to identifying potential releases of contaminants to ground water. The expected benefits of similar ground water monitoring programs at CKD landfills is addressed in Section 6.3.2.

6.3.1 Ground Water Monitoring Design and Performance

A network of upgradient and downgradient monitoring wells/points are being monitored on a quarterly basis at the Montour and Titus/Beagle Club coal ash landfills. At the Titus/Beagle Club site, downgradient monitoring wells, located less than 90 meters (300 feet) from the landfill, have provided timely warning that the ground water system has been impacted from ash disposal operations. None of these landfills are located over karst aquifers. For CKD landfills at karstic sites, EPA is proposing a greater degree of site characterization and more sophisticated ground water monitoring than those used for the studied coal ash landfills.

Potential ground water degradation downgradient of the Montour Ash Storage Area 2 was identified within one year following commencement of ash disposal activities in 1981. A site investigation was conducted with trace element analysis of the ground water near the landfill. The site investigation report attributed the elevated concentrations in the downgradient wells to oxidation of pyrite in the native bedrock materials and not from waste leachate. According to the report, earthwork activities during construction of the landfill accelerated the rate of pyrite oxidation in native materials resulting in increased concentrations of sulfate and TDS. Elevated concentrations of indicator trace elements such as lithium, selenium, chromium and boron associated with the fly ash waste were not detected in the ground water monitoring wells (PP&LC, 1987). PDEP is currently evaluating the Montour Ash Disposal Area 3 ground water monitoring results as part of the site's permit renewal effort. It is unclear if the circa-1996 rise in sulfate and other constituents in downgradient wells is due to landfill leakage or recent leachate/run-off pond repair work. The site operator suspects that the earth work associated with repair of the leachate/run-off pond affected the water quality in the nearby monitoring wells (Hamilton, 1997).

At the Titus/Beagle Club site, the operator/owner used a statistical method with a 99 percent confidence level to evaluate ground water monitoring data and identified several constituents including sulfate and TDS in downgradient wells at concentrations exceeding background (CEC, 1992). The statistical analysis of the ground water data indicates that waste disposal operations at the site have impacted the ground water quality. As discussed in Chapter 5.2.3, EPA is proposing statistical techniques similar to those in 40 CFR 258.53(g) and 40 CFR 264.97 to evaluate ground water monitoring data at CKD landfills. The regulations include statistical methods similar to those used for the Titus/Beagle Club ground water assessment.

6.3.2 Benefits of Ground Water Monitoring

Based on the evaluations of the CKD damage cases identified in Section 2.1.1, the Agency has determined that additional controls, including ground water monitoring, are warranted to identify and prevent potential releases of hazardous constituents from CKD landfills into ground water. A ground water monitoring program, when correctly designed and implemented, determines whether a waste management system effectively prevents contaminant releases to ground water; detects releases quickly, avoiding costly contamination and cleanup; provides data to accurately determine the nature and extent of any contamination that occurs; and can assess the effectiveness of corrective actions. In the case of the Titus/Beagle Club coal ash landfill discussed in Section 6.3.1, the ground water monitoring system allowed early detection of a release. At CKDLF units, semiannual ground water monitoring is expected to facilitate the timely evaluation and remediation of potential releases of CKD contaminants to ground water systems.

Current and past CKD disposal practices have resulted in a number of cases where CKD constituents have contaminated ground water at CKD disposal sites. In response, EPA is proposing a new set of performance standards and default technical design standards for new and actively managed CKD landfills. The Agency believes that the proposed standards will provide a number of benefits including increased protection of ground water resources and reduced risks to human health. The proposed standards require CKD landfills to meet specific performance standards which are protective of human health and the environment. EPA believes that implementation of the proposed ground water monitoring standards that were described in Section 5.2.3, coupled with the proposed design standards at new CKD disposal sites, will ensure that future impacts on ground water resources will be minimized and future costs associated with cleaning up contaminated sites can be avoided.

6.4 Effectiveness of the Use of CKD as a Landfill Liner or Cover

The use of CKD as engineered components of CKD landfills has been proposed by representatives of the cement industry. At some existing or proposed CKD disposal sites, compacted CKD has been proposed or used as a liner or capping material. As part of development of the proposed regulations for CKD, EPA conducted a review of information on the physical properties of CKD, identified the performance characteristics necessary for the use of CKD as liners or caps in CKD landfills and reviewed specific cases where CKD has either been proposed or used as liners or caps at existing or proposed CKD disposal facilities.

The results of the analysis indicate that very low hydraulic conductivities (less than 1×10^{-7} cm/sec) are readily achievable in the laboratory and in field trials using heavy equipment to compress CKD to high densities. However, evaluation of field data indicate that compaction control is difficult to maintain over an area that is acres in size. Nevertheless, EPA is not proposing a prohibition on the use of CKD as a liner or cap material: EPA will allow its use as part of an alternative unit design if the facility can demonstrate that the design meets the performance standard for ground water, including establishing that the material will maintain integrity over long periods of time and, therefore, has a low potential for release of contaminants.

This section describes EPA’s findings on the effectiveness and efficiency of CKD proposed or used as liners or caps at CKD landfills. Section 6.4.1 summarizes the findings of EPA’s review of the engineering properties of CKD from published sources and from information in the records of selected CKD disposal locations where CKD has been proposed or used as engineered components of landfills. Sections 6.4.2 and 6.4.3 provide summaries of circumstances where CKD was proposed or used, respectively, for liners or caps at CKD disposal facilities. Section 6.4.4 compares the performance of conditioned CKD as a liner or cap material with respect to the RCRA hazardous waste (Subtitle C) and solid waste (Subtitle D) regulations. Section 6.4.5 addresses the use of CKD and selected CKD-based materials as a daily or intermediate landfill cover. Estimated costs associated with using CKD as a landfill liner and a cover material are discussed in Section 6.4.6. Section 6.4.7 summarizes the findings from available field data on CKD liners and covers.

6.4.1 Engineering Properties of CKD and CKD-Based Liners and Caps

Sources of information on engineering properties of CKD identified include the references cited in the Report to Congress on Cement Kiln Dust (USEPA, 1993b), reports and publications identified subsequent to the Report to Congress and engineering design and construction information available from CKD disposal sites in New York, Michigan and Washington.

The primary measure of performance for any landfill liner or capping material is its ability to serve as a barrier to the movement of liquid vertically under the influence of gravity and hydraulic forces. For liners at the bottom of a landfill the liquid includes water from precipitation and dissolved constituents from the waste (leachate). For caps, the liquid is the precipitation that infiltrates to the capping barrier layer. The degree to which a liner or cap limits the movement of liquid is generally measured by its hydraulic conductivity or permeability.

For synthetic membranes used as liners or caps, the degree to which the movement of liquid occurs generally depends on molecular diffusion through the membrane material, to a limited extent, and to a much more significant extent, on imperfections ("pin holes") that may be present in the supplied material, the degree to which holes or tears may occur during installation or in the longer term and the success in sealing the seams in the material as it is placed (USEPA, 1993c).

For soil and soil-like materials that are used as liners or caps the permeability is measured in terms of Darcy's law, Q = KAI, where Q = the rate of flow through a given cross sectional area of the material, A, under a specific hydraulic gradient, I, and K is the coefficient of permeability, typically measured in cm/sec. As described above, clay liners used in conjunction with synthetic liners in RCRA Subtitle D municipal solid waste landfills (MSWLF) and hazardous waste landfills are required to show a coefficient of permeability, K, of 1×10^{-7} cm/sec or less. For comparison, poorly graded sand has a saturated permeability of about 1.0×10^{-2} cm/sec (USEPA, 1994). An extensive discussion of soil liners, tests for permeability and other physical characteristics and compaction of soil liners is presented in EPA's Technical Manual for Compliance with 40 CFR Part 258 in the design and construction of MSWLFs (USEPA, 1993c).

6.4.1.1 Overview - Physical Properties and Testing - Soils

The following sections describe the physical properties and tests used in the engineering evaluation of soil and soil-like materials that are also used in the engineering evaluation of CKD.

Soil Texture and Particle Size Distribution

Several classification systems are in use to characterize soils in terms of particle size and particle size distribution. Two classification systems widely used are the U.S. Department of Agriculture's system and the Unified Soil Classification System.[1] In the Unified System (ASTM

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[1] The Engineering Documentation for Version 3 of the Hydrologic Evaluation of Landfill Performance (HELP) Model provides a comparison of the two classification systems in terms of typical soil characteristics (EPA,

D2487), soils are classified into three major groups: coarse grains, fine grains, and highly organic. Coarse grained particles are those larger than a No. 200 sieve (.075 mm or 75 μm), with gravel classed as particles smaller than 3 inches but larger than a No. 4 sieve (3/16-inch or 4.75 mm) and sand classified as particles smaller than a No. 4 sieve, but larger than a No. 200 sieve. Fine grains are smaller than a No. 200 sieve and include silts and clays.

The amounts of the various sizes of grains in a soil can be determined by sieving, for the more coarse grains and by sedimentation (ASTM D422), or other means for the fine material. In a well graded soil, there is a good representation of all particle sizes from the largest to the smallest. Poorly graded soils are considered uniform when most of the particles are the same size or skip or gap graded when there is an absence of one or more intermediate sizes (USBR, 1977).

The terms well sorted and poorly sorted are also frequently used when describing the particle size distribution of soil samples. Size sorting refers to the degree to which the soil particles approach being the same size (Compton, 1973). In a well sorted soil, most of the soil particles are about the same size. In a poorly sorted soil, a wide range of soil particle sizes are present.[2]

Particle size distribution tests conducted on samples of CKD from three different types of cement kiln processes showed in excess of 90 percent of the CKD particles smaller than the No. 200 sieve size (75μm) (Todres, et al., 1992). Applying the Unified Soil Classification System definitions to CKD, CKD would be classified as a silt or clay based on particle size. Particles in this size range are not amenable to sieve analysis. Particle size distributions for small particles may be determined by hydrometer (ASTM D422) or by methods such as the Sedigraph cited by Todres et al., which uses x-ray intensity to determine the settling rate of particles in a liquid for subsequent correlation with the associated particle size distribution.

Particle size distribution and particle size has relevance to the density and permeability and other engineering properties of soils. For granular soils, the greater the range of particle sizes present, the greater the maximum density (e.g., in poorly sorted soil, the voids among larger particles can be filled with smaller particles) (Lamb and Whitman, 1969). In the CKD tests conducted by Todres et al., particle size distribution analyses of three types of dusts (from a long wet rotary kiln, a long dry rotary kiln, and from an alkali bypass, precalciner system) showed the particle sizes of dust from the long wet kiln to be poorly sorted while the dusts from the other sources were well sorted. The results of the maximum density tests showed the long wet kiln dust achieving a higher maximum density than the other dusts (Todres, et al., 1992). Density testing is described below. The size of the particles present also has relevance to potential for emissions of fugitive dust, which is being addressed in other EPA documents.

1994). Hereinafter, descriptions of soils and soil-like materials refer to the Unified Soil Classification System.

[2] The terms “graded” and “sorted” are in common usage in engineering and geological practices, respectively. A well graded soil using engineering definitions would be described as poorly sorted using geological practice definitions.

Density, Porosity, and Compaction Testing

Soil density is the weight per unit volume of the soil including any water present, expressed in grams per cubic centimeter (g/cm^3), kilogram per cubic meter (kg/m^3) or pounds per cubic foot (pcf).[3] The in-situ density of a soil will depend on the specific gravity of the soil particles present, the volume of pore space (void space) in the soil matrix, and the degree to which the pore space is saturated with water. Samples of in-situ soil may be taken to determine undisturbed density using a thin wall push tube with subsequent recording of the weight of the soils and, if required, the weight and volume relationships, including a determination of moisture content (see ASTM D2937). The use of thin wall tubes to obtain CKD samples for permeability testing is noted in a number of the references discussed in Section 6.3. The use of the sand cone density test has also been referenced (ASTM D1556).

The use of a nuclear source in measurement of in-place density and moisture content of field compacted CKD has also been reported in several of the references. In this method, the attenuation or scattering of radiation is recorded and correlated to density and moisture content values determined by conventional means to provide a rapid means for determining if desired density and compaction is achieved in the field (see ASTM D2922 and ASTM D3017).

Porosity is the volume of void space in a unit volume divided by the total volume, normally given as a percent. Void ratio is the volume of void space divided by the volume of the solid soil particles in the soil matrix, also given as a percent. The porosity or void ratio of a soil is of significance to the consideration of soil permeability because as a soil is compressed (compacted), the volume of the voids decrease and the permeability of the soil decreases (Terzaghi and Peck, 1967).

The properties of soil may be significantly altered by compaction and standard tests are available to establish the relationships between density, water content, and compactive effort. The standard Proctor test (ASTM D698) and Modified Proctor test (ASTM D1557) are widely used to determine these relationships. In these tests, samples of soils are placed in standard size containers and subjected to compaction using standardized means. The water content (moisture content) of soil samples are varied and resulting densities (unit weights) are plotted to determine the moisture content at which density is maximized. The resulting maximum density is referred to as maximum dry density (MDD) and the moisture content at which MDD occurs is referred to as the optimum moisture content (OMC) (Todres, et al., 1992).

Often, densities of at least 95 percent of the maximum dry density determined from Proctor tests are specified in the construction of compacted fills (Merritt, 1976). In the data reviewed on compaction of CKD, 95 percent of Proctor maximum dry density (or “95 percent Proctor”) is frequently specified.

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[3] The term “density” is commonly used in engineering practice, but the actual resulting value is “unit weight”. In the historical information reviewed concerning engineering properties of CKD, the density of CKD (e.g., the unit weight) is provided in the pcf units.

Permeability Testing

The significance and importance of a liner and cap permeability in landfill performance is described in the foregoing sections of this document. Prior to construction of liners or caps using soils or soil-like materials such as CKD, the relationship between water content, density and permeability may be established in the laboratory. For compacted clay soil the lowest permeability is achieved when the soil is compacted at a moisture content slightly greater than optimum (USEPA, 1993c).

Ideally, placement of the liner or cap material in the field could be accomplished at the moisture content and degree of compaction that laboratory results show would result in the lowest permeability. However, EPA reports that differences between laboratory and field conditions (e.g., uniformity of material, control of water content, compactive effort, compaction equipment) make it unlikely that minimum permeability values measured in the laboratory on pre-construction samples are the same values that will be achieved during actual soil liner construction (USEPA, 1993c).

Several types of apparatuses are available for laboratory determination of permeability of soils and soil-like materials. In the information reviewed on CKD permeability tests, the use of a flexible wall permeameter (ASTM Method D5084-90) is most frequently referenced. Push-tube or core samples from the field may be taken for laboratory analysis or in-field tests using an infiltrometer may be conducted to verify and compare the results of pre-construction values predicted by laboratory tests to tests of the materials as placed.

EPA has identified four types of permeability tests for application in-situ including: borehole tests; porous probes; infiltrometer tests, and underdrain tests (USEPA, 1993c). An infiltrometer testing procedure used during closure of a the Lehigh Cementon CKD landfill in New York is described in subsequent sections of this document.

Compaction in the Field and Test Pads

As described above, tests to determine maximum dry density (e.g., the Proctor Test) of soil and soil-like materials are conducted under standardized conditions where the compactive effort is controlled. In the Proctor test or Modified Proctor test the compactive effort is determined by the energy transferred to successive layers of material in a mold via a tamping rod of specified weight, dropping from a specified height a specified number of times.

Placement of a soil or soil-like lining such as clay or CKD under field conditions requires the use of heavy equipment to achieve the degree of compaction specified based on the laboratory compaction tests. The method used to compact the soil liner is an important factor in achieving the required minimum permeability. Higher degrees of compactive effort increase soil density and lowers the permeability for a given moisture content of the soil being placed (USEPA, 1993c).

In the construction of a soil liner field compaction unit, a sheepsfoot roller is frequently used (USEPA, 1993c). Other field compaction equipment units include rubber tire rollers, smooth wheel rollers, crawler tractors, vibratory compactors and power tampers (USEPA, 1980).

At the Ash Grove Cement Plant in Chanute, Kansas, field studies using test pads were conducted to assess the compaction and permeability of CKD using various compaction techniques. Equipment used in these tests included a vibratory padfoot roller, a rubber tire roller and a vibratory drum roller (Todres, 1992). Studies of CKD compaction and permeability using a rubber tire scraper and a vibratory drum roller were recently conducted on test pads located at the Medusa Portland Cement Company facilities in Charlevoix, Michigan (RMT, 1996a). The results of these tests are summarized in Section 6.3.

Other Testing Procedures

There are a number of other testing procedures used in designs of foundations, designs of structures supported by soil or designs using soils as structural elements. These include, but are not limited to:

- **Atterberg Limits** - These tests are conducted on fine grained cohesive soils and determine water content at the boundary between liquid, plastic, semisolid and solid states of the soil matrix (see ASTM D4318).

- **Confined Compression Tests** - These tests are conducted to obtain information on the volume change in soils subject to vertical loading when lateral deformation is restricted.

- **Direct and Triaxial Shear Tests** - These tests measure the strength of the soil in resisting stresses.

Data available on the physical properties of CKD are summarized in the following section.

6.4.1.2 Engineering Properties of CKD

Permeability

Table 6-1 summarizes the test data on the permeability of CKD that were reviewed to assess the effectiveness of CKD as a liner or cap material at CKD landfills. The source of the information reported is provided along with notations, as appropriate, on the circumstances of the testing and related explanatory information.

As shown in Table 6-1, a wide range of permeability values have been reported for CKD. The only in-field permeability data found were developed during the closure of the Lehigh Cementon CKD landfill in Green County, New York, in 1988 (see entry No. 2 in Table 6-1). As described in further detail in Section 6.4.2.1.1, a falling head field testing procedure, approved by the New York State Department of Environmental conservation, was used. CKD permeability ranged from 7.9×10^{-7} to 2.5×10^{-5} cm/sec, with a median value of 3.2×10^{-6} cm/sec for the fifteen (15) tests.

In the other test results summarized in Table 6-1, permeability tests were performed in the laboratory, in many cases on remolded samples taken from the field in Shelby tubes. Where testing on remolded samples was conducted, the results do not necessarily reflect actual, in-place permeability.

As discussed in more detail in Section 6.4.2.1.2, difficulties in retrieving undisturbed samples were reported. In the closure of the Lehigh Alsen CKD landfill, the results of 24 tests were reported. (See entry No. 4 in Table 6-1). Of these 24 tests, nine (9) were reported as undisturbed. These nine (9) tests showed a range of permeability from 2.9 x 10^{-6} to 1.6 x 10^{-4} cm/sec, with a median value of 5.1 x 10^{-5} cm/sec, which is similar to the range and median reported for all samples taken during closure of the Alsen facility.

The tests reported by Todres et al. (1992) on three different cement dusts, at three different compaction rates show the variations that may occur when compaction changes and the variability among dusts. (See entry Nos. 11, 12, and 13 in Table 6-1). In these tests, the influence of compaction on permeability is readily seen. With light compaction (to a density of 86.5 pounds per cubic foot (pcf)), dust sample “G” from a long wet kiln showed a permeability of 1.5 x 10^{-3} cm/sec; with medium compaction (to 93.7 pcf) this dust showed a permeability of 7.6 x 10^{-6} cm/sec; with heavy compaction (to 108.2 pcf) this dust showed a permeability of 1 x 10^{-10} cm/sec.

The most extensive array of verification test information for CKD actually placed in the field is provided in entry No. 6 in Table 6-1. During closure of portions of the Independent Cement Corporation CKD landfill in Greene County, New York, fifty-eight (58) permeability tests were conducted for CKD placed and compacted in the field. As shown in Table 6-1 and described in more detail in Section 6.4.2.2, the median value for permeability of these samples was 2.1 x 10^{-5} cm/sec. Additional discussion of permeability of CKD is provided in Sections 6.4.2 and 6.4.3.

Table 6-1 Summary of CKD Permeability Test Data (Permeability Reported in cm/sec)

Entry No.	No. Of Tests	Minimum	Maximum	Average	Median	Test Location	Test Procedure	CKD Type	Comments	Reference
1	3	6.7×10^{-9}	3.2×10^{-8}	2.2×10^{-8}	2.7×10^{-8}	Laboratory	Flexible Wall Permeameter	Fresh	Sample with lowest value compacted at optimum moisture	CHA 1986a. Lehigh, Cementon (Design Phase)
2	15	7.9×10^{-7}	2.5×10^{-5}	6.0×10^{-6}	3.2×10^{-6}	Field	Infiltrometer on test panel constructed during site closure	Field compacted with sheepsfoot and steel drum rollers	Field testing approved by New York State Department of Environmental Conservation	CHA 1989. Lehigh, Cementon (Construction Phase)
3	9	7.7×10^{-7}	7.0×10^{-5}	1.3×10^{-5}	1.6×10^{-6}	Laboratory	Flexible wall permeameter	Fresh, weathered or test pad	Minimum value was fresh. CKD maximum value was from test pad.	Dunn, 1992a. Lehigh, Alsen (Design Phase)
4	24	2.7×10^{-6}	1.6×10^{-4}	6.8×10^{-5}	5×10^{-5}	Laboratory		Field compacted	See Section 6.4.2. of text. Undisturbed samples show median of 5×10^{-5}	Spectra 1995. Lehigh, Alsen (Construction Phase)
5	17	9×10^{-7}	1.7×10^{-4}	4.4×10^{-5}	2.5×10^{-5}	Laboratory	Flexible wall permeameter	Wet process. Stockpiled CKD prior to use in capping.	Shelby samples remolded in the laboratory	Malcom Pirnie, 1997. Independent Cement Corp., Catskill, NY (Preconstruction)
6	58	3.1×10^{-7}	1.1×10^{-4}	2.8×10^{-5}	2.1×10^{-5}	Laboratory	Flexible wall permeameter	Wet process. CKD as placed in landfill cap.	Shelby samples remolded in the laboratory.	Malcom Pirnie, 1997. Independent Cement Corp., Catskill, NY (Construction)
7	30	2.1×10^{-7}	4.7×10^{-5}	6.3×10^{-6}	2.4×10^{-6}	Laboratory	Flexible wall permeameter	Conditioned CKD	Samples collected by Shelby tubes or coring. Samples not remolded.	RMT 1993. Lafarge, Alpena, MI (Preliminary Phase)

Entry No.	No. Of Tests	Minimum	Maximum	Average	Median	Test Location	Test Procedure	CKD Type	Comments	Reference
8	6	3.8×10^{-10}	1.2×10^{-6}	3.0×10^{-7}	4.7×10^{-8}	Laboratory	Flexible wall permeameter	Conditioned CKD		RMT 1994a. Lafarge, Alpena, MI (Design Phase)
9	20	2.6×10^{-8}	1.0×10^{-5}	4.0×10^{-6}	3.0×10^{-6}	Laboratory	Flexible wall permeameter	Conditioned CKD Test Plot		Lafarge 1996a. Lafarge, Alpena, MI (Design Phase).
10	7	1.4×10^{-6}	1.7×10^{-4}	3.8×10^{-5}	4.5×10^{-6}	Laboratory	Flexible wall permeameter	Samples from pile. Both relatively undisturbed and remolded samples.	Highest permeability from relatively undisturbed sample. Remolded samples show lower permeability.	USEPA 1997b. Metaline Falls, WA
11	12	4.5×10^{-6}	1.5×10^{-4}	4.0×10^{-5}	2.3×10^{-5}	Laboratory		Samples from test plots	Field compaction performed using vibratory padfoot rollers, tire tollers, and other equipment.	Todres, H.A 1992. Chanute, KS
12	3	5.1×10^{-4}	3.0×10^{-3}	1.7×10^{-3}	1.5×10^{-3}	Laboratory	Fixed wall permeameter	Dust G from long wet kiln. Dust H from long dry kiln. Dust S from alkali bypass precalciner system.	Light compaction to 86.5 to 76.2 pcf. Dust S is minimum. Dust H is maximum.	Todres et al. 1992. Dust from 3 sources.

Entry No.	No. Of Tests	Minimum	Maximum	Average	Median	Test Location	Test Procedure	CKD Type	Comments	Reference
13	3	7.0×10^{-6}	2.1×10^{-5}	1.2×10^{-5}	7.6×10^{-6}	Laboratory	Fixed wall permeameter	Dust G from long wet kiln. Dust H from long dry kiln. Dust S from alkali bypass precalciner system.	Medium compaction equivalent to Standard Proctor. 43.7 to 81.0 pcf. Dust H is minimum. Dust S is maximum.	Todres 1992. Dust from 3 sources.
14	3	1.0×10^{-10}	1.6×10^{-6}	5.5×10^{-7}	4.9×10^{-8}	Laboratory	Fixed wall permeameter	Dust G from long wet kiln. Dust H from long dry kiln. Dust S from alkali bypass precalciner system.	Heavy compaction equivalent to Modified Proctor 108.2 to 84.2 pcf. Dust G is minimum. Dust S is maximum.	Todres et al. 1992. Dust from 3 sources.
15	20	2.6×10^{-7}	2.7×10^{-5}	8.5×10^{-6}	4.9×10^{-6}	Laboratory	Flexible wall permeameter	Conditioned CKD - Dry process.	Core samples taken from test plots compacted with scrapers or rollers.	RMT 1996a. Medusa Cement Company, Charlevoix, MI (design phase).

Density
The density of soils and soil-like materials depends on the specific gravity of the solid material, the porosity or void ratio, the moisture or degree of saturation of the material, and the particle size and particle size distribution. As described in the foregoing part of this section, compaction increases density and maximum density is achieved at the optimum degree of saturation.

For most of the actual field test data available, maximum dry density is determined by standard Proctor tests and field verification of density is determined indirectly using a nuclear source. Where field tests show less than required density, recompaction is required and indirectly it is assumed, subject to permeability tests, that when the in-place density is within stated limits, the permeability of the material will also be within stated limits. In short, the in-place density is related to compaction, the resulting permeability is also related to compaction, and the starting point is the determination of maximum dry density in terms of standard tests.

A typical range of maximum dry density for CKD was reported in the closure of the Independent Cement Corporation CKD landfill in Greene County, New York (Pirnie, 1997). In twelve (12) tests conducted, the maximum dry density determined by the standard Proctor test (ASTM 698) ranged from 73.8 pcf with a corresponding moisture content of 36.2 percent to 88.6 pcf with a corresponding moisture content of 23.3 percent.

In the medium compaction tests conducted by Todres et al. (1992), maximum dry density was determined using a compaction method similar to the standard Proctor test. In these tests, the maximum dry density was determined to be:

• long wet rotary kiln dust:	93.7 pcf
• long dry rotary kiln dust:	83.0 pcf
• recalciner dust:	81.0 pcf

Selected data on maximum dry density and optimum moisture content for CKD are provided in Table 6-2. As shown in Table 6-2, variations in test results indicate needs to establish density/moisture relationships using CKD specific to a location during design of closure or landfill facilities.

6.4.1.3 Other Characteristics of CKD

CKD possesses other characteristics that are also to be considered in the evaluation of its use in liners or caps. Several of those characteristics are addressed below.

Reaction with Water
CKD is highly dehydrated in its generated form due to the thermal treatment it receives in the kiln system. The action of absorbing (rehydrating) releases a significant amount of heat from the

Table 6-2. Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) for CKD

Entry No.	No. Of Tests	Average		Compaction	Material	Comment	Reference
		MDD (pcf)	OMC (%)				
1	12	79	34	Standard Proctor ASTM D698	CKD, wet process	Samples for in-place material prior to closure.	Pirnie 1997. Independent Cement, Green County., New York.
2	2	67	50	ASTM D698	Dry process and moisture conditioned CKD		RMT 1996a. Medusa Cement, Charlevoix, MI.
3	1	94	18	Similar to ASTM D698	CKD	Dust "G", wet process.	Todres et al. 1992.
4	1	83	27	Similar to ASTM D698	CKD	Dust "H", dry process.	Todres et al. 1992
5	1	81	29	Similar to ASTM D698	CKD	Dust "S", precalciner system.	Todres et al. 1992
6	1	67	23	ASTM D698	CKD	CKD from pile.	Dames and Moore 1996. Lehigh, Metaline Falls, WA

non-weathered dust (USEPA, 1993b). A temperature of 101°C (214°F) was recorded when water was added to one of the CKD samples being tested to determine density and moisture relationships, with the generation of large volumes of steam. Sample preparation included overnight storage of the samples in capped containers at 100 percent relative humidity to allow hydration to occur (Todres et al., 1992).

In a report of studies on the use of CKD as a landfill liner conducted at the University of Sherbrooke in Sherbrooke, Quebec, the stabilization of CKD is said to depend on the control of the expansion reactions that result from "the hydration of combinations of elements such as sulphate, alumina, lime, silica and alkalis" which produce high volume, low density mineral phases such as erringite, valerite, thaumasite and portlandite (Ballivy et al., 1992). In these studies, mixtures of CKD with fly ash and/or silica fume were analyzed to determine potential effectiveness as a liner for sanitary landfill sites. The results of the studies show 28 day compressive strengths for CKD/fly ash/silica fume mixtures in the range of 17.7 to 30.0 megapascals (Mpa) [2,560 to 4,350 pounds per square inch (psi)] and permeability in the range of about $5x10^{-9}$ to $5x10^{-8}$ cm/sec developed in 28 days. [The 28 day strength specified for concrete is typically specified in the range of 17.2 to 34.5 Mpa (3,000 to 5,000 psi).]

The Ballivy et al. report concludes that the expansion effect expected due to hydration may be offset by the pozzolanic reactions which produce C-S-H gel that occur when silica fume is added to the CKD. Permeability studies showed all CKD/fly ash/silica fume mixes attaining permeabilities less than 1×10^{-7} cm/sec using distilled water.

To test the potential effectiveness of CKD/fly ash/silica fume liners, leachate water from a sanitary landfill was used. This leachate was characterized as slightly acidic (pH 6.82 SU) with "a strong concentration of calcium, sodium, magnesium, manganese, iron (141.5 mg/ℓ) and zinc (1.55 mg/ℓ) and low concentrations of copper, nickel, chloride and lead." The results of the testing showed a rapid increase in pH to a plateau of about 12 SU and attenuation of metals present in the landfill leachate to levels close to Province of Quebec standards. The effectiveness in metals removal is attributed to the availability of high levels of alkalis for heavy metal precipitation and high pH conditions (Ballivy et al., 1992).

The studies conducted by Ballivy do not address testing on samples containing 100 percent CKD, although one of the mixtures contained CKD and silica fume only, with silica fume representing only 1 percent of the weight. Compaction and compressive strength tests were conducted in accordance with applicable ASTM Methods. Permeability testing was conducted using "radial permeameters in the convergent mode" said to be an experimental apparatus with an accuracy of ±0.8 percent (Ballivy et al., 1992).

Observations of the strength of CKD as placed in landfills is also of interest. When stored fresh, unconditioned CKD is a fine, dry dust that readily absorbs water. CKD can retain these characteristics within the pile while developing an externally weathered crust due to absorption of moisture and cementation of dust particles on the surface of the pile (USEPA, 1993b). Findings of conditions at the Metaline Falls, Washington, CKD disposal site indicate, however, that at that location, although the CKD dries to form a crust, a high moisture content commonly prevails within a few inches of the surface, where the CKD is very soft (Dames and Moore, 1996).

Compatibility with Leachate

Design of any landfill liner system requires consideration of the chemical properties of the leachate to be generated within the landfilled area and the potential impact the chemicals present in the leachate may have on the lining system. In the case of a CKD landfill, the leachate to be generated is expected to be highly alkaline and expected to contain some of the metals present within the CKD. Evidence of metals in CKD leachate, simulated by leaching tests, has been reported (USEPA, 1993b).

There are currently no landfill-generated CKD leachate data available. The Ballivy report, cited above, addresses potential leachate quality using a municipal landfill leachate and a CKD material mixed with fly ash and/or silica fume. These results indicate the generation of leachate with a high pH and some metals present. While no conclusive evidence is provided for 100 percent CKD material, the Ballivy findings suggest that releases through a CKD liner could be expected to show elevated pH and some metals, characteristic of CKD, present in the liquid released. The long term performance of a compacted CKD liner within a CKD landfill, subjected to a continuing supply of leachate of elevated pH from overlying layers of CKD that are more loosely compacted, has not been studied.

6.4.2 Analysis of Instances Where CKD Was Considered or Used for a Landfill Liner or Cap

Currently available information shows several locations where CKD has been proposed or used as either a liner or cap at CKD landfill/CKD disposal locations. These locations include several in New York, two in Michigan and one in Washington. A brief overview of each location and engineering considerations relating to liner or cap effectiveness are summarized in the following sections.

6.4.2.1 Lehigh Portland Cement Company - CKD Disposal Areas - Green County, New York

Lehigh Portland Cement Company (Lehigh) has operated two cement plants in Greene County, New York. One facility is located near Cementon, the other near Alsen. Neither of these Lehigh plants are currently active (Per. Com. Kircher, 1997). The properties owned by Lehigh, including quarries, plant sites and disposal sites are adjacent to one another and comprise about 2,440 acres located just west of the Hudson River, about 35 miles south of Albany (CHA, 1990). CKD permeability and density data were collected at two CKD disposal facilities associated with Lehigh's Greene County plants: the Lehigh Dust Disposal Landfill, Cementon, NY; and the Lehigh Dust Disposal Facility, Alsen NY.

6.4.2.1.1 Lehigh Dust Disposal Landfill, Cementon, New York

Overview

The Lehigh Cementon CKD landfill is located just east of the Hamlet of Cementon, about 600 feet west of the Hudson River. The landfill site comprises about 20 acres of property owned by Lehigh, located about 500 feet southwest of Lehigh's Cementon Cement Plant property, as described in a Clough, Harbor and Associates (CHA) closure report prepared in 1986 (CHA, 1986a). An estimated 547,000 cubic yards of CKD have been placed on the site. This CKD landfill was closed in 1988 (CHA, 1989).

Closure and Design and CKD Tests Prior to Construction

The closure design proposed to the New York State Department of Environmental Conservation (NYSDEC) included an 18-inch cap of fresh CKD compacted in 6-inch (15 cm) lifts, covered by 6 inches of topsoil material capable of supporting vegetative growth (CHA, 1986b). The report cites results of tests of CKD engineering properties in support of applications to construct and operate Lehigh's solid waste facility for the neighboring Alsen plant. (The Alsen facility is discussed in the following section of this document.) CKD is reported as a fine grained material of low density (35 to 65 pcf, uncompacted). A grain size analysis shows 100 percent of the dust particles finer than a No. 200 sieve (75 μm), 92 percent finer than 25 μm, 62 percent finer than 18μm, 13 percent finer than 13 μm, 8 percent finer than 9 μm, 7 percent finer than 6.5 μm and 6 percent finer than 4.5 μm (CHA, 1986a).

Maximum dry density, established using standard proctor tests, was reported to be 1,530 kg/m^3 (95.2 pcf) at an optimum water content of 24 percent. At 90 percent proctor compaction, a coefficient of permeability of 8.1 x 10^{-7} cm/sec was reported (CHA, 1986a). Additional information on CKD permeability is provided in Supplement No. 1 to the CHA report, which cites findings of tests performed at Rennselaer Polytechnic Institute (RPI) by Dr. Thomas F. Zimmie. In these tests, fresh CKD from Lehigh's Cementon Plant was used. Compaction and associated permeability were reported as follows:

- CKD compacted dry of optimum (Water content, W=17.5%[4]): 3.2 x 10^{-8}cm/sec
- CKD compacted at optimum (W = 20.9%): 6.7 x 10^{-9}cm/sec
- CKD compacted wet of optimum (W = 23.5%): 2.7 x 10^{-8} cm/sec

The report concludes that the compacted fresh CKD is a material suitable from construction of the dust pile closure cap and can meet a cap permeability criterion of 1 x 10^{-7} cm/sec (CHA, 1986a).

Construction and Results of Verification Tests

In a letter to the NYSDEC on February 8, 1989, CHA provides the results of the closure

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[4] W = Weight of water/weight of solids or moisture content in %.

certification for Lehigh's Cementon CKD pile (CHA, 1989). This letter reports that closure of the CKD pile was conducted during the period June through November, 1988.

A test panel was constructed on top of the CKD pile in June 1988 for the purpose of verifying the compaction and permeability characteristics of the CKD material during closure. Four (4) 30 cm (12-inch) CKD lifts were placed within the test area and a nuclear density meter was used to test the compacted CKD for density, moisture and compaction. Results of twenty (20) tests conducted on June 14, 1988 in the test panel area show:

- wet density in the range of 1,595 kg/m^3 to 1,845 kg/m^3 (99.3 to 114.7 pcf);
- moisture in the range of 41 to 60 percent; and
- percent compaction in the range of 93 to 114 percent of Proctor compaction.

Compaction was afforded using a sheepsfoot and steel drum roller, with highest densities recorded for 6 passes of the compaction equipment.

Shelby tube (undisturbed) samples of compacted CKD were collected in the field for triaxial permeability testing at the RPI laboratory. Laboratory personnel were unable to retrieve workable samples from the Shelby tubes. An alternative method for determining the undisturbed permeability of the compacted CKD in the field was adopted in consultation with the NYSDEC. In this method a four (4) foot section of rigid plexiglass tubing, 2.6 inches in diameter, is advanced 12 inches into the compacted CKD. The tube is filled with dye-colored water, and the drop in water level with time is measured to simulate a falling head permeability test (CHA, 1989).

The permeability testing was conducted over a period of about seven (7) weeks. NYSDEC also approved the installation field permeability testing apparatuses with tubing of 2.6 inch or 2.0 inch at other locations on the CKD pile in lieu of trying to retrieve undisturbed CKD samples. The results of the fifteen (15) in-field permeability tests are shown in Table 6-3.

The letter concludes with a statement to NYSDEC indicating that the CKD pile should now be considered fully closed and in its final state (CHA, 1989). Variations in permeability by location and time are not addressed in the report.

Table 6-3: Lehigh Cementon, NY - CKD Landfill Closure Field Permeability Test Results

Date	Location 1	Location 2	Location 3	Location 4
9/7/88	4.1×10^{-6}	---	---	---
9/8/88	3.2×10^{-6}	---	---	---
9/12/88	2.3×10^{-6}	---	---	---
9/14/88	2.0×10^{-6}	---	---	---
9/19/88	2.5×10^{-6}	---	---	---
10/18/88	---	1.8×10^{-6}	1.2×10^{-5}	2.5×10^{-5}
10/20/88	---	2.5×10^{-6}	5.2×10^{-6}	1.0×10^{-5}
10/25/88	7.9×10^{-7}	3.0×10^{-6}	5.9×10^{-6}	9.6×10^{-6}

Source: CHA 1989.
Note: Results expressed in cm/sec. See text for explanation of test method.

6.4.2.1.2 Lehigh Dust Disposal Facility - Alsen, NY

Overview

Lehigh's Alsen Dust Disposal Facility is located on Lehigh property southeast of the Hamlet of Alsen, east of the now inactive Alsen Cement Plant, Town of Catskill, Green County, New York. The facility is bordered to the north by Independent Cement Corporation property, to the east by the Hudson River, to the south by Lehigh's Cementon Plant property, and to the west by quarries (Dunn 1992). The site comprises about 13 acres (CHA, 1987).

On May 7, 1987, Lehigh entered into an Order on Consent with the NYSDEC for the closure of the facility (Dunn, 1992). At the time of final closure, the facility contained an estimated 1,400,000 cubic yards of CKD (Spectra, 1995).

Closure was conducted in three phases so that approximately one third of the facility could be graded, capped, topsoiled, and closed in each of three successive years. Phase I of the closure was conducted in the period of July-November 1992, Phase II in the period of August-November 1993, and Phase III in March-June 1994.

Closure Design and CKD Tests Prior to Construction

Closure plans called for the facility to be capped with 54 inches (1.37 m) of compacted CKD following grading and shaping of the dust pile. The cap was to consist of three 18-inch (46 cm) layers, each comprising two 9-inch (23 cm) compacted lifts. Phase I and II of the closure were conducted using this method. The closure report notes that while the results of the Phase I and Phase II closures were satisfactory, control of lift thickness was difficult and compaction on the side slopes (3 horizontal: 1 vertical) was very time consuming.

Test results for CKD permeability used in the closure design are provided for samples from the kiln, the existing pile, and test panels. Table 6-4 summarizes the test results.

According to the Dunn report (Dunn, 1992a), the fresh CKD was compacted to a maximum dry density of 90 pcf and laboratory permeability tests were performed at various moisture contents, both dryer and wetter than optimum. It was concluded that there was no significant change in permeability with moisture content for the fresh CKD, given the reported range in permeability from 1.6×10^{-6} to 7.7×10^{-7} cm/sec (Dunn, 1992a).

The weathered CKD was found to have a permeability of 2.7×10^{-5} cm/sec. Field test panels constructed of both fresh and weathered CKD demonstrates that actual in-place permeability varies little between fresh and weathered CKD, with a reported range of 7.0×10^{-5} and 4.9×10^{-6} cm/sec (Dunn, 1992a).

Table 6-4: Results of CKD Permeability Testing Used in the Design of the Alsen CKD Landfill Closure

No.	Permeability	Notation
1	7.7×10^{-7}	Fresh CKD. Bulk Sample.
2	1.6×10^{-6}	Kiln Dust. Bulk Sample.
3	9.7×10^{-7}	Fresh CKD. Bulk Sample.
4	8.2×10^{-7}	Fresh CKD. Bulk Sample.
5	7.8×10^{-7}	Fresh CKD. Bulk Sample.
6	2.7×10^{-5}	Old Alsen Landfill, as received. Bulk Sample.
7	1.5×10^{-5}	Kiln Dust. Shelby Tube. Test Pad Sample.
8	4.9×10^{-6}	Kiln Dust. Shelby Tube. Test Pad Sample.
9	7.0×10^{-5}	Kiln Dust. Shelby Tube. Test Pad Sample.

Source: Dunn 1992a

Notes: Results expressed in cm/sec.
All tests were conducted in a laboratory using a flexible wall permeameter in accordance with ASTM D5084-90.

Testing required before and during construction (closure) included the following (Dunn, 1992a):

- Soil particle size analysis;
- Atterberg limits;

- Lab permeability test (triaxial cell);
- Moisture content;
- Moisture density relationship;
- In-place density tests;
- In-place moisture; and
- Lab permeability.

Construction and Results of Verification Tests

The results of testing conducted during site closure are available in the closure certification report (Spectra, 1995). The results of 33 permeability tests are reported (of which 9 test results are illegible). The results of the permeability testing showed, for the 24 results, a range of permeabilities from 1.6 x 10^{-4} cm/sec to 2.7 x 10^{-6} cm/sec, with an average of 6.8 x 10^{-5} cm/sec, and a median value of 5 x 10^{-5} cm/sec.

Various notations are included in the test results, indicating some difficulty in testing procedures. The results of the permeability testing are summarized in Table 6-5. As shown in Table 6-5, where Shelby tube samples were recompacted, resulting permeability values are somewhat lower (e.g. less permeable) and samples which were noted as "brittle" show somewhat higher permeabilities. Whether the brittle nature of samples resulted from loss of moisture after sample collection or whether the in-place material was brittle, is unknown. The nine samples indicated as "undisturbed" may be most representative of in-place conditions. As shown in Table 6-5, these samples showed a range in permeability from 2.9 x 10^{-6} to 1.6 x 10^{-4} cm/sec and a median permeability of 5.1 x 10^{-5} cm/sec.

In the closure report, it was noted that Shelby tubes were extracted from compacted layers of CKD throughout all phases of the closure and in the majority of cases, the density of CKD was such that the Shelby tubes deformed (e.g., while the Shelby tubes were being pushed into the CKD, the walls of the tubes deformed) (Spectra, 1995). This may have accounted for some of the difficulties reported in the permeability data.

Proctor testing showed an optimum moisture content of 50 percent, but over three years of testing, a moisture content in the low 40 percent range was found to be the most desirable to avoid rutting and shrinkage cracks in the CKD as placed. The average moisture content for the 715 density tests performed during closure was 40.5 percent (Spectra, 1995).

Table 6-5: Results of CKD Permeability Testing During Closure of the Alsen CKD Landfill

No. Of Sample Results	Minimum	Maximum	Average	Median	Notations
24	2.7×10^{-6}	1.6×10^{-4}	6.82×10^{-5}	5.05×10^{-5}	All Samples
6	2.7×10^{-6}	8.1×10^{-5}	3.63×10^{-5}	3.2×10^{-5}	Notation showing “shelby tube/recompacted”
9	2.3×10^{-5}	1.5×10^{-4}	8.58×10^{-5}	8.2×10^{-5}	Notation showing “Sample in tube was dry and brittle”, “Sample was dry and brittle and had to be recompacted”, “Filter page clogged; only one permeability run was made”, or no notation (one sample)
9	2.9×10^{-6}	1.6×10^{-4}	7.33×10^{-5}	5.1×10^{-5}	Notation showing “Undisturbed tube sample”

Source: Spectra 1995.
Note: Permeability values in cm/sec.

In-place density tests were performed using the Sand Cone Method (ASTM 1556) and the Nuclear Density Method (ASTM D292), 73 tests and 642 tests, respectively. In the final phase of closure, 215 nuclear density tests were performed with more than 94 percent of the test showing values exceeding 95 percent of Proctor Density, which was required. Where tests showed values less than the 95 percent Proctor Density, recompaction was performed (Spectra, 1995).

The spectra report concludes, in part, that the closure report and documentation serves to verify that the closure was accomplished in accordance with stated plans and procedures, with modifications or deviations identified and justified (Spectra, 1995).

6.4.2.1.3 Lehigh’s Alsen Quarry CKD Disposal Landfill

Overview

Lehigh’s Alsen Quarry Landfill site is located in an unused portion of Lehigh’s quarries situated southwest of the Hamlet of Alsen, about 4,500 feet west of the Hudson River. In September 1990, an application pursuant to NYSDEC’s Part 360 Solid Waste regulation was made to the NYSDEC for renewal of a Part 360 permit issued to Lehigh in 1981 for use of the Alsen Quarry CKD landfill. At the time of the application, Lehigh’s Alsen plant was not in operation, but the Lehigh Cementon plant was producing CKD at an annual rate of about 55,000 tons or about 50,000 cubic yards (CHA, 1990).

Closure Design and CKD Tests Prior to Construction

The landfill liner design proposed consisted of a single 18-inch layer of compacted CKD installed in 3 lifts, each 6 inches thick. No leachate collection system was proposed. The final cap proposed consisted of an 18-inch layer of CKD, compacted in 6-inch lifts overlain by 6 inches of topsoil to support vegetative growth.

The permeability of the compacted CKD was said to be less than 1 x 10^{-7} cm/sec (CHA, 1990). The source of this information on CKD permeability was not found in the applications, but apparently it may have been based on the tests cited in the CHA 1986 closure design (CHA, 1986a) for the Cementon CKD landfill.

Status

Whether NYSDEC granted approval to Lehigh to construct the Quarry landfill is unclear, but it was considered by Lehigh to be a temporary facility only (Dunn, 1992b). Lehigh has not pursued construction of the Quarry Landfill (Per. Com. Kircher, 1997).

6.4.2.2 Independent Cement Corporation - CKD Landfill - Green County, New York

Overview

The Independent Cement Corporation (ICC) property comprises about 2,200 acres located north of and adjacent to the Lehigh Cement Corporation property described in Section 6.4.2.1.2. The ICC CKD landfill comprises about 29 acres located just west of the Hudson River. The landfill is undergoing a phased closure under an Order on Consent entered into between ICC and NYSDEC in July 1994 (SGY, 1995).

The closure is to take several years, with on-going operations of the ICC cement plant to continue generating CKD at 100,000 tons per year to supply required CKD to the landfill for two years, with a decrease in ensuing years to result in closure in 1998 (SGY, 1995).

Closure Design and CKD Tests Prior to Construction

The cap proposed in the closure plan consists of three (3) 46 cm (18-inch) CKD layers, each compacted in two 23 cm (9-inch) lifts, bringing the overall thickness of the CKD cap to 1.37 meters (54 inches) (SGY, 1995).

The revised closure design cites physical characteristics and engineering properties for CKD based on prior studies of CKD generated at ICC. The CKD is described as a fine-grained material of low density (35 to 65 pcf). A grain size analysis of the ICC CKD, taken from the SGY report, is provided in Table 6-6. The CKD is described as “having a grain size distribution approximately that of a silt” (SGY, 1995).

Table 6-6. CKD Grain Size Analysis, Independent Cement Corporation, Greene Co., New York

Particle Size	percent Finer by Weight
1/4" Sieve	100
#10 Sieve	99.8
#40 Sieve	99.5
#200 Sieve	85.7
#270 Sieve	82.6
0.035 mm	81.8
0.025 mm	79.6
0.018 mm	77.3
0.013 mm	65.4
0.009 mm	56.4
0.0065 mm	19.5
0.0045 mm	9.2
0.0034 mm	8.5
0.0015 mm	3.5

Source: SGY 1995

The closure report cites the properties of CKD from the ICC plant and other cement plants as similar, owing to the nearly identical nature of the process of their origin and refers to data from other manufacturers indicating that fresh compacted CKD has been shown to be able to achieve a permeability of less than 1 x 10^{-7} cm/sec. The fresh CKD compaction and permeability data from Lehigh's Cementon Plant (see Section 6.4.2.1.1) was cited as typical.

Construction and Results of Verification Tests

The closure is being conducted in three phases; Phase I, Phase II, and Phase III. Phase I consisted of site surveying and rough grading and started in November 1995 (Pirine, 1997). Grading and compaction of existing weathered CKD to provide a subgrade of the cap was started in July 1996. Compaction was provided with a self-propelled vibratory roller. Placement of the low permeability cover layer, which consisted of weathered and freshly generated CKD, was placed on the subgrade layer in July and August 1996. The low permeability layer was placed in six 9-inch lifts to form a 1.37 m (4.5 feet) compacted CKD cap over approximately 9 acres. Each lift was compacted to 95 percent of the maximum standard Proctor density of the most representative material using a smooth drum roller (Pirnie, 1997).

A total of 567 in-place density tests, using a nuclear densitomer (ASTM D2922), and 61 laboratory tests (ASTM D5084) to determine permeability of samples taken using Shelby tubes, were performed (Pirnie, 1997). The laboratory reports indicate that all samples were remolded and compacted, resulting in the potential that laboratory permeabilities are less than actual in-place permabilities. The permeability tests for 58 samples are summarized in the report. Data for percent moisture and percent compaction (as a percent of maximum standard Proctor density) are also provided with the permeability data. For the 58 tests reported for July 9, 1996-September 16, 1996, the permeability test results show the following:

Maximum Permeability	1.1×10^{-4} cm/sec
Minimum Permeability	3.1×10^{-7} cm/sec
Average Permeability	2.8×10^{-5} cm/sec
Median Value of Permeability	2.1×10^{-5} cm/sec

The percent moisture ranged from 18.2 percent to 46.2 percent and compaction ranged from 73.7 percent to 109.7 percent of maximum standard Proctor density.

The certification report noted that due to the low moisture content of the source material used in the cap (the CKD to be used) Atterberg limit tests were not performed, noting that CKD exhibits non-plastic characteristics. The certification report further noted that several test results showed compaction not in accordance with specifications, but since testing of source material showed acceptable permeability at lower densities, the cap placed in 1996 provided a low permeability cover system meeting the intent of the closure plan (Pirnie, 1997).

The topsoil layer was placed over the CKD layer, graded and seeded in October 1996 (Pirnie, 1997).

6.4.2.3 Lafarge Corporation - CKD Landfill - Alpena, Michigan

Overview

The Lafarge Corporation cement plant in Alpena, Michigan is located northeast of the City of Alpena. Limestone has been mined from a quarry at this site since the early part of the century. Lafarge has owned the quarry and operated the plant since 1986 (RMT, 1994b). The quarry is located about 600 to700 feet from Lake Huron and comprises approximately 600 acres.

The quarry is being mined to a depth of about 100 to 120 feet below ground surface. The local topography is relatively flat, and the bottom of the quarry is about 60 to 80 feet below the elevation of Lake Huron. A dewatering system is operated at the quarry to collect ground water and surface water. The water is discharged to Lake Huron via an NPDES permitted outfall at a rate of 0.4 to 2.7 million gallons per day (RMT, 1994b).

In 1995, Lafarge generated 199,208 metric tons of CKD waste. Since Lafarge has operated the plant, CKD has been disposed in the southeastern portion of the active quarry at a location referred to as the “existing CKD Placement Area”. Crushed limestone and shale, gypsum, coal rejects, clinker, cement and other material have been placed in the western part of the quarry at a location known as the “Wessel Road Site” (RMT, 1995).

In a letter of September 21, 1991 to Lafarge, the Michigan Department of Natural Resources (MDNR) (now known as the Michigan Department of Environmental Quality - MDEQ), MDNR informed Lafarge that CKD disposal in the quarry is regulated under the Michigan Solid Waste Management Act (SWMA). Lafarge disagreed, citing prior approvals under the Reclamation of Mineral Act. To settle the matter, Lafarge and MDNR signed a Consent Judgment in December 1994 which outlines a compliance program for CKD management (RMT, 1995).

CKD Test Plot Data - 1992 and 1993

In June 1993, RMT, Inc., consultants to the Lafarge Corporation, submitted a report to the MDNR summarizing results of field testing of CKD placed in test plots located in the Lafarge quarry in Alpena (RMT, 1993). The report includes the results of both field and laboratory testing performed to determine the properties of CKD which was treated by adding water, mixing and compacting.

Moisture conditioned CKD was placed in eight (8) test plots. Two methods were used for moisture conditioning and CKD placement. In the first method, the CKD was placed in a pug mill, water was added, the CKD was mixed with the water in the pug mill, the mixture was transferred in a conveyor belt, and additional water was added as the CKD was dropped into a scraper or into a stockpile. CKD dropped into a scraper was transported directly to the test plots for placement. Stockpiled CKD was locaded into a scraper by an end loader and then transported to the test plots for placement. The CKD was placed using a scraper. In the second method, a concrete truck was used. Water was added to the dry CKD in the truck, as the barrel of the concrete truck was rotated. When the desired moisture content was achieved, the truck transported the CKD to the test plots, where the CKD was placed using the truck’s concrete chute.

The moisture content of the CKD was varied and the CKD was placed in the test plots in 3-inch, 6-inch, and 12-inch layers.

The results of the permeability testing are shown in Table 6-7.

As shown in Table 6-7, the test results indicate a range of CKD permeabilities from a minimum of 2.1×10^{-7} cm/sec to a maximum of 4.7×10^{-5}, an average of 6.3×10^{-6} and a median value of 2.4×10^{-6}.

Table 6-7 Results of CKD Permeability Testing - Test Plots at the Lafarge Facility - Alpena, Michigan

No.	Target Moisture Content (%)	Layer Thickness (inches)	Placement Means	Permeability (CMS/sec)
1	57	6	Truck	4.70E-07
2	57	6	Truck	2.40E-06
3	57	6	Truck	2.40E-06
4	57	6	Truck	2.60E-07
5	67	6	Truck	3.10E-06
6	67	6	Truck	3.20E-06
7	67	6	Truck	3.20E-06
8	67	6	Truck	1.90E-06
9	32	6	Truck	2.40E-06
10	32	6	Scraper	2.10E-06
11	32	6	Scraper	3.20E-06
12	32	6	Scraper	1.10E-05
13	28	6	Scraper	1.60E-05
14	28	6	Scraper	1.40E-05
15	28	6	Scraper	4.70E-05
16	28	6	Scraper	2.60E-05
17	67	6	Truck	3.30E-06
18	67	6	Truck	9.70E-07
19	67	6	Truck	9.90E-07
20	67	6	Truck	2.30E-06
21	67	3	Truck	2.20E-06
22	67	3	Truck	3.10E-07
23	67	3	Truck	2.70E-06
24	67	3	Truck	7.90E-07
25	67	12	Truck	4.20E-07
26	67	12	Truck	2.00E-06
27	32	6	Scraper	2.10E-07
28	32	6	Scraper	4.50E-06
29	32	6	Scraper	6.40E-06
30	32	6	Scraper	2.40E-05
			Maximum	4.70E-05
			Minimum	2.10E-07
			Average	6.32E-06
			Median	2.40E-06

Some of the principal findings of the RMT report (RMT, 1993) are summarized below:

- At moisture contents greater than 38%, the CKD was too wet to be workable using scraper. At moisture contents less than 15%, the CKD was too dry. RMT notes that controlling blowing CKD could be a problem. RMT reports that moisture conditioned CKD is easily placed with a scraper when the moisture content is between approximately 15% and 38%.

- At moisture contents of less than 54%, the CKD was too thick to remove from the concrete truck. Moisture conditioning CKD in a concrete truck was acceptable for moisture contents of 57% or greater according to RMT.

- Steam generation was observed 1 to 2 hours after CKD was placed in the tests where moisture contents ranged from 28% to 57%. The boiling temperatures were reported to be caused by hydration of the CKD.

- Visible cracking was observed on all of the test plots. The cracks ranged from hairline cracks only a few inches long to larger cracks, approximately 1/8 inch to 1/4 inch wide, 2 to 6 inches deep, and 2 to 5 feet long.

- The RMT report notes that the method of placement and average density due to compaction had a statistically significant effect on hydraulic conductivity, with higher dry density corresponding to lower permeability.

Closure Designs and Closure Design Data

A March 8, 1995 letter from the MDNR to Lafarge (MDNR, 1995) addresses an Interim Closure and Action Plan submitted on November 18, 1994 (RMT, 1994a). In the letter, MDNR approved the use of conditioned CKD as an interim cover, but required further evaluation of CKD proposed as a final cover.

The final closure, maintenance, and monitoring plan (RMT, 1995) refers to the MDNR letter of March 8, 1995 and refers to the construction Quality Assurance Plan as specifying that CKD liners will be constructed to meet a permeability of 1×10^{-7} cm/sec. Citing a reduced CKD generation rate resulting from Lafarge investment in new raw materials, the final closure report (RMT, 1995) proposes:

- capping of the Wessel Road site with a geomembrane in lieu of a CKD cap;

- capping the existing CKD placement area with a combination of a geomembrane on the side slopes and a CKD barrier of a thickness of 6 feet over the upper slopes.

In the HELP Model evaluation of landfill leakage conducted in support of the proposed closure method for the existing CKD placement area, RMT used a 24-inch layer of CKD with a permeability of 1 x 10^{-7} cm/sec, and notes that the actual thickness is 6 feet (RMT, 1995). The closure report makes reference to earlier studies demonstrating the low permeability of conditioned and compacted CKD. Presumably, the earlier studies are those reported in Appendix L of the Interim Closure Plan (RMT, 1994a). These permeability data are shown in Table 6-7.

New CKD Landfill - 1994 Design

In the Type III Landfill Design Report (RMT, 1994b) a new CKD landfill was proposed, to be located within the quarry, just north of the existing CKD placement area. The proposed landfill would occupy about 112 acres. In the report, RMT assesses a landfill liner design consisting of a 6-foot layer of conditioned CKD, overlain by a 12-inch drainage layer of secondary crusher stone and a non-woven geotextile over the drainage layer. The design also calls for water collection drains above the conditioned CKD base, manholes to collect the water and a pump and force main to remove collected water to a holding tank (RMT, 1994b).

RMT proposed capping the landfill at closure with conditioned CKD in phases. As the waste CKD is placed and brought up to grade a 12-inch drainage layer (secondary crushed stone) would be placed above the landfilled waste CKD, covered with a non-woven geotextile and topped with a 6-foot layer of conditioned CKD. The conditioned CKD would be covered by a 2-foot general fill erosion layer. In its modeling runs, RMT used a permeability for CKD of 1 x 7^{-7} cm/sec.

The design report (RMT, 1994b) also provides information on strength properties of CKD. Compressive strength of 28-day old samples ranged from 53 pounds per square inch (psi) to 240 psi, with most samples showing strengths equal to or greater than 100 psi.

Results of laboratory testing of permeability (using flexible wall permeameter) of conditioned CKD in the period 12/19/94 through 2/20/95 are provided in an October 30, 1996 letter from Lafarge to the MDEQ (Lafarge, 1996a). The results of 20 samples show a range of permeabilities from 2.6 x 10^{-8} cm/sec (minimum) to 1 x 10^{-5} cm/sec (maximum), with an average of 3.99 x 10^{-6} cm/sec and a medium value of 2.95 x 10^{-6} cm/sec.

Revised Designs

In December 1996 Lafarge sent a letter to the MDEQ requesting approval of two conceptual alternatives to the design of cell 1 of the new landfill proposed in the quarry (Lafarge, 1996d). The letter outlines the conceptual design alternatives as follows:

- Alternative 1 - The approved alternative. A base of conditioned CKD with a permeability of 1 x 10^{-7} cm/sec, 6 feet thick, overlain by a 1 foot drainage layer.

- Alternative 2 - A proposed alternative. A base of general fill, 6 feet thick, overlain by a geomembrane (40 mil minimum thickness) and a 1 foot drainage layer overlying the membrane.

- Alternative 3 - A base of general fill, 3 feet thick, overlain by select clay fill with a permeability of 1 x 10^{-7} cm/sec and thickness of three feet and a 1 foot drainage layer overlying the clay.

Citing the ease of construction, the availability of materials, and uncertainty concerning the results of the CKD pilot test program, the letter requests approval, with details to follow after a decision by Lafarge in early 1997 (Lafarge, 1996d).

Submittals by Lafarge to the MDEQ in early 1997 indicate substantial changes to the closure and new CKD landfill designs originally proposed. A February 20, 1997 letter indicates that the barrier layer originally proposed for the cap of the existing CKD placement area (a conditioned CKD layer two feet thick) was replaced with a geosynthetic clay liner (Lafarge, 1997b).

Current New Landfill Design - Cell 1

For the new landfill area, major changes in the design are also seen. Details of the current design for Cell 1 indicate that the liner will be a 60 mil high density polyethylene (HDPE) membrane, overlain by a drainage layer of sand, 2 feet thick (RMT, 1997). Plans showing the latest capping details were not found. An April 18, 1997 letter from Lafarge to MDEQ indicates that a geonet drainage layer is now proposed to overlay the HDPE liner in lieu of the drainage layer shown on the March 1997 drawings (Lafarge, 1997c). No further information was found in MDEQ files reviewed on April 24, 1997.

6.4.2.4 Medusa Portland Cement Company - Charlevoix, Michigan

Overview

The Medusa Portland Cement Company (Medusa) owns and operates a cement manufacturing plant located about one mile west of the City of Charlevoix, Michigan. The Medusa property is bounded to the north and west by Lake Michigan (RMT, 1996b).

The facility has been in operation since 1968. Since 1980, the company has used a dry process. A total of 2 million tons of CKD has been disposed on the site since 1968. The company has identified 9 locations where CKD has been disposed, with 75 percent disposed above ground and 25 percent below ground. All disposal areas have been covered with overburden and seeded, except one area which has been used since 1983 and is identified as Pile #9. The facility does not burn any waste materials, does not currently reuse any wastes in the process and does not recycle CKD back into the process (MDNR, 1994). In 1995, the plant produced 46,560 metric tons of CKD.

The present quarry floor elevation is approximately 548 feet, which is approximately 31 feet below Lake Michigan's water level. The Medusa facility and the surrounding area are within a matured karst terrain, with sinkholes, closed depressions and vertical shafts that extend beneath the ground surface (RMT, 1996b). The company discharges water at a rate of 8.5 million gallons per day from the quarry to Lake Michigan (MDNR, 1994).

Proposed Pile 9 Closure and New Type III Landfill

Under a plan for closure of existing CKD disposal areas and development of a new landfill, a new landfill is proposed over the existing Pile 9 and the adjacent area, the plan calls for the bottom of the new landfill to serve as the final cover for the waste piles. The base of the new landfill would consist of a double liner of two 3-foot thick conditioned compacted CKD liners, separated by a secondary collection system. The secondary collection system (i.e., leak detection system) would be a 1-foot thick stone drainage layer. The landfill would be capped in phases with a 2-foot compacted CKD barrier layer (infiltration layer) and a 2-foot vegetated general fill layer. Water contacting the CKD (contact water) would be collected and used in CKD conditioning or would be treated (RMT, 1996a).

CKD Testing Program - Medusa Site

A conditioned CKD testing program was conducted to evaluate the feasibility of using CKD as a Type III landfill liner and final cap barrier layer. The purpose was to determine if the CKD is capable of achieving a permeability of 1 x 10^{-7} cm/sec, whether it has adequate compressive strength and whether it can attain its required permeability when placed in the field (RMT, 1996a).

The testing was conducted in two phases. In the first phase, laboratory analyses were performed to assess whether a permeability of 1 x 10^{-7} cm/sec could be achieved in the laboratory and to determine the compressive strength of the CKD. In the second phase, a field program was conducted to verify the laboratory results under field conditions.

After laboratory testing showed acceptable permeability results, twelve (12) test plots were constructed and conditioned CKD was compacted in 6-inch lifts at each test plot with either a scraper or a roller. The scraper test plots were rolled 11 to 14 times (e.g., compacted by the tires of the scraper) and roller compaction was conducted using a smooth vibratory drum with 4 passes (RMT, 1996a). Diamond core bit samples of the compacted CKD, collected about 28 days following placement, were tested in accordance with ASTM D6084 (flexible membrane permeameter). The results of the tests are shown in Table 6-8.

As shown in Table 6-8, none of the test results show a permeability attained in the field of 1 x 10^{-7} cm/sec or less. The minimum permeability was 2.6 x 10^{-7} cm/sec and the maximum 2.7 x 10^{-5} cm/sec, with a median value of 4.9 x 1^{-6} cm/sec.

The nine (9) tests reported for scraper compaction show a permeability range of 2.6 x 10^{-7} to 2.7 x 10^{-5} cm/sec, with a median value of 3.3 x 10^{-6} cm/sec. The overall range in reported permeability is about two orders of magnitude for roller compaction and one order of magnitude for the scraper (tire) compaction.

The compressive strength of CKD is reported to range between 180 pounds per square foot (psf) and 575 psf using ASTM D2166 (Unconfined Compressive Strength of Cohesive Soil).

Detailed studies of potential landfill settlement and slope stability were included. The analysis indicated a potential for 0.7 feet settlement of the cover and 2.8 feet for the liner, given a total thickness of CKD in the pile of 106 feet and time period of 30 years. Noting that the actual settlement will typically be less than predicted, the report further notes that differential settlement should not be excessive and settlement is not expected to cause problems in the long-term operation of the landfill (RMT, 1996a).

The stability analysis was performed using a shear strength of 400 psf and a unit weight of 96 pcf for the conditioned CKD. For the waste CKD, a shear strength of 1,750 psf was used. The analysis concluded that the landfill will be stable (RMT, 1996a).

RMT, Inc. Conclusions Concerning CKD Permeability

In its conclusions, the report notes that field tests indicate that CKD may be compacted to attain permeabilities as low as 2.6×10^{-7} cm/sec and further notes that placement and compaction techniques will be refined to attain permeabilities of 1×10^{-7} cm/sec or less (RMT, 1996a).

Table 6-8. CKD Permeability - Test Plots, Medusa Cement Company Charlevoix, Michigan

Test No.	Permeability (cm/sec)	Compaction Equipment
1	1.1×10^{-5}	S
2	5.5×10^{-6}	S
3	9.4×10^{-6}	S
4	2.6×10^{-7}	R
5	2.0×10^{-6}	R
6	4.8×10^{-7}	R
7	2.7×10^{-6}	S
8	4.3×10^{-6}	S
9	2.7×10^{-5}	S
10	1.2×10^{-5}	R
11	2.6×10^{-5}	R
12	2.6×10^{-6}	R
13	3.3×10^{-6}	R
14	3.9×10^{-6}	S
15	3.4×10^{-6}	R
16	2.2×10^{-5}	R
17	7.8×10^{-6}	S
18	1.5×10^{-5}	S
19	1.0×10^{-5}	R
20	1.0×10^{-6}	R
Average	8.5×10^{-6}	Compaction achieved with scraper or vibratory roller
Minimum	2.6×10^{-7}	"
Maximum	2.7×10^{-5}	"
		"

Source: RMT 1996a
Note: S = Scraper
R = Vibratory Roller

6.4.2.5 Lehigh Portland Cement Company CKD Pile - Metaline Falls, Washington

Overview

The Lehigh Portland Cement Company (Lehigh) CKD Pile is located southwest of the Town of Metaline Falls, Washington. Lehigh operated a cement plant in Metaline Falls from 1952 to 1989, when Lehigh sold its plant to the Lafarge Corporation. Use of the CKD disposal site ceased in 1989 when Lehigh sold its plant. Lehigh retained ownership of the CKD disposal site, which comprises a parcel of about 13 acres (Dames & Moore, 1996). The pile is located about 360 feet east of Sullivan Creek, a tributary of the Pend Oreille River. Prior to its closure in 1996 the footprint of the pile comprised about 7.2 acres, its maximum thickness was estimated at about 75 feet and the total weight of CKD disposed in the pile was estimated at about 550,000 tons (Dames & Moore, 1996).

Available Information on Properties of CKD - Metaline Falls, Washington

Reports available addressing physical properties of the CKD in the pile are summarized by EPA (1997b) as follows:

- analysis of samples of the CKD from the pile indicate that the material is similar to a non-plastic, silty soil;
- particle size analysis indicates the CKD contains approximately 80 to 90 percent silt and fine sand;
- the moisture content of the CKD in the pile (prior to closure) is about 60 to 75 percent near the surface;
- the dry density of CKD ranges from 35 to 65 pcf;
- zones of higher moisture content within the pile are noted to have a greater degree of plasticity; and
- the optimum moisture content is in the range of 23 to 50 percent.

CKD density, moisture content, and permeability data summarized by EPA (1997b) are presented in Table 6-9. As shown in Table 6-9, the saturated hydraulic conductivity in two relatively undisturbed CKD samples ranged from 1.7×10^{-4} to 1.2×10^{-5} cm/sec. CKD compacted to about 90 percent of Standard Proctor maximum dry density showed permeabilities ranging from 7.5×10^{-5} to 1.4×10^{-6} cm/sec.

Table 6-9: CKD Density, Moisture Content and Laboratory Permeability Data Lehigh CKD Pile, Metaline Falls, Washington

Test No.	Wet Density (pcf)	Moisture Content (%)	Permeability (cm/sec)
1 (U)	74.6	58.4	1.7×10^{-4}
2 (U)	90.7	87.3	1.2×10^{-5}
3 (R)	94.3	59.3	7.5×10^{-5}
4 (R)	106.7	57.2	1.4×10^{-6}
5 (R)	100.6	53.9	2.2×10^{-6}
6 (R)	99.6	42.2	3.9×10^{-6}
7 (R)	101.7	46.2	4.5×10^{-6}

Source: USEPA 1997b

Note: "U" denotes testing performed on a relatively undisturbed sampled.
"R" denotes testing performed on a remolded field bulk sample.

The EPA report (1997b) also summarizes information available on strength and compression characteristics of the Metaline Falls CKD, as follows:

- Penetration data from split-tube sampling of the CKD pile indicate that the physical strength of the material is variable and ranged from 1 to over 33 blows per foot (blow counts corrected for Standard penetration Test analysis). Blow counts of 4 to 9 per foot were most typical.

- The normal shear strength of the CKD material ranged over almost an order of magnitude, from 25 to 200 kg/m^2 (500 to 4,000 pounds/foot^2).

- A cohesion of 30 kg/m^2 (600 pounds/foot^2) and friction angle of 25 degrees was selected for slope stability analysis purposes in designing the CKD pile closure.

- Compression tests indicate that CKD is moderately compressible. Compression index values of 0.25 and 0.4 were observed in the virgin compression portion of the tests. Grading and capping of the CKD pile is estimated to result in somewhat lower compression indices, on the order of 0.21 and 0.35.

Use of CKD as a Capping Material

In the planning for closure of the CKD pile, the use of compacted CKD as the barrier within the capping system was considered based on cost. In subsequent review, compacted CKD was rejected based principally on concerns about placement on steep slopes (USEPA, 1997b).

Site Closure

The capping system designed and implemented in 1996 had as its principal element a geosynthetic clay liner (GCL), overlain by a geocomposite drainage layer and a 3-foot layer of cover material over the geocomposite drainage layer (USEPA, 1997b). Post closure monitoring is currently underway.

6.4.3 Evaluation of Instances Where CKD Was Actually Used as a Cap or Liner Material

In Sections 6.4.1 and 6.4.2, the engineering properties of CKD that determine its effectiveness as a liner or cap are identified, the engineering properties of CKD determined in the laboratory and the field are summarized, and cases where CKD has been proposed or used as a liner or cap are described.

In this section, the use of CKD as a liner or cap is evaluated in terms of its performance and constructability based on cases described in Section 6.4.2. Use of CKD is compared with Subtitle C and D liners and cap materials in Section 6.4.4 and the use of CKD material as an intermediate or daily cover is evaluated in Section 6.4.5.

As described in Section 6.4.1, the principal performance criterion for CKD or any other material used as a liner or cap at a landfill is its ability to serve as a barrier to precipitation (in a cap) or leachate (in a liner). The permeability of the barrier is the primary measure of performance and a number of laboratory and field studies are reported that provide information on the predicted and actual permeability of compacted CKD.

6.4.3.1 Cases Where CKD Has Been Used

In the case studies reviewed, three locations were identified where CKD has been used as an engineered component of a CKD landfill:

- capping the Lehigh Cementon CKD Landfill, Greene County, New York;
- capping the Lehigh Alsen CKD Landfill, Greene County, New York; and
- capping the Independent Cement Corporation CKD Landfill, Greene County, New York.

These facilities were discussed earlier in Sections 6.4.2.1.1, 6.4.2.1.2, and 6.4.2.2. Design phase and construction phase data on CKD permeability are summarized below.

Lehigh Cementon Site - Capping

In the design phase of this closure project, laboratory testing of CKD showed permeability in the range of 1×10^{-8} cm/sec (see Table 6-1). NYSDEC requirements for the closure specified a permeability of 1×10^{-5} cm/sec or less (NYSDEC, 1985). Field permeability tests conducted at fifteen (15) locations showed permeabilities in compacted CKD test plots with a median value of about two orders of magnitude greater than the design phase laboratory permeability. The median value for permeability, 3.2×10^{-6} cm/sec, conformed to NYSDEC requirements, with two samples showing permeabilities slightly in excess of the 1×10^{-5} cm/sec permeability required (see Table 6-1).

Lehigh Alsen Site - Capping

As shown in Table 6-1, during the design phase of closure, permeability studies showed a median CKD permeability of 1.6×10^{-6} cm/sec, with a range of 7.7×10^{-7} cm/sec to 7×10^{-5} cm/sec. The results of twenty-four (24) tests during construction showed a median value for CKD permeability of 5×10^{-5} cm/sec, and a range of 2.7×10^{-6} cm/sec to 1.6×10^{-4} cm/sec. Compared to the design phase median value, the construction phase values showed a permeability of more than one order of magnitude greater. See Tables 6-1, 6-4, and 6-5.

Independent Cement Corporation - Capping

During the preconstruction phase, seventeen (17) samples of stockpiled CKD showed permeability values in the range of 9×10^{-7} cm/sec to 1.7×10^{-4} cm/sec, with a median value of 2.5×10^{-5} cm/sec (see Table 6-1). The results of fifty-eight (58) CKD permeability tests conducted during capping of part of the site in 1996 showed a range in permeability from 3.1×10^{-7} cm/sec to 1.1×10^{-4} cm/sec and a median value of 2.1×10^{-5} cm/sec. These permeability values are in general agreement with the preconstruction values and in general agreement with the values attained at the Alsen site.

Summary - CKD Permeability at Locations Where CKD Has Been Used as a Cap

At the three (3) locations where CKD has been used as a cap, testing of the CKD as placed in the field shows median permeability values of 3.2×10^{-6} cm/sec (Cementon); 5×10^{-5} cm/sec (Alsen); and 2.1×10^{-5} cm/sec (ICC). The minimum permeability noted in the results of 97 tests reported is 3.1×10^{-7} cm/sec and the maximum is 1.6×10^{-4} cm/sec. For all 97 tests, the median value is 2.3×10^{-5} cm/sec and the average is 3.4×10^{-5} cm/sec.

Referring to Table 6-1, Entry Nos. 2 through 6, 8, 10, and 14, comprise 175 test results for CKD permeability during construction, from test plots and/or from the pre-construction phase. Considering all of these test results, the expected permeability of CKD would be as follows:

- Minimum: 2.6×10^{-8} cm/sec
- Maximum: 1.7×10^{-4} cm/sec
- Median: 1.2×10^{-5} cm/sec
- Average: 1.8×10^{-5} cm/sec

6.4.3.2 Conclusions - Performance of CKD Used as a Liner or Cap

Data are available from a number of sources addressing the permeability of compacted CKD. Data from testing prepared in the laboratory appear to understate the permeability of CKD compared to the results of testing on test pads and samples during construction. Field testing has shown some permeability values less than 1×10^{-7} cm/sec. However, in the test data reviewed, 50 percent of the field tests measured permeability in excess of 1.2×10^{-5} cm/sec.

Recently reported test results for test plots at the Medusa Facility in Charlevoix, Michigan (RMT, 1996b), suggest that median values in the range of 5×10^{-6} cm/sec may be attained using multiple pass compaction techniques and other controls. Historical data show, however, that in general, compacted CKD would be likely to show a permeability slightly in excess of 1×10^{-5} cm/sec when placed in the field.

Stability studies of CKD show acceptable strength characteristics. Settlement studies show some settlement expected and designs must consider this possibility in selection of slopes and appurtenances that are expected to perform as designed for long periods of time.

The performance of CKD liners subject to leachate flow from above has not been studied in terms of chemical stability. Studies by Ballivy et al. (1992) suggest that water permeating a CKD liner may show elevated pH and some metals, not from the quality of water entering the liner, but from the liner itself.

The double liner system recently proposed for the closure of CKD piles at the Medusa Plant in Charlevoix, Michigan is of significant interest. In the design proposed, the new landfill will serve as the cap for existing CKD piles, and will essentially be a piggyback landfill. At this location, a performance value for CKD permeability of 1 x 10-7 cm/sec is established. However, this performance has not yet been demonstrated (Per. Com. Polasek, 1997).

6.4.3.3 Constructability

As described in Section 6.4.2.1.2, a principal concern in the use of CKD as a cap are construction problems that may result when compaction of the material on relatively steep slopes is required. In the closure of the Lehigh Alsen CKD landfill, rupture of the surface of the cap was reported when a dozer-pulled compactor traversed the slopes. Successive horizontal lifts were required to remedy this condition. A similar concern was noted in the design of the Metaline Falls, Washington closure, where steep slopes were contemplated. The condition of the existing waste CKD (e.g. a thin crust, overlying moist material) was also reported. In the case of the Metaline Falls closure, a geosynthetic membrane was ultimately selected as the barrier layer in the cap.

In general, the construction of a CKD liner or cap requires control of moisture content, compaction, and density in an environment involving the use of heavy equipment and exposure to varying conditions of temperature and precipitation. Results from small area test plots show substantial variations in permeability under relatively controlled conditions.

6.4.4 Comparison of CKD Liners and Caps to Subtitle D and Subtitle C Liners and Caps

For landfilled wastes subject to regulation under RCRA Subtitles D and C, detailed requirements for liners and caps have been established. As a point of reference in EPA's evaluation of CKD, Subtitle D and C liner and cap requirements are reviewed below.

New or laterally expanded municipal solid waste landfills (MSWLFs) that are designed and constructed in accordance with RCRA Subtitle D and implementing regulations 40 CFR Part 258, must have a composite bottom liner and leachate collection system.[5] The bottom liner consists of two components, an upper component with a minimum 30-mil flexible membrane liner (FML)[6] and a lower component which is, at minimum, 60 cm (2 feet) of soil compacted to a hydraulic conductivity (permeability) of no more than 1×10^{-7} centimeters per second (cm/sec). The leachate collection system must be designed to maintain a depth of leachate less than 30 cm (12 inches) above the liner. At closure a final cover system is required to minimize infiltration of precipitation into the landfilled waste and, as a minimum, must have a barrier layer with a permeability less than or equal to the permeability of any bottom liner system or a permeability no greater than 1×10^{-5} cm/sec, whichever is less. An earthen infiltration layer at least 18 inches thick and an erosion layer of at least 6 inches must also be provided.

For RCRA Subtitle C landfills, constructed for the disposal of hazardous wastes in accordance with 40 CFR Part 264, a double liner system is required. The top liner is a highly impermeable layer such as a geomembrane with a leachate collection system above. The bottom liner consists of two components, a top component such as a geomembrane and a bottom component constructed of at least 91 cm (3 feet) of earth compacted to a permeability of 1×10^{-7} cm/sec or less. Other components, such as leak detection systems, are also required. See 40 CFR 264.300. At closure, a cover system must be provided that has a permeability less than or equal to any bottom liner or natural subsoils present.

In order to construct a landfill liner in compliance with the Subtitle D and Subtitle C requirements, a layer of soil (clay) is required to have a permeability of 1×10^{-7} cm/sec or less. The requirements and challenges in achieving the required permeablity in a soil liner include ensuring that a sufficient liner thickness is established, that compaction is performed in thin lifts, and that bonding is assured between lifts.

All of these considerations are applicable to the use of CKD as a liner or cap. The principal

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[5] Alternative designs are acceptable if it is demonstrated that groundwater will not be significantly impacted. See 40 CFR 258.40.

[6] If the FML is high density polyethylene (HDPE) it must have a minimum thickness of 60-mil (one mile = 1/1,000 inches).

concern in the comparison with RCRA Subpart D and Subpart C landfill liner requirements is whether CKD can consistently be placed in the field to provide a permeablity of 1 x 10^{-7} cm/sec or less. As described in Section 6.4.3.2, the current data do not demonstrate that a value of 1 x 10^{-7} cm/sec can be achieved consistently in CKD placed in the field. Field data from the Alsen CKD landfill indicate that CKD can be compacted to achieve a permeability of 1 x 10^{-5} cm/sec or less and can be used as a low permeability barrier in a landfill cover system. A low permeablity barrier consisting of compacted CKD with a maximum permeability of 1 x 10^{-5} cm/sec may be used in a final landfill cover system, if the bottom liner system and native materials under an existing landfill have a permeability of 1 x 10^{-5} cm/sec or greater. Mixing fly ash with CKD may also improve performance in terms of permeability.

6.4.5 Daily and Intermediate Landfill Covers Using CKD or CKD Based Material

The Subtitle D landfill regulations require that operators of municipal solid waste landfills cover the disposed waste with 15 cm (6 inches) of earthen material at the end of each working day. Intermediate cover of greater thickness may be required on landfill sections where filling is not occurring. Alternatives to the use of earth for daily or intermediate cover of greater thickness may be required on landfill sections where filling is not occurring. Alternatives to the use of earth for daily or intermediate cover may be approved by regulatory authorities if the operator demonstrates that such alternatives will control disease vectors, fires, odors, blowing litter, and scavenging without presenting a threat to human health or the environment. CKD has been approved for use as landfill cover material as described below.

Two CKD-based products have been identified for potential use as a daily or intermediate cover for a CKD landfill. The Report to Congress (USEPA, 1993b) identifies a project known as N-Viro Soil®, which is a mixture of CKD and sewage sludge, and notes its use as a cover method at landfills. A product known as Posi-Shell®, also CKD-based, has also been used as a cover material at landfills. As part of the evaluation of CKD as landfill liners and caps, N-Viro Soil®, and Posi-Shell®, were briefly evaluated based on vendor information and available information.

The evaluation of these products is summarized below. No endorsement of nor lack of endorsement of these products by EPA or its contractors should be implied and the evaluation is limited to the information as stated herein.

6.4.5.1 N-Viro Soil®

Process Overview

The N-Viro Soil® process is a patented process used in the treatment of denatured municipal wastewater treatment plant sludge. In the process, CKD is added to the sludge as an alkaline reagent. Other possible alkaline reagents include lime kiln dust, lime, alkaline fly ash and other residuals. CKD is used at most of the facilities.

The CKD is mixed with the sludge at dose rate of 30 to 65 percent by sludge cake weight. The pH is raised to 12 standard units from 1 to 3 days, the temperature is maintained at 52 to 62° C for at least 12 hours and the solids content is raised above 50 percent for at least 12 hours. The material is then windrowed for 3 to 7 days to further dry and improve handling characteristics. The process is said to destroy all pathogens and is said to produce a material that meets federal sludge concentration limits.

Physical Properties

N-Viro Soil® is a soil-like material that is highly permeable, workable under a wide range of moisture conditions and has a high water retention capacity. Wet sieve analysis shows average grain size distribution to be 40 percent aggregate greater than 2mm, 25 percent medium to coarse sand (0.25 to 2mm) and 34 percent smaller than 0.25mm (Logan and Harrison, 1995).

Other physical property averages are reported as follows:

- Solids: 62 percent
- Particle Density (mg/cm^3): 1.96
- Bulk Density (mg/cm^3): 0.59
- Porosity: 69.9 percent
- Permeability: 0.0278 cm/sec (uncompacted)
  0.000915 cm/sec (compacted - ASTM D698)

Current Uses of N-Viro Soil®

In 1994, over 285,000 metric tons (300,000 tons) of N-Viro Soil® was used as a daily landfill cover at municipal landfills including: Novato, CA; Easley, SC; Easte Hyde, UK; Greenville, SC; Lexington, KY; Middlesex County, NJ; and Saugerties, NY. At these facilities, N-Viro Soil® is used as an alternative to importing topsoil. According to vendor information, N-Viro Soil® could also be used as a component in the final landfill cover, because the organics and nutrients in the soil would facilitate the establishment of a stable vegetative cover.

N-Viro Soil® as a Landfill Cover

As noted above, N-Viro Soil® has been found to be suitable for use as an intermediate or daily cover at several municipal solid waste landfills in the United States. Vendor information reports that the free draining, high aggregate content, and low plasticity properties of N-Viro Soil® allow it to be readily used under most conditions as an intermediate or daily cover at CKD landfills to minimize fugitive dust and erosion hazards. It would also be suitable as a component in the final cap design to support a vegetative cover. On rare occasions, if not properly drained, leachate from the N-Viro Soil® could become septic, with anaerobic bacterial growth, and could emit foul odors due to the high organic content of the CKD N-Viro Soil® mixture. Vendor information indicates that the use of N-Viro Soil® in a landfill is not expected to adversely impact nearby water resources because the N-Viro Soil® meets the federal limits for release of treated sludge, and CKD contaminants that might migrate through the pile are likely to be adsorbed in the organic-rich N-Viro Soil® and to have a reduced bioavailability. The School Of Medicine In New Orleans conducted a lead bioavailability study on lead contaminated soils (i.e., soil collected at an inter city location, soil with 10% N-Viro Soil®, and soils with 10% other biosolids). This study found that the bone lead concentration of rats that ingested the N-Viro Soil® was about 33% lower than that found in rats which consumed the control soil (Heneghan, 1994). N-Viro Soil®'s primary limitations at CKD landfills are its cost (unless the landfill is located near a N-Viro® facility) and potential marginal improvement over using native soils at the site locality. In addition, the N-Viro International Corporation has a policy against using CKD from cement plants which burn hazardous waste.

6.4.5.2 Posi-Shell®

Posi-Shell® is a mixture of CKD, recycled paper pulp, and short recycled polyester fiber and water. Various mixtures are available, adding cement in various proportions depending on needs.

The mixture is manufactured on-site using mixing machines, CKD, bagged fiber and cement. The mixed Posi-Shell® material is then applied by pump spray to the areas to be covered. Application is generally about ½ inch thick, but thicker applications are also possible.

Its uses include dust control and covers for landfills for daily and intermediate cover and covers for waste disposal sites to control fugitive emissions.

Wet density is about 95 pcf at a 60 percent moisture, with dry density about 60 pcf. Densities may vary with the proportions of fiber and cement that may be used. Hydraulic conductivity is reported to be about 6 x 10^{-6} cm/sec. TCLP leaching tests show leachate within acceptable limits.

Posi-Shell® has been approved for use as a daily cover at a number of landfill locations. Its use as an intermediate cover material has also been approved.

Posi-Shell® is currently being used as a cover at a landfill in the State of Rhode Island. At this landfill, Posi-Shell® has been applied as part of management measures to control hydrogen sulfide emissions. Preliminary reports show the use of Posi-Shell® at this location is effective as a measure to control hydrogen sulfide emissions in conjunction with a landfill gas extraction system also installed at the site.

6.4.6 Cost Evaluation

Because the instances of the use of CKD as a barrier material in a landfill are few, actual cost data are sparse. Two sources of information were identified in the review of the cases described in Section 6.4.3. The information identified and comparisons with other cost data are summarized below.

6.4.6.1 Lafarge Facility - Alpena, Michigan

In a February 20, 1997, letter from Lafarge to the Michigan DEQ, a comparison of the costs of a

CKD liner versus a geosynthetic clay liner (GCL) is provided (Lafarge, 1997b). In that letter, the unit cost for a CKD barrier 24 inches thick is said to be $1.00 per cubic yard (cy). [Note: This cost is said to be the cost for placement of the CKD by Lafarge as part of daily operations and may not reflect the costs that may appear in a contract bid by a separate contractor.]

6.4.6.2 Medusa Facility - Charlevoix, Michigan

In the interim closure/landfill design plan at the Medusa facility described in Section 6.4.3, a feasibility study of landfill alternatives is provided (RMT, 1996a). In the cost estimate portion of the feasibility study, liner construction cost is estimated at $75,000 per acre. [Note: This represents an estimated cost of about $7.70 per cy as compared to the Lafarge estimate of $1.00 per cubic yard. The costs included in these estimates may not be comparable.]

6.4.6.3 Recent Information on Construction Costs for Clay Liners

In April 1997, bids for placement of a 2-foot layer of clay, compacted to 1×10^{-7} cm/sec permeability, at the Town of Lakeville, Massachusetts Sanitary Landfill, were received by the Town of Lakeville Board of Health. Bids (for placement only—not supplying the clay) from ten (10) contractors ranged from $3.50 to $10.00 per cy, and averaged $6.60 per cy.

Based on the Lakeville, Massachusetts bids, the estimates prepared for the Medusa facility appear to include costs that may be experienced in placement of a CKD liner by an outside contractor.

6.4.6.4 Cement Kiln Dust Monofill Cost Model

As part of the development of the proposed regulations for CKD management, a Cement Kiln Dust Monofill Cost Model was developed (ICF, 1995).

The unit cost for compacted CKD used in the model is $4.51/m^3 (or about $3.50/cy), which is in line with the low bid recently received for placement of clay at the Lakeville, Massachusetts landfill, as described above.

6.4.6.5 Conclusions - Cost for Use of CKD as a Liner or Cap

Since CKD is already available at CKD landfills, the costs for its use as a liner or cap are those involved with placement, compaction, and associated testing and quality control. Estimates of costs associated with use of CKD as a liner or cap range from a low of $1.00/cy to a high of $7.70/cy. Based on comparisons with earlier estimates for CKD placement and current estimates of placement costs for clay liners, expected costs for construction of CKD liners or caps, in the range of $3.50/cy to $7.70/cy, could be expected, with a nominal estimate of $5.00 to $6.00 per cubic yard appropriate for rough estimates. Additional refinement of this estimate would be required to ensure that the comparisons are based on comparable assumptions.

6.4.7 Summary

Representatives of the cement industry have proposed the use of compacted CKD as liners and caps at CKD landfills and compacted CKD has been proposed or used as a CKD liner or cap at several locations in the United States. As part of the development of regulations for CKD, EPA evaluated the use of CKD as landfill liners and caps, focusing on information for actual locations where CKD has been used or proposed.

In the evaluation, the permeability of CKD, as placed in the field, is identified as the principal physical characteristic controlling the effectiveness of CKD in providing an acceptable barrier to the migration of precipitation into a CKD landfill (capping) and in providing an acceptable barrier to leachate release into the subsurface beneath a CKD landfill (e.g. a landfill liner).

The evaluation first reviews and identifies the characteristics of soils and soil-like materials such as CKD, which determine how they may perform as a barrier to the flow of liquids. Particle size, particle size distribution, moisture, voids, and compaction are identified as the primary determinants and standard tests used are described for subsequent reference in the description of the engineering properties of CKD. The evaluation notes concerns that permeabilities of liners, as actually placed in the field, may not be as low as predicated by laboratory tests, based on experience in the use of clay liners.

Locations where CKD has either been proposed or used as liners or caps for CKD landfills are described. These include:

- The Lehigh Cementon CKD landfill in Greene County, New York, where a 46 cm (18-inch) compacted CKD layer was installed in 1988 as part of the cap during site closure.

- The Lehigh Alsen CKD landfill in Green County, New York, where a 1.37 m (54-inch) layer of compacted CKD was used in capping the site between June 1992 and June 1994.

- The Lehigh Alsen Quarry landfill in Greene County, New York, where a single layer of compacted CKD, 46 cm (18-inch) thick, was proposed as a CKD landfill liner and a similar layer of CKD was proposed as a cap.

- The Independent Cement Corporation CKD landfill in Greene County, New York, which is undergoing phased closure using a 1.37 m (54-inch) thick compacted CKD cap.

- The Lafarge Corporation CKD disposal facilities in Alpena, Michigan, where a 1.83 m (6 foot) layer of compacted CKD was proposed as part of the bottom liner for a new landfill and a similar layer was proposed for its cap; and capping the existing disposal area with CKD (in part) was also proposed.

- The Medusa Cement Company CKD disposal facilities in Charlevoix, Michigan, where a double liner of compacted CKD is proposed, each 91 cm (36-inch) thick, as part of a new CKD landfill would serve as a cap for existing disposal areas.
- The Lehigh CKD disposal site in Metaline Falls, Washington, where CKD was initially considered as part of the cap design for closure.

The evaluation tabulates the findings of studies conducted to determine the engineering properties of CKD, focusing on laboratory and in-field permeability test results available from locations where CKD has been proposed or used. Information from the Portland Cement Association is also included in the tabulation.

Findings concerning the permeability of CKD include the following:

- Laboratory test results of CKD permeability may understate CKD permeability when results are compared to permeability test results from CKD placed in the field at actual locations.
- During capping of the Lehigh Cementon CKD site in New York, the median value for CKD permeability was 3.2×10^{-6} cm/sec based on in-field tests.
- During capping of the Lehigh Alsen CKD site in New York, the median value of permeability tests during construction was 5×10^{-5} cm/sec.
- During capping of part of the Independent Cement Corporation CKD site in New York, the permeability test results showed a median value of 2.1×10^{-5} cm/sec.
- Ninety-seven (97) permeability test results are available for CKD placed as a cap at the three New York sites (Cementon, Alsen, and Independent Cement). The median permeability value for these ninety-seven tests is 2.3×10^{-5} cm/sec.
- Recent testing of CKD placed in test plots at the Medusa facility in Charlevoix, Michigan, show a median permeability value of about 5×10^{-6} cm/sec in tests where compaction was provided by 11 to 14 passes of tire compaction equipment or 4 passes of a vibratory roller.
- In test plots constructed at the Larfarge facility in Alpena, Michigan, a median value for CKD permeability of 2.4×10^{-6} cm/sec was shown in CKD placed by scraper and concrete trucks. Cracking was observed in all test plots.
- In test plots constructed at the Ash Grove Cement Plant in Chanute, Kansas, a

median value of CKD permeability of 2.3 x 10^{-5} cm/sec is shown in test results where compaction equipment included a vibratory padfoot roller, a rubber tire roller, and a vibratory drum roller.

- In 205 test results for CKD permeability during construction, from tests plots, and from pre-construction data, the median value for CKD permeability is 1.0 x 10^{-5} cm/sec.

The evaluation finds that while testing has shown compacted CKD with permeabilities of 1 x 10^{-7} cm/sec or less, the current information shows permeabilities exceeding 1.0 x 10^{-5} cm/sec in 50 percent of the tests.

The EPA evaluation cites findings of design studies indicating that CKD has strength and stability characteristics that are acceptable. Potential problems in constructing caps on CKD landfills when compaction is required on steep slopes is noted. The need to consider long-term settlement in the design of CKD landfills is also noted.

A brief comparison of CKD liners with liners required for Subtitle D and Subtitle C landfills indicates that CKD liners would not be expected to consistently meet 1 x 10^{-7} cm/sec permeability requirements, based on currently available information. In situations where existing landfills lack a bottom liner and the permeability of the native geologic materials exceed 1 x 10^{-5} cm/sec, compacted CKD may warrant consideration for use as a low permeability barrier in the final cover system.

Approximate costs of using CKD in liners or caps are addressed in the final section of the evaluation. Current cost estimates for compacted CKD to be placed at CKD landfills are available from facilities in Charlevoix and Alpena, Michigan. Noting the potential that the estimates from the Michigan facilities may not be comparable, recent bids for placement of a compacted clay liner in Massachusetts and earlier cost modeling prepared by EPA, the evaluation concludes that costs for CKD liners or caps may be in the range of about \$5.00 to \$6.00 per cubic yard (\$6.50/m^3 to \$7.80 m/^{3}).

Observations based on the information reviewed include the following:

Following placement, substantial cracking has been observed as hydration occurs. Severe cracking may compromise the performance of the CKD in achieving the permeability required to effectively serve as a liner or cap at the landfill.

The addition of fly ash to CKD may improve its performance in achieving the permeability required for service as a liner or cap.

The use of heavy equipment to achieve required compaction and resulting low permeability is important during placement of CKD for service as a liner or cap. As noted above, steep slopes will hinder the use of heavy equipment at CKD landfills.

As in the case of soils, the degree of compaction and resulting density are also good indicators of the permeability of CKD as placed in the field. Careful control of moisture, compaction, and density are required to achieve the desired permeability of CKD to be used as landfill liners or caps.

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Chapter 7: Site Characterization, Ground Water Monitoring, and Corrective Action

EPA is proposing ground water monitoring and corrective action requirements for all facilities that manage waste CKD in land-based management units to detect the presence of regulated constituents in the ground water and allow for swift remediation of ground water problems. The ground water monitoring and corrective action requirements proposed by the Agency are based on requirements promulgated under Part 258 for MSWLFs. Using the approach provided under Part 258 for MSWLFs will provide flexibility to facilities that manage CKD and to States in selecting and implementing the remedy. This chapter describes the implementation considerations for site characterization, ground water monitoring, and corrective action at CKDLF units.

7.1 Site Characterization

Prior to the design and construction of a CKD landfill and design and implementation of a ground water monitoring program, it is necessary to characterize the subsurface conditions at the proposed landfill location. This section discusses some of the technical requirements for performing site characterization.

As discussed in Chapter 5, EPA is proposing special site characterization and certification requirements for CKDLF units located in karst terrains. Section 7.1.1 addresses how to evaluate whether a CKDLF unit is located in karst terrain. Technical considerations for the design and implementation of a ground water monitoring system are described in Sections 7.2, and technical and regulatory requirements for unit-specific corrective action are described in Section 7.3.

Meeting the ground water monitoring requirements for CKDLF units in karst terrains with a significant component of conduit flow will be very difficult. The Agency strongly recommends that owners and operators forego siting their facility above conduit-flow karst aquifers.

Environmental damage has been documented for at least nine CKD disposal sites where the ground water systems had conduit-flow characteristics. The number of cement plants disposing of CKD in mature and immature karst terrains were estimated at 5 and 51, respectively (see Section 4.3). Under the proposed rule, owners or operators of new CKDLF units located in potential karst terrain must perform site-specific evaluations to determine if conduit-flow karst aquifers are present beneath the site. In addition, all facilities should conduct a hydrogeologic investigations to properly design and implement a ground water monitoring program.

7.1.1 Characterizing Site Hydrogeology in Karst Terrain

Owners or operators of new and existing CKDLF units located in karst terrain must demonstrate that engineering measures have been incorporated into the CKDLF unit's design to ensure that the integrity of the CKDLF unit will not be disrupted. As an initial step the owner or operator must gather site-specific information to determine whether or not the site is located in karst terrain and whether or not karst aquifers or formations underlie the site. Sites which are found to be located in karst terrain must collect additional site-specific soil and ground water data for designing the CKDLF unit (see Sections 7.1.2 and 7.1.3).

The facility should assume that karst conditions potentially are present if the site overlies rocks which may be dissolved by water, including but not limited to limestone and dolomite formations. If soluble rocks are present in the CKDLF unit vicinity, a qualified professional must review available literature or conduct basin-wide field study and certify whether or not that the site is located in karst terrain. At a minimum, the following data must be collected and evaluated in order to determine whether a terrain is karstic:

- On-site and local geologic or geomorphologic features (as depicted in U.S. and State Geological Survey reports, State and local regulatory agency reports, and private reports; aerial photos and topographic maps to locate lineaments, sinkholes, springs and to identify drainage patterns);

- On-site and local soil conditions (including review of Soil Conservation Services reports and maps);

- On-site and local hydrology conditions (including identification of downgradient springs and potential receptors and evaluation of the response of ground water levels and springs to storm events); and

- Past and current human activities that may have altered topographic features and ground water conditions, and thus mask evidence of karst features (aerial photographs and previous land uses must be reviewed).

If a CKDLF unit is certified to be located in karst terrain, the notice of certification must be submitted to the State Director. An additional investigation then is required to characterize karst aquifers and/or other karstic features that may be present at the site. These site characterization activities must include:

- An inventory to identify springs, wells, streams, caves and other karst features in the site’s ground water basin; and

- Characterization of the ground water flow rate and path from the CKDLF unit to all potential intermediate sampling locations and to the spring(s) in the ground water basin.

Other methods to determine whether karst features may be present in the site vicinity include:

- Detailed geologic field mapping to locate and verify the presence of additional sinkholes, springs, caves, and other karst features not shown on topographic maps;

- Quantifying ground water recharge/discharge relationships as determined by dye or other suitable tracing techniques;

- Plotting the orientation and density of joints, local stratigraphic and lithologic variations and subsurface relationships not readily discernible from the field mapping; and

- Plotting of ground water levels or potentiometric surfaces on a map to determine the relationship of the aquifer unit to other stratigraphic units.

During the course of conducting previous site characterization activities, hydraulic slug tests may have been conducted in monitoring wells to facilitate calculation of ground water flow rates. In karst areas, hydraulic conductivities measured by slug tests typically underestimate ground water flow rates by several orders of magnitude relative to tracer dye studies and should be evaluated with caution (Smith, 1997). Wells that were originally sited without consideration of conduit flow should be used for monitoring only if dye tracing has first proven a connection between from the CKDLF unit to each of the wells under varying flow conditions (USEPA, 1992).

Because the definition of karst is so broad, however, the Agency recognizes that some limestone or other carbonate rock terrains may be suitable for siting a CKDLF unit. The Agency is providing an opportunity for a demonstration by the CKDLF unit owner or operator to show that subsidence will not adversely affect the CKDLF unit and that the site's hydrogeology can be characterized, and ground water can be monitored effectively.

If the unit is located in karst terrain and springs are found in the ground water basin near the unit, then a comprehensive karst ground water study must be conducted which includes a qualitative tracer dye study. Because contaminant pathways in karst aquifers are often discrete and tortuous, and identification of the uppermost aquifer and its ground water flow paths is a formidable task, the Agency recommends that CKDLF operator avoid siting disposal units over karst aquifers with demonstrated conduit flow characteristics. At a minimum, multiple quantitative tracer dye studies and ground water modeling would be required to properly characterize the site and to optimize detection of potential releases from the proposed CKDLF unit.

7.1.2 Data Required for Design of Ground Water Monitoring Systems in Karst Terrain

The ability to characterize a site's hydrogeology and monitor ground water effectively is vital for the early detection of contaminant releases from any landfill unit. Under the ground water monitoring standards being proposed for CKDLF units and summarized in Chapter 5, monitoring wells are required to detect contaminant releases at a point of compliance in the uppermost aquifer at a distance no more than 150 meters from the landfill unit boundary, on land owned by the landfill owner. One upgradient and at least three downgradient monitoring wells are required to determine, by comparing upgradient and downgradient water quality, whether releases, if any, may be attributed to the landfill. Where releases are detected, appropriate corrective measures must be implemented.

Ground water monitoring wells must be installed to monitor the relevant point of compliance that ensures detection for ground water contamination in the uppermost aquifer. A site's hydrogeology must be characterized to identify ground water flow pathways at the site and its vicinity. In karst terrains, subsurface conduits are the primary pathways that contaminant releases will follow. Identifying and intercepting these conduits with wells is a extremely formidable task. Owners or operators of CKDLF units in karst terrain must define the direction and rate of ground water flow, the depth to water, the configuration of the potentiometric surface of the uppermost aquifer, and points of discharge (springs, surface water bodies, pumping wells, etc.) for the karst ground water basin(s) that the facility might affect. In addition, because karst aquifers typically show strong responses to rainfall events, a conceptual model must be developed which identifies the optimum time for collecting ground water samples. Ground water and contaminants found in ground water will have a higher propensity to migrate off-site during and immediately after peak ground water flows associated with storms (Smith, 1997).

Quantitative tracer dye studies during base flow and storm flow events must be conducted to properly place monitoring wells at appropriate locations and depths and ensure that monitoring results are indicative of impacts to ground water that may be occurring. Because flow pathways in karst aquifers are characteristically discrete, tortuous, and sensitive to storm events, repeated studies using several types of tracer dyes with continuous monitoring of tracer dye concentration, turbidity, and specific conductance may be warranted in order to characterize the ground water flow system's response to storm events, to prepare chemographs, and to identify optimum sampling times (Smith, 1997).

Even if the major flow pathways at a site are traced and the points of ground water discharge (such as seeps and springs -- which may be offsite) have been identified, the uppermost aquifer must be monitored on site, at the point of compliance. EPA believes that monitoring seeps and springs alone does not provide adequate protection of human health and the environment because releases to the uppermost aquifer will not be detected until the contaminants have migrated off site.

Even if accurate monitoring is demonstrable using tracer studies, the studies are not always sufficiently reliable, unless the entire network of conduits can be characterized. In some cases, the only instances of when flow rates and directions from a release point can be determined is after contamination is detected and the damage to human health or the environment has occurred. During storm events, contaminants in karst terrains may migrate off-site in matter of a few hours or days where significant conduit flow is present. Accordingly, it would be essentially impossible to demonstrate that corrective action could be performed under these conditions.

7.1.3 Data Required for Design of CKDLF Units in Karst Terrain

If a facility can demonstrate that the ground water system beneath a CKDLF unit located in karst terrain can be monitored in accordance with the proposed standards, then the facility must also demonstrated that the CKDLF unit can be designed to control the effects of significant differential settling, collapse, or puncture of the landfill liner due to the presence of karst.

Of particular concern are those karst areas where the karst is considered mature. As shown in Table 2-3, of the 110 cement plant locations in the United States, 20 are estimated to be located in mature karst areas where there is a potential for subsidence (e.g., sinkholes). Of these 20 locations, 5 currently dispose of CKD in on-site landfills. EPA believes, however, that special consideration for the stability of foundation material is warranted in all karst areas because surficial evidence of sinkholes may not be present. Relatively small subsurface voids may result in sinkhole formation and the absence of large voids is insufficient evidence that sinkholes are not likely to develop at a specific site.

To ensure that foundation conditions are suitable when locating CKD landfills in karst areas, EPA believes that a site-specific characterization is required to include consideration of the potential for the presence of sinkholes or sinkhole-like subsurface conditions. This characterization should be conducted in concert with the delineation of ground-water flow pathways as described in this section. EPA has described methods for use in the characterization of subsurface conditions in karst areas. These methods include subsurface drilling, sinkhole monitoring, geophysical techniques, and remote sensing (USEPA, 1993a). Sophisticated gravity and electromagnetic geophysical surveys may be appropriate for determining potential sinkhole locations, the presence of underground caverns, and the bedrock topography which may be substantially different from the surface topography.

Karst terrains are often unstable due to the sudden formation of sinkholes as collapse of overlying soil into void spaces occur. Most instances of serious subsidence in areas underlain by solutioned limestone have accompanied or have followed substantial lowering of the ground-water table, and most incidences of subsidence are induced by human activity such as operation of water supply wells and quarry construction dewatering. Hydrographs of ground water levels and site conditions near the CKDLF unit should be reviewed to evaluate if declining water levels could trigger sinkholes beneath the CKDLF unit.

Methods to mitigate karst terrain problems include solutions such as the control of ground water and surface water conditions to minimize the rate of dissolution within near-surface limestone. In areas where development of karst topography is minor, loose soils overlying the limestone may be excavated or heavily compacted to achieve the required stability. In areas where the karst voids are relatively small and limited in extent, infilling of the voids with grout may be an option (USEPA, 1993a).

7.2 Ground Water Monitoring

This section describes the technical considerations for implementing the ground water monitoring requirements for CKDLF units.

7.2.1 Need for Ground Water Monitoring at CKDLF Units

In the RTC (USEPA, 1993b) and in subsequent investigations presented in the NODA (USEPA, 1994), the Regulatory Determination (60 FR 7366), and site-specific case studies and risk modeling summarized in Chapter 2 of this background document, the Agency has documented potential and actual impacts to ground water caused by releases to the subsurface from CKDLF units. As demonstrated by the damage cases, various hazardous constituents listed in Appendix VIII of 40 CFR Part 261 found in CKD have a high potential to migrate from the waste into the environment, and pose unacceptable risks to human health and the environment via the ground water pathways. The constituents of concern include antimony, arsenic, barium, beryllium, cadmium, chromium, lead, mercury, nickel, selenium, silver, and thallium.

The number and severity of the damage cases and the potential for damages to recur provide the basis for the Agency's need to develop standards and operating criteria to protect ground water resources at CKDLF units. Releases of constituents of concern from CKDLF units can be detected by installing ground water monitoring wells along ground water flowpaths hydraulically downgradient of CKD disposal sites. Therefore, as part of these proposed standards, the Agency is proposing requirements for ground water monitoring at CKDLF units. The Agency believes that a properly designed ground water monitoring system at a CKDLF unit will provide a number of benefits. Ground water monitoring will allow the owner/operator to:

- measure the effectiveness of the CKDLF unit design in preventing releases,
- detect releases quickly thus avoiding costly contamination and cleanup,
- determine the nature and extent of any contamination if it does occur, and
- assess the effectiveness of any implemented corrective action.

The proposed ground water controls are flexible and can be tailored to site-specific conditions. EPA believes this approach avoids over regulation and provides adequate environmental protection at a reasonable cost.

7.2.2 Implementation and Technical Considerations for Ground Water Monitoring

As described in Chapter 5 of this background document, the proposed technical requirements for site characterization and ground water monitoring at CKD disposal units are based on those already promulgated under 40 CFR Part 258 (for MSWLFs) and 40 CFR Part 264 (for hazardous waste management units). In developing these standards, EPA also considered a draft proposal submitted to the Agency from the cement industry entitled *Cement Kiln Dust Management*

Practices (Portland Cement Association, 1995). The proposed requirements have been tailored to address the characteristics of CKD and provide sufficient flexibility to allow effective implementation by States.

Upon completion of the site characterization and design and construction of the CKDLF unit, the Agency proposes that a ground water monitoring program be implemented. EPA's proposed standards for ground water monitoring at CKD landfills include provisions for:

- ground water monitoring well design, and construction (see Section 7.2.2.1),
- ground water sampling and analysis (see Section 7.2.2.2),
- statistical analysis of ground water monitoring data (see Section 7.2.2.3),
- detection monitoring (see Section 7.2.2.4), and
- assessment monitoring (see Section 7.2.2.5)

7.2.2.1 Ground Water Monitoring Well Design And Construction

As discussed in Section 5.4.1, a ground water monitoring system must have a sufficient number of wells strategically located to determine background ground water quality and the quality of ground water passing the point of compliance. However, if deemed to be appropriate by the State, a multi-unit ground water monitoring system, based on the requirements of a single-unit ground water monitoring system, may be used where several CKDLF units are located within the same facility.

Owners and operators of a CKDLF unit must ensure that:

- monitoring wells be cased to maintain the integrity of the well borehole;
- well casings be screened or perforated and, if necessary, packed with gravel or sand to allow the collection of ground water samples; and
- monitoring wells be sealed to prevent contamination of ground water or collected samples.

The design of the ground water monitoring system must be based on site-specific information. Lithology and grain sizes of geologic formations drilled through should be used to determine proper packing and sealant materials. In addition, the screen length for the interval to be monitored should be determined from the stratigraphy of the site location.

Monitoring well casing and screen materials may be constructed of any of several types of materials, but should meet the following requirements:

- Monitoring well casing and screen materials should maintain their structural integrity and durability in the environment in which they are used over their operating, closure and post-closure life.

- Monitoring well casings and screens should be able to withstand the physical forces acting upon them during and following their installation and use including forces due to suspension in the borehole, grouting, development, purging, pumping, and sampling and forces exerted on them by the surrounding geologic materials.

- Monitoring well casing and screen materials should not chemically alter ground water samples, especially with respect to the chemical constituents of concern, as a result of any sorbing, desorbing, or leaching of analytes from the well casing or screen into the sample being collected.

- Monitoring well casing and screen materials should be relatively easy to install into the borehole during construction of the well.

For facilities located in karst terrain, EPA is also proposing that a ground water monitoring strategy include, where necessary, seeps, springs, and caves which are the ultimate discharge points of the karst ground water basin in which the facility is located. Monitoring wells are rarely effective when used in karst terrains with conduit flow, and supplemental monitoring points (such as seeps, springs, and cave springs) should be used in conjunction with point of compliance wells to detect releases from the CKDLF unit.

Because more than half of all cement facilities in the USA are located above limestone formations in potentially karstic terrains, there is an increased probability that ground water will experience conduit flow beneath these sites. The Agency recognizes that designers of ground water monitoring systems at CKDLF units in karst terrains face special challenges since contaminants can potentially migrate long distances through open conduits with little attenuation, adsorption, and dispersion occurring. Ground water flowpaths may also be more difficult to locate and may require the use of dye tracer studies. In addition, the number and organization of drains in the flooded or saturated part of the karst aquifer may vary over relatively short distances, thus affecting the transmissivity values of the aquifer throughout the site. These considerations highlight the need to conduct thorough site characterizations at CKDLF units before installing ground water monitoring systems. Guidance on designing appropriate ground water monitoring systems in karst terrains and in conducting dye tracer studies is available in *RCRA Ground Water Monitoring: Draft Technical Guidance* (USEPA, 1992) and *Ground-Water Monitoring in Karst Terranes: Recommended Protocols and Implicit Assumptions* (USEPA, 1989a).

7.2.2.2 Ground Water Sampling and Analysis

Ground water sampling and analytical methods used must be able to provide accurate and precise measurements of indicator chemical constituents and physical parameters over time. Similarly, protocols should be developed to ensure that sample collection, preservation, shipment, and storage is always performed in a consistent manner. These factors as well as chain-of-custody control, quality control and quality assurance procedures are necessary to ensure the validity of the results of the ground water monitoring program.

During detection monitoring, samples should be collected at least semiannually. The frequency of sampling should be based on site-specific hydrogeologic conditions. Background characterization should include at least four independent samples at each monitoring well during the first semiannual round of sampling. More frequent sampling may be appropriate to evaluate seasonal effects on ground water quality. Owners or operators of a CKDLF unit should select a sample collection frequency that facilitates collection of a data set that is statistically independent of the previous set. Guidance on the collection of statistically independent ground water samples in provided in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance* (USEPA, 1989b)

Water level elevations must be measured at all wells prior to sampling. Measurements should be taken in a time frame that avoids changes that may occur due to barometric pressure changes, significant infiltration events, or aquifer pumping. Water level measurement devices must be decontaminated prior to use at each well to prevent cross-contamination at wells.

Well purging should be accomplished by using a pump to slowly remove ground water from the well. Bailers should be avoided because of their “plunger” effect resulting in continual development or overdevelopment of the well. Wells should be purged at or below their recovery rate to prevent migration of water in the formation above the well screen. All purging equipment must be decontaminated prior to use.

Sample collection equipment should be made of inert materials to preserve sample integrity. The use of dedicated sample equipment for each monitoring well is recommended to prevent cross-contamination problems arising from improper decontamination procedures. Further guidance on ground water sampling methodology is provided in *RCRA Ground Water Monitoring: Draft Technical Guidance* (USEPA, 1992) and *Ground-Water Monitoring in Karst Terranes: Recommended Protocols and Implicit Assumptions* (USEPA, 1989a).

7.2.2.3 Statistical Analysis of Ground Water Monitoring Data

The proposed rule for CKD requires the owner or operator of a CKDLF unit to determine whether or not there is a statistically significant increase over background levels for each parameter and constituent the owner or operator is required to monitor for under the appropriate program (i.e., detection monitoring, assessment monitoring, or corrective action). The owner or operator is required to make these statistical determinations each time he or she assesses ground water quality. In making this comparison, the owner or operator must apply a statistical procedure specified in the proposed rule and make a determination of whether there has been a statistically significant increase or decrease over background within a reasonable time period, set by the State, after completing sampling.

In deciding which statistical test is appropriate, the owner or operator will need to consider the theoretical properties of the test, the characteristics of the data, and site-specific conditions such as the hydrogeology and the fate and transport characteristics of the potential contaminants. The owner or operator must also ensure the selected test(s) meets the performance standards established for statistical methods. Guidance on choosing appropriate statistical methods can be found in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance* (USEPA, 1989b) and in *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Addendum to Interim Final Guidance* (USEPA, 1992)[1]. EPA also offers software, entitled the *Ground-Water Information Tracking System (GRITS) with Statistical Analysis Capability, GRITS/STAT* Version 5.0.[2]

7.2.2.4 Detection Monitoring

At least four independent samples from each background and downgradient well must be collected and analyzed during the first semiannual sampling event. This is required because almost all statistical procedures are based on the assumption that samples are independent of each other and therefore reflect the true range of natural variability in ground water. Replicate samples are not considered to be statistically independent measurements. The detection monitoring program must include monitoring for pH, conductivity, total dissolved solids, potassium, chloride, sodium, and sulfate.

To account for seasonal differences, it may be necessary to collect the independent samples over a range of time. The sampling interval chosen must ensure that sampling is being done on different volumes of ground water. This may be achieved by determining the velocity of ground water at the site using site data for effective porosity, hydraulic conductivity, and hydraulic gradient. Additional information on establishing the sampling interval can be obtained from *Statistical Analysis of Ground-Water Monitoring Data at RCRA Facilities - Interim Final Guidance* (USEPA, 1989b). During each subsequent sampling event, the same requirements will apply except that only one sample must be collected and analyzed from each background and downgradient well.

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[1] EPA's guidance documents on the statistical analysis of ground water monitoring data currently are being updated into a unified guidance document. The draft Unified Guidance is in peer review as of 3/18/98. Contact Hugh Davis, OSW PSPD.

[2] GRITS/STAT is available for free on EPA's World Wide Web site at: http://www.epa.gov/epaoswer/hazwaste/ca/gritsstat/gritsstat.htm

If statistical analyses show that downgradient monitoring points have a statistically significant increase over background for one or more indicator parameters, the owner or operator must (a) note the finding, identify the indicator parameter(s) in the operating record, and inform the State of the notice in the operating record within 14 days, and (b) establish an assessment monitoring program.

If an owner or operator can successfully demonstrate that the statistically significant increase is the result of sampling error, analysis, statistical evaluation, or natural variation in ground water quality, this demonstration must be certified by a qualified ground water scientist or approved by the State and placed in the operating record. The owner or operator may then continue with a detection monitoring program. If the owner or operator cannot file a successful demonstration within 90 days, an assessment monitoring program must be initiated.

7.2.2.5 Assessment Monitoring

During an assessment monitoring program, at least one sample must be collected and analyzed from each downgradient well during each sampling event. If assessment monitoring confirms the detection of any of the release parameters specific in the rule (see Table 5-3 in this background document), at least four samples must be collected from each background and downgradient well and analyzed to determine background concentrations for that constituent. In addition, within 14 days of the detection, the owner or operator must place a notice in the operating record identifying the detected indicator parameter(s) and notify the State that the notice has been placed in the operating record.

If for two consecutive sampling events the concentrations of all assessment monitoring parameters identified in Table 5-3 are shown to be at or below background values using the statistical procedures in Section 7.2.3, the owner or operator shall notify the State and resume detection monitoring. If, based upon the results of statistical tests, assessment monitoring parameter concentrations are above background concentrations but below ground water protection standards (see Section 5.4.5), assessment monitoring must be continued. If the concentrations of any assessment monitoring parameters are detected at statistically significant levels above the ground water protection standards established in Section 5.4.5 in any sampling event, the owner or operator must, within 14 days of the finding:

- place a notice in the operating record identifying the indicator parameter(s) exceeding the ground water protection standards,
- inform the State and appropriate local government officials that the notice has been placed in the operating record,
- install additional monitoring wells to characterize the nature and extent of the release,

- install and sample at least one additional monitoring well at the facility boundary along the direction of contaminant migration,
- notify land owners or residents on land directly above the contaminant plume of the off-site contaminant migration, and
- begin an assessment of corrective measures within 90 days.

In the event that an owner or operator can successfully demonstrate that a source other than the CKDLF unit caused the contamination or that the statistically significant increase is the result of sampling error, analysis, statistical evaluation, or natural variation in ground water quality, this demonstration must be certified by a qualified ground water scientist or approved by the State and placed in the operating record. The owner or operator may then continue the assessment monitoring program as specified in this section. Detection monitoring may be resumed if indicator parameters are at or below background concentrations. If the owner or operator cannot file a successful demonstration, the assessment monitoring program must continue and an assessment of corrective actions be initiated.

The Agency is proposing a ground water protection standard to be the MCL (if available) or the background concentration if background is greater than the MCL. If an MCL has not been established for a constituent, the background concentration will be used as the ground water protection standard. Available MCL values for constituents of concern are listed in Table 5-3, and site-specific background concentrations are obtained by sampling hydraulically up-gradient wells as discussed in Section 5.4.2.

7.3 Corrective Action

The proposed rule addressing CKD requires corrective action at active CKDLF units that exhibit a statistically significant exceedance of ground water protection standards. The proposed rules for corrective action are similar to corrective action requirements for municipal solid waste landfills (MSWLF), and give owners and operators lead responsibility for initiating, planning, and implementing remedial activities under state supervision. The goals of corrective action at active CKDLF units are to (1) address existing releases, and (2) contain possible future releases before environmental damages or health risks occur.

EPA is proposing corrective action for CKDLFs based upon empirical data and a series of risk modeling studies that demonstrate significant risks to human health and the environment from releases of CKD constituents into the environment. Existing regulatory authorities have led to effective cleanups for some units. However, implementation of cleanups varies significantly from state to state, and EPA believes there is a general lack of consistent regulations to address releases of CKD constituents in a timely manner.

CKD cleanups under existing authorities have shown that karst terrain, fractured bedrock, and other site-specific factors can pose significant challenges to effective remediation. Because of these challenges, the proposed regulations provide owners and operators with flexibility in selecting appropriate remedies and remedial schedules. In addition, the regulations include a practicability determination procedure to allow alternate response strategies when ground water protection standards can not be attained with available technologies.

7.3.1 Need for Regulation and Regulatory Options Considered

As described in Section 2.1, EPA has documented at least 16 cases of damage to surface water and/or ground water resulting from existing CKD management practices. In addition, the Agency estimates that about 80 percent of the cement plants in the U.S. are located in areas with karst terrain or fractured bedrock, where there is an increased risk to ground water from CKD disposal (See Table 2-3 in Section 2 of this background document). Based on these concerns, EPA's CKD regulatory determination (60 *FR* 7366) concluded that additional environmental controls are warranted to address "the existence of damages to ground water and air that are persistent and continuing, and for which no requirements exist to address the risks posed via these pathways."

The proposed corrective action requirements for CKDLFs are based on RCRA Subtitle D corrective action requirements for MSWLFs. The proposal also is similar to Subpart F (rather than Subpart S) corrective action requirements under RCRA Subtitle C in that remedial responses are directed at releases from CKDLFs, rather than all potential sources at the facility. A comparison of selected features of these various approaches is provided in Table 7-1.

Table 7-1. Comparison of Corrective Action Programs

	Subtitle C		Subtitle D	Proposed Rule for CKD	
	Regulated Units (40 CFR 264 Subpart F)	SWMUs (Proposed 40 CFR 264 Subpart S)	MSWLF	CKDLFs containing waste-derived and characteristically hazardous CKD	All other CKDLF Units
Affected Media	Ground Water	All Media	Ground Water	All Media	Ground Water
Facility-wide or unit-specific corrective action required?	Unit-specific	Facility-wide	Unit-specific	Same as Subtitle C	Unit-specific
Point of compliance (POC)	Hydraulically downgradient limit of the waste management area	Unit and medium-specific (based on migration and exposure potential)	Up to 150 meters downgradient of unit boundary	Same as Subtitle C	Up to 150 meters downgradient of unit boundary
"Trigger" for Corrective Action	GWPS exceeded at or beyond POC	Media-specific (health and environmentally-based levels)	GWPS exceeded at or beyond POC	Same as Subtitle C	GWPS exceeded at or beyond POC
Cleanup Standard	GWPS or cleanup level specified in permit	Concentrations in GW, SW, air, or soil that provide long-term protection of HHE	GWPS (i.e., MCL, alternate compliance limit, or background)	Same as Subtitle C	GWPS (i.e., MCL, or background)

GWPS = ground water protection standard
POC = point of compliance
SWMU = solid waste management unit
HHE = human health and the environment
MSWLF = municipal solid waste landfill
CKDLF = cement kiln dust landfill
GW =ground water
SW = surface water

As EPA has demonstrated in the proposed rule, CKD meets the hazardous waste listing criteria, and EPA considered subjecting CKDLFs to the Subpart F corrective action requirements (40 CFR 264.90-264.101). However, the proposed corrective action approach based on Subtitle D provides environmental protection equivalent to Subpart F with less regulatory burden and more flexibility for owners and operators. For example, [insert example of burden reduction estimate when available]. Further, the Agency believes that existing state laws and federal imminent hazard authorities under Section 7003 of RCRA and Section 106 of CERCLA should be adequate to address any genuine threats to human health and the environment.

In addition, EPA evaluated whether deferral to existing state remedial authorities would be an acceptable alternative to new corrective action rules for CKDLFs. As described in Chapter 2, EPA determined that existing state authorities do not correct contaminant releases from CKDLFs adequately or uniformly. Therefore, national corrective action standards are warranted.

EPA's approach to corrective action for CKDLFs is consistent with lessons learned from sites where remedial activities have been performed. In particular, remediation of some CKDLFs has been complicated by their large size, common proximity to wetlands or other surface waters, and frequent siting on karst terrain or fractured geologic media. These complications necessitate a flexible remedy selection procedure suited to site-specific conditions. Also, remedy selection and implementation must be adaptive to difficulties encountered and the limitations of available remedial technologies.

Because site-specific flexibility is needed, the proposed corrective action rules do not prescribe extensive remedy design criteria (e.g., cap materials), but provide performance-based standards and evaluation criteria to guide owners and operators in developing and implementing remedial programs. This approach gives CKDLF owners and operators flexibility to select remedies appropriate to site-specific conditions, with minimal direction from EPA or state regulators.

7.3.2 Implementation and Technical Considerations for Corrective Action

EPA expects that remedial activities implemented under CKD corrective action will be similar to remedies implemented under existing authorities, except that no corrective action is required for inactive CKDLFs (i.e., units not accepting CKD waste after the effective date of the rule.) Although the proposed CKD rule will not significantly increase the stringency of remedies, it is likely to cause additional cleanups to occur in the event of a release. Additional cleanups are expected because of the financial assurance requirements for corrective action, closures, and post-closure care in the proposed rule, and the provision for federal enforcement if CKD is not managed in compliance with the proposed standards. In addition, the proposed CKD rule will support more timely implementation of remedies at CKDLF where corrective action is needed.

The primary goal of CKD remedies under existing authorities has been to control leachate contamination of ground water and/or surface water. As discussed in Section 2.1.2, almost all existing CKDLFs were constructed without liner systems sufficient to protect ground water. Many of the CKDLFs are located in abandoned quarries, adjacent to surface waters, or in other settings where CKD may come into direct contact with ground water or surface water.

CKDLF remedies generally consist of in-place source control and ground water remediation. Source control usually includes placing a clay or synthetic cap over the landfill, and may also include slurry walls, interceptor trenches, drain systems, or run-on/run-off controls. Remediation of contaminated ground water has been performed by installing recovery wells or trenches to intercept contaminant plumes. Ground water remediation is complicated at many CKDLF sites by karst aquifers or fractured geologic media. High hydraulic conductivities are frequently encountered in both karst aquifers and fractured geologic media, and these conditions may require treatment and removal of large quantities of contaminated ground water during site remediation. For example, at the Holnam facility in Mason City, IA, a drain system and ground-water extraction wells were required to collect runoff and ground-water inflow and prevent migration of contaminated ground water from the quarry in which CKD was disposed (see Section 2.1).

In-place remedies have been favored for CKDLFs, because of large waste volumes and the difficulty of handling wet CKD. This explains why none of the source control remedies implemented at damage case sites has included retrofitting landfills with liners. For the same reasons, it is uncommon for CKD to be excavated for off-site treatment or disposal. An exception is the Portland Cement Company site in Salt Lake City, Utah, which is currently being remediated under CERCLA authority. The heavily urbanized setting of this site was a major reason for removing CKD waste materials from the site. At least 750,000 tons of CKD and CKD-contaminated debris have been shipped to an off-site RCRA Subtitle D landfill, and 109 tons of chromium-contaminated brick have been removed to a RCRA Subtitle C landfill (USEPA, 1997).

The corrective action provisions of the proposed CKD rule will allow remedy selection to continue on a case-by-case basis, with recognition of site-specific factors such as existing environmental controls, potential risks, and hydrogeological conditions. EPA believes this approach will produce swift and effective cleanups, yet provide flexibility for the inherent difficulties (e.g., karst terrain, large waste volumes) of remediating many CKDLFs. The remainder of Section 7.3 describes the three steps in the proposed CKD corrective action program: assessment of corrective measures, remedy selection, and remedy implementation.

7.3.2.1 Assessment of Corrective Measures

Under the proposed CKD rule, the corrective action process is initiated by owners or operators of CKDLFs within 90 days of detecting a hazardous constituent (listed in Appendix VIII of 40 CFR Part 261) during assessment monitoring at a statistically significant level exceeding the ground-water protection standard. The objective of this step is to identify and analyze potential remedies and to discuss them with interested and potentially affected parties. The assessment of corrective measures addresses at least the following:

(1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination;

(2) The time required to begin and complete the remedy;

(3) The costs of remedy implementation; and

(4) The institutional requirements such as State or local permit requirements or other environmental or public health requirements that may substantially affect implementation of the remedy(s).

The CKDLF owner or operator must complete the assessment of corrective measures within a reasonable period of time and continue monitoring in accordance with the assessment monitoring program while the assessment of corrective measures is underway. In addition, the CKDLF owner or operator must hold a public meeting to discuss the results of the assessment of corrective measures before proceeding to remedy selection.

7.3.2.2 Selection of Remedy

The proposed remedy selection process is performed by the CKDLF owner operator based on the results of the assessment of corrective measures, public input, and remedy selection standards specified in the proposed rule. Within 14 days of completing a remedy selection report, the CKDLF owner or operator must notify the State Director and describe how the remedy meets the required standards.

Remedy selection standards for CKDLFs are essentially the same as remedy selection for MSWLFs. Specifically, the remedies must meet the following four standards:

(1) Be protective of human health and the environment;

(2) Attain the ground water protection standards (see Section 5.4.5);

(3) Control the source(s) of releases so as to reduce or eliminate, to the maximum extent practicable, further releases of selected Appendix VIII constituents into the environment that may pose a threat to human health or the environment; and

(4) Comply with standards for management of wastes (i.e., protective of human health and the environment and fulfills applicable RCRA requirements).

In addition, the remedy selection must take these factors into consideration:

(1) Long- and short-term remedy effectiveness and protectiveness;
(2) Source control effectiveness;
(3) Ease or difficulty of implementation;
(4) Technical and economic practicability; and
(5) Community concerns.

The remedy selection provisions of the proposed CKD rule give owners or operators flexibility to schedule the initiation and completion of remedial activities. However, the proposed remedy must include a schedule that requires initiation of remedial activities within a reasonable amount of time.

7.3.2.3 Implementation of Remedies

The proposed rules for implementing corrective action at CKDLFs define when and how remedial actions are determined to be complete, and guide owners or operators who are unable to comply with remedial standards.

CKDLF owners and operators must implement a corrective action ground water monitoring program that will measure the effectiveness of the remedy in attaining the ground water protection standards. Remediation is complete when ground water protection standards are met (based on statistical procedures) for three consecutive years at all points within the contaminant plume that lie beyond the ground water monitoring well and spring system. The number and placement of wells for corrective action monitoring must meet the minimum requirements of the assessment monitoring program.

EPA recognizes that some owners and operators of CKDLFs may not be able to meet the standards for completing corrective action. In particular, ground water recovery systems may have limited effectiveness at sites with non-Darcy or conduit ground water flow (e.g., sites located in areas with karst aquifers or highly fractured geologic media). In such cases, the proposed rules include a practicability determination process that allows owners and operators to implement alternate remedies with state approval. EPA considers this flexible approach a necessity, because 79 of the 110 cement plants in the U.S. are estimated to be located in areas characterized by karst hydrogeology. An additional 9 cement plants are located in non-karst areas with moderate to high potential for non-Darcy conduit ground water flow due to fractured bedrock aquifers. In all, about 80 percent of the cement plants in the U.S. are located in areas that potentially have non-Darcy ground water systems.

At some CKDLFs where damage has occurred, interim measures have been required and implemented to control continuing releases before the initiation of full-scale remedies. For example, Ash Grove Cement (Chanute, KS) instituted immediate control measures including surface regrading and interim trench pumping after leachate discharges were found flowing into a tributary to Village Creek. National Gypsum Company implemented interim controls to prevent further erosion and deposition of contaminants into Lake Huron. Consistent with these examples, the proposed CKD corrective action rules require interim measures as necessary to protect human health and the environment.

7.3.3 Applicability of Corrective Action Regulations

7.3.3.1 Active Units

The proposed CKD rule lists CKD that is disposed after 90 days following publication of the final rule as a hazardous waste unless it qualifies for a conditional exemption from RCRA Subtitle C regulations as a result of management in accordance with specified requirements, including design and operating standards and corrective action requirements. However, if the CKD is derived from burning hazardous waste and the CKD exhibits a hazardous waste characteristic, then it can not be exempt from the RCRA Subtitle C requirements.

The proposed corrective action standards apply to both new units and to existing units that receive CKD waste after the effective date of the rule and are expanded laterally or vertically. EPA anticipates that, with few exceptions, existing CKDLF units that are actively managed after the effective date of the rule will be required to perform corrective actions, as necessary, according to the methodology summarized in Section 7.3.2. New or existing CKDLF units, or lateral expansions, that receive less then 10 tons of CKD per week, based on an annual average, are exempt from the design criteria, ground water monitoring, and corrective action provisions of the proposed rule, as long is there is no evidence of ground water contamination.

For listed CKD that is not managed in accordance with the specified requirements in the proposed rule, additional RCRA Subtitle C requirements are also specified (i.e., a RCRA hazardous waste permit would be required under 40 CFR Part 270). However, these additional requirements would be specific to CKDLFs in use after the effective date of the rule and do not include facility-wide corrective action requirements.

7.3.3.2 Inactive Units

The proposed corrective action provisions do not apply to CKDLFs that are not actively managed after 90 days following publication of the final regulations. Existing state and federal (e.g., CERCLA) authorities will continue to govern cleanups at closed or inactive CKDLFs. Closed or inactive CKDLFs at facilities that are subject to full RCRA Subtitle C requirements (due to treatment, storage, or disposal of characteristically hazardous CKD or other activities that require a RCRA Subtitle C permit, such as hazardous waste treatment) are subject to the corrective action requirements of Subtitle C, including 40 CFR 264.90, 40 CFR 264.101, and Subpart S of 40 CFR 264.

Based on a screening-level analysis, the Agency estimates that at the close of 1995 there were approximately 740 inactive CKD piles at the 110 U.S. cement plants that are currently (i.e., as of 1998) active. The Agency further estimates that approximately 90 million metric tons of CKD are stored in these inactive piles. These estimates were compiled using data from the 1974, 1990, and 1993 editions of the Portland Cement Association's Plant Information Summary and PCA's 1991 PCA Cement Kiln Dust Survey. A explanation of the methodology used to prepare these estimates is provided in SAIC (1996). The five states with the greatest number of inactive CKD piles at active facilities are presented in Table 7-2.

Table 7-2.
Five States with the Estimated Greatest Number of Inactive CKD Piles at Active Facilities

State	Estimated Number of Inactive CKD Piles
Pennsylvania	118
California	87
Texas	43
Illinois	39
South Carolina	35

7.3.3.3 Waste-Derived CKD

The proposed corrective action provisions are not applicable to CKD that exhibits a characteristic of a hazardous waste and is waste-derived (i.e., generated using hazardous waste as fuel). According, the proposed rule essentially maintains in place the rules for CKD from hazardous waste burners that exist currently under 40 CFR, Part 266.

7.3.4 Benefits of Corrective Action

The proposed corrective action standards for CKD will protect the public from human health risk and prevent environmental damage resulting from current CKD disposal practices. EPA believes that the proposed corrective action standards are fully protective of human health and the environment while avoiding unnecessary regulatory burden and cost.

Although some releases from CKDLFs have been remediated successfully under existing authorities, there are a number of CKDLFs with known damages at which only limited or no remedial action has been performed. The proposed corrective action provisions will cause some of these CKDLFs to be cleaned up (if they remain active after the effective date) and will prevent significant environmental damages at CKDLFs where future releases occur. Additional benefits of EPA's proposed approach to corrective action include:

- Flexibility for owners and operators to select appropriate remedies and remedial schedules;
- Additional reduction of direct contact and inhalation exposures to CKD and its constituents resulting from ground water source control remedies; and

- Improved compliance with state and federal air and water quality standards and goals.

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