Contractor's Report to the Board

Landfill Facility Compliance Study Task 8 Report—Summary of Findings and Comprehensive Recommendations

August 2004

Produced under contract by:

GeoSyntec Consultants, Inc.
Oakland, California

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The information contained herein is based on the contractor's interpretation of comments provided by landfill owners and operators and regulators and of existing regulations and documentation available on the topics discussed at the time the report was written.

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1 Executive Summary

This report represents the culmination of the California Integrated Waste Management Board's (CIWMB) contracted Landfill Facility Compliance Study. This study is the most comprehensive cross-media inventory ever undertaken of California landfills, involving multiple regulatory agencies in measuring the overall environmental effects of MSW disposal in California. The study is a unique, two-phase, cross-media study of the state's municipal solid waste (MSW) landfills. Phase I of the study consists of a comprehensive, cross-media inventory and assessment of the environmental performance of MSW landfills for the time period from January 1998 through December 2001. Phase II consists of an assessment of the effectiveness of current regulatory requirements for control of environmental impacts over time and identification of possible ways to improve regulations to provide for greater environmental protection.

In addition to presenting findings from the study[*], this report also recommends improvements or enhancements to California's multimedia regulation of MSW landfills that could result in greater environmental performance (Phase II). The process of performing the Landfill Facility Compliance Study was complex. It included the collection and evaluation of cross-media data from 224 California landfills (Phase I). Fifty-three landfills were evaluated in additional detail to address issues associated with existing regulations' ability to protect human health and safety and the environment (Phase II, Tasks 4 and 5). Regulations from other states and countries (Phase II, Task 6), as well as emerging landfill technologies being implemented worldwide (Phase II, Task 7), were evaluated for applicability to California. These tasks, complicated in their own right, were made even more challenging by the heterogeneous nature of the physical and social conditions in California and the complexity of California's regulatory structure. Developing recommendations for changes to California's existing landfill regulations and practices to accommodate the diversity and complexity of the state was a difficult undertaking. To address some of these difficulties, various approaches were used in collecting and analyzing information. The approaches are described for each of the tasks in Section 3 of this report. Selected findings and recommendations of the landfill study are discussed briefly below and in more detail in the remainder of this report, as well as in the previous reports developed for the study.

Phase I Environmental Performance Findings

Quantifying environmental performance is complex and difficult for any single site, and is even more complex and difficult when examining the performance of 224 sites with respect to each other. To address this difficulty, a simplified measure of environmental performance was developed for the analyses conducted as part of Task 3 (the Phase I report). Because regulation by the State is a factor common to all 224 sites, the actions taken by the various regulators were used as indicators of environmental performance. Information regarding the actions of each of the three primary regulators was used to derive five variables that served as indicators of environmental performance. One variable was developed to serve as an indicator for groundwater impacts, two for gas impacts, one for surface water impacts, and one for air quality impacts.

The experiences of Phase I demonstrated that this type of simplified approach could provide a relatively uniform and effective measure of environmental performance that

[*] Developed in Tasks 1–7 of the study.

allows for the rapid analysis of a wide range of site characteristics with respect to cross-media environmental performance. These types of variables, as described in Section 3.1 of this report and in greater detail in the Phase I report, could be used for future studies of statewide landfill environmental performance.

The results of the Phase I statistical analyses demonstrate that sites most likely to be in corrective action or to have water-related cleanup and abatement orders are larger, located in urban areas, at least partially unlined, and located in areas of higher-than-average precipitation. In contrast, small, rural, unlined sites in dry climates tend to have a lower occurrence of corrective action or water-related cleanup and abatement orders. The results of the statistical analyses further demonstrate that landfills in drier climates tend to have fewer surface water compliance issues, including leachate seeps and excessive erosion. Additionally, sites that have undergone closure have a significantly lower occurrence of surface water actions.

The Phase I results also show the typical MSW landfill in California is publicly owned, active, located inland, fully unlined or partially unlined in the case of active sites, fully uncovered, and has no gas collection system. The typical site is underlain by sand and/or gravel, has a minimum depth to underlying groundwater of 34.5 feet, and receives an average annual precipitation of 16 inches.

The Phase I results also show the majority of MSW landfills are unlined. Sixty-two percent of the landfills studied (138 landfills) were fully unlined, while 1.8 percent (4 landfills) were fully lined with Subtitle D[†] liners. The remaining had a combination of liner types. Note that if closed and inactive sites are excluded from this tally, fully unlined sites are reduced to approximately 52 percent of the total.

Phase II Regulatory Assessment and Recommendations

Numerous recommendations have been developed in conjunction with Phase II, and have been presented in detail in the Phase II report, Task 6 report, and Task 7 report. Some of the recommendations are for changes to the existing landfill regulations, some are for additional study prior to implementing any changes to the regulations, and some are for changes to industry practices without changes to the regulations. Section 3 summarizes these recommendations. All of these recommendations were evaluated with respect to the potential benefit to the environmental performance of landfills if implemented in California. Four of the Phase II recommendations were identified as having immediate tangible benefits to the environmental performance of landfills.

The four recommendations are summarized as follows:

1. It is recommended that landfill gas monitoring be either explicitly incorporated into the regulations as part of the detection monitoring program for water quality to address the recurring issue of impacts of landfill gas on groundwater, or promoted to encourage this practice through the regulatory agencies.

2. It is recommended that the regulatory agencies promote monitoring for explosive gases in the vadose zone closer to the waste mass at sites with larger buffers, to address the issue of landfill gas impacts to groundwater, as well as the migration of explosive gases.

[†] Also known as Subtitle D of the federal Resource Conservation and Recovery Act. Refers to requirements found in Title 40, Part 258 (40 CFR, Part 258) of the Code of Federal Regulations.

3. It is recommended that requirements regarding monitoring and control of landfill gas to protect against the impacts of landfill gas migration be as comprehensive during the active life of the landfill as they currently are for the post-closure care period.

4. It is recommended that all landfills be either explicitly required to submit a winterization plan annually for review and approval by the enforcement agency (EA) with the concurrence of the regional water quality control board (RWQCB) to provide additional protection or promoted to encourage this practice through the regulatory agencies.

The remaining recommendations were not included because the potential environmental protection benefit associated with the recommended change is not readily apparent when compared to current practices or regulations, or substantial additional study is required prior to implementation of the recommended change.

Implementing these recommendations will require greater coordination among regulators than is done under the existing regulations. Each of these recommendations requires the cooperation of multiple agencies, which, under the existing structure, have separate, divided responsibilities.

2 Introduction

This report presents the results of work completed by GeoSyntec Consultants, Inc. (GeoSyntec) and its subcontractors under Task 8 of Phase II of the Landfill Facility Compliance Study[‡] for the CIWMB.

The landfill study consists of two phases.

- Phase I includes Tasks 1–3 (compiling a checklist of pertinent environmental regulatory requirements, developing a cross-media database inventory of 224 California MSW landfills, and assessing MSW landfill environmental performance for the time period from January 1998 through December 2001).
- Phase II consists of Tasks 4–8 (these tasks include assessing the effectiveness of current regulatory requirements in controlling environmental impacts over time and identifying possible ways to improve regulations to provide for greater environmental protection).

2.1 Purpose and Organization of This Report

This report represents the culmination of the Landfill Facility Compliance Study and presents comprehensive cross-media findings on the environmental performance of MSW landfills in California and the assessment of current regulatory effectiveness in protecting the environment over time, as well as recommend improvements or enhancements to California's multimedia regulation of MSW landfill that could result in greater environmental performance.

The various findings were presented in previous reports prepared for the study (Tasks 1–7). Based on these findings, recommendations were developed for possible improvements or enhancements to California's multimedia regulation of MSW landfills that could result in greater environmental performance of the state's MSW landfills. Recommendations were also developed for changes to landfill practice in California, (including design and operations) that, while not associated with specific regulatory requirements, could result in improved environmental performance of the state's MSW landfills. The Task 8 report provides a summary of some of the findings and all of the recommendations presented in the previous reports, and, based on an evaluation of all of the findings, identifies those recommendations that are expected to have the most immediate tangible benefits to the environmental performance of landfills if implemented in California. The report also identifies indicators that could be used to track ongoing environmental performance for possible inclusion in a single statewide database system.

Section 2.2 presents the structure and goals of the Landfill Facility Compliance Study. Section 2.3 provides a brief summary of California's regulatory structure. Section 3 presents the methodology and the primary findings and recommendations of each of the previous reports submitted for this study. These findings are considered collectively, and those recommendations that could result in immediate tangible benefits to environmental performance are presented in Section 4.

[‡] A description of the Landfill Facility Compliance Study and progress updates may be found on the CIWMB's website at www.ciwmb.ca.gov/Landfills/.

2.2 Structure and Goals of the Landfill Facility Compliance Study

The Landfill Facility Compliance Study was commissioned by the CIWMB as a unique, two-phase, cross-media study of the state's MSW landfills. Phase I of the study consists of a comprehensive, cross-media inventory and assessment of MSW landfill performance for the time period from January 1998 through December 2001. Phase II consists of an assessment of the effectiveness of current regulatory requirements in controlling environmental impacts over time and identifying possible ways to improve regulations that could result in greater environmental protection. This study is the most comprehensive inventory ever undertaken of California landfills, involving multiple regulatory agencies in measuring the overall environmental effects of solid waste disposal in California.

The study is comprised of eight tasks. Tasks 1–3 make up Phase I of the study, and Tasks 4–8 make up Phase II of the study. The purpose of each of the tasks is defined in the remainder of this section.

Task 1: Checklist of Pertinent Environmental Regulatory Requirements: The purpose of this task was to compile in one document the local, State, and federal environmental regulations governing MSW landfills in California. Each requirement is listed, including who enforces it and the environmental media affected. This summary was presented to the CIWMB in April 2002 (GeoSyntec, 2002) and can be accessed online at www.ciwmb.ca.gov/Publications/default.asp?pubid=934.

Task 2: Cross-Media Inventory of Existing California Landfills: The purpose of this task was to provide a comprehensive, cross-media inventory of information for MSW landfills in California. The 224 landfills included in the inventory have accepted waste since October 9, 1993. This date was chosen as the cutoff date, since it was the effective date for Part 258 of Title 40 of the Code of Federal Regulations (40 CFR, Part 258), also known as Subtitle D, which was the first comprehensive federal standard for MSW landfills. The information in the inventory includes general site characteristics and environmental performance information for the period from January 1998 through December 2001. The inventory was finalized in April 2003 and posted online at www.ciwmb.ca.gov/landfills/complystudy/DB/default.asp.

Task 3: Screening Analyses of 224 California MSW Landfills: The purpose of this task was to assess the environmental performance of the 224 landfills included in the Task 2 cross-media inventory by developing a census of landfill characteristics and performing a screening analysis of environmental performance using statistical methods. The results of the census and screening analysis were summarized in a Phase I report that was presented to the CIWMB in December 2003 (GeoSyntec, *Phase I Report*, 2003), and can be accessed online at www.ciwmb.ca.gov/Publications/default.asp?pubid=1046.

Task 4: Collection of In-Depth Information of 53 Selected Landfills: The purpose of this task was to collect additional information on 53 MSW landfills regarding environmental controls and performance, beyond what was compiled in the Task 2 cross-media inventory, to better understand why a landfill is not in compliance and if the lack of compliance is related to current regulation. The 53 landfills consist of 40 landfills selected from the 224 included in Task 2, as well as 13 selected landfills that closed prior to 1993. The collected information for each of the 53 sites will be available online in early September 2004 at www.ciwmb.ca.gov/Landfills/ComplyStudy/Landfills/InDepth/.

Task 5: Evaluation of Regulatory Effectiveness Based on a Review of 53 MSW Landfills: The purpose of this task was to evaluate the effectiveness of the current California MSW landfill regulations in controlling environmental impacts over time by using the 53 select landfills as case studies. The information compiled in Task 4 was reviewed to identify recurring issues of environmental performance that may be associated with deficiencies in the existing landfill regulations. Recommendations for changes to the existing multimedia landfill regulations that could result in greater environmental protection were summarized in a Phase II report presented to the CIWMB in June 2004 (GeoSyntec, May 2004). The report can be accessed online at www.ciwmb.ca.gov/Publications/default.asp?pubid=1083.

Task 6: Review of MSW Landfill Regulations From Selected States and Countries: The purpose of this task was to identify those elements of other state and country MSW regulations that, if adopted in California, could improve or enhance California's multimedia regulation of MSW landfills. The existing landfill regulations for eight states and five countries were reviewed. Recommendations for changes to California's existing landfill regulations were developed and summarized in a report that was presented to the CIWMB in April 2004 (GeoSyntec, March 2004), which can be accessed online at www.ciwmb.ca.gov/Publications/default.asp?pubid=1079.

Task 7: Study of Emerging Technologies in Waste Management for MSW Landfills: The purpose of this task was to identify new, emerging, and advanced technologies, as well as new approaches, that if applied in California could possibly improve and/or enhance the operation of California's landfills. Several technologies most applicable to California were identified and summarized in a report that was presented to the CIWMB in December 2003 (GeoSyntec, *Task 7 Report*, December 2003), which can be accessed online at www.ciwmb.ca.gov/Publications/default.asp?pubid=1058.

Task 8: Summary of Findings and Comprehensive Recommendations: The purpose of this report is to compile the findings of the previous tasks and develop a comprehensive set of recommendations for possible improvements or enhancements to California's multimedia regulation of MSW landfills that could result in greater environmental performance. In addition, this report identifies indicators that could be used to track ongoing environmental performance for possible inclusion in a single statewide database system. The final project report was presented to the CIWMB in June 2004 and can be accessed online at: www.ciwmb.ca.gov/Publications /default.asp?pubid=1082.

2.3 California Regulations and Regulatory Agencies

Regulation of California's MSW landfills is the responsibility of several regulatory bodies, including the CIWMB, the State Water Resources Control Board (SWRCB) which promulgates water quality protection regulations, the 9 RWQCBs which apply the SWRCB's regulations, and the 35 local air quality management districts (AQMD) and air pollution control districts (APCD). California is currently enforcing regulations with respect to siting, design, operations, monitoring, post-closure, and landfill gas control, as set forth in the California Code of Regulations[§] (CCR) (Title 27, Division 2), SWRCB

[§] GeoSyntec's source for information on Title 27 of the California Code of Regulations was the regulatory text approved by the Office of Administrative Law on June 18, 1997: "Combined SWRCB/CIWMB Regulations Division 2, Title 27," California Integrated Waste Management Board, Sacramento, California. The text is available on CIWMB's website at www.ciwmb.ca.gov/RuleArchive/1997/AB1220/ ("AB 1220 Regulations in Title 27").

Resolution Number 93–62, the federal Subtitle D regulations (40 CFR, Part 258), and 40 CFR, Part 60, Subparts Cc and WWW.

The promulgation of the regulations in 27 CCR, Division 2 is divided between the CIWMB and the SWRCB. At the local level, EAs enforce CIWMB regulations and RWQCBs enforce SWRCB regulations.

In California, the 35 local AQMDs and APCDs have primary authority to regulate emissions from MSW landfills. Each district is responsible for developing and enforcing air quality regulations within its district. The Air Resources Board (ARB) provides technical support to the districts and oversees local district compliance with State and federal law. A complete discussion of California's regulatory requirements can be found in the Landfill Facility Compliance Study Task 1 report (GeoSyntec, 2002).

2.4 Glossary and Acronyms

The following terms are used throughout the body of this report. For purposes of this report these terms have the following meanings:

- **Aerobic degradation/digestion:** Reduction of the waste mass by biochemical processes (for example, growth of bacteria) that occur in the presence of oxygen.
- **Anaerobic degradation/digestion:** Reduction of the waste mass prior to disposal by biochemical processes (for example, growth of bacteria) that occur in the absence of oxygen.
- **Capillary break:** A zone across which capillary tension (due to molecular attraction between soil particles and water) cannot be maintained because the space between the particles is too large.
- **Diffusion:** Dispersion of a mass through a medium by kinetic activity in the direction of the concentration gradient.
- **Double composite liner system:** Landfill base containment consisting of two single composite liner systems with a secondary leachate collection system/leak detection system in between the liners.
- **Double liner system:** Landfill base containment consisting of two liner systems (none of which must be a composite liner) with a secondary leachate collection system/leak detection system in between the liners.
- **Emissions:** Uncontrolled discharges of liquid, gas, or solid particles from a landfill to air, water, or land.
- **Evapotranspiration:** The evaporation and transpiration processes of vegetation planted on the ground surface that can minimize the infiltration of water through soil.
- **Head:** Pressure exerted by a column of liquid.
- **Landfill gas:** A product of the anaerobic microbial decomposition of organic waste, consisting principally of approximately 50 percent methane, 50 percent carbon dioxide, and typically less than 5 percent nonmethane organic compounds.
- **Mechanical-biological pre-treated waste:** The residual waste remaining after mechanical processing and biological pre-treatment has been performed.

- **Performance-based regulation / requirement:** A regulation or requirement defined with the intent to meet a particular performance criterion (for example, a requirement to design a geosynthetic component to survive tensile loading would be a performance-based requirement).

- **Phytoremediation:** The direct use of living green plants for in-situ risk reduction for contaminated soil, sludges, sediments, and groundwater, through contaminant removal, degradation, or containment.

- **Prescriptive regulation/requirement:** A regulation or requirement in which the specifics for how a component is to be constructed are defined (for example, a requirement for a single composite liner system consisting of a compacted clay liner (CCL) and a geomembrane liner with defined minimum thickness and hydraulic conductivity would be a prescriptive requirement).

- **Pyrolysis:** The thermal degradation of waste under controlled conditions at high temperatures in the absence of oxygen.

- **Single composite liner:** Landfill base containment consisting of a synthetic membrane barrier overlying a clay-based barrier layer that consists either of a compacted clay liner (CCL) or, where approved by the RWQCB, either a geosynthetic clay liner (GCL) or a combination of a GCL overlaying a CCL. The synthetic membrane component is subject to a minimum thickness requirement. When used without a GCL component, the CCL must meet a requirement for minimum thickness and maximum allowable hydraulic conductivity. Where allowed by the RWQCB, the term includes, an extra-thick synthetic membrane barrier overlying a prepared surface on native soil, for use only on steeply sloped portions of the landfill.

- **Sole source aquifer:** An aquifer (designated by the United State Environmental Protection Agency [U.S. EPA] pursuant to section1424e of the Safe Drinking Water Act [Public Law No. 93-523]) which is the sole or principal drinking water source for an area and which, if contaminated, would create a significant hazard to public health.

- **Waste stabilization:** The reduction in biological, chemical, and physical reactions in the waste mass with time caused by the depletion of the sources for these reactions. The degradation of organic matter, leaching of chemical constituents, and settling of the waste mass (that reduces void space), are examples of biological, chemical, and physical components of waste stabilization.

The following acronyms are used throughout the body of this report.

APCD: Air pollution control district

AQMD: Air quality management district

ARB: Air Resources Board (California)

Btu: British thermal unit

CCL: Compacted clay liner

CCR: California Code of Regulations

CFR: Code of Federal Regulations

CIWMB: California Integrated Waste Management Board

CQA: Construction quality assurance

EA: Enforcement agency for the CIWMB

EGCS: Exposed geomembrane cover system

ET: Evapotranspiration

EU: European Union

GCL: Geosythetic clay liner

LCRS: Leachate collection and removal system

LEL: Lower explosive limit

LFG: Landfill gas

MBP: Mechanicaly-biologically processed

MRF: Materials recycling facility

MSW: Municipal solid waste

RWQCB: Regional water quality control board

SWFP: Solid waste facility permit

SWRCB: State Water Resources Control Board (California)

tpd: Tons per day

U.S. EPA: United States Environmental Protection Agency

VOC: Volatile organic compound

WDR: Waste discharge requirement

3 Summary of Findings From Previous Reports

This section summarizes the primary findings of each of the reports that have been prepared and submitted to the CIWMB in conjunction with Tasks 3 (Phase I report), 5 (Phase II report), 6, and 7 of this Landfill Facility Compliance Study.[**] Information in this section is taken mostly from the results or recommendations sections of these reports and supplemented with pertinent details from the bodies of the reports, as appropriate. The Task 1 report (*Landfill Facility Compliance Study: Checklist of Pertinent Environmental Regulatory Requirements*) (GeoSyntec, 2002) is not included in this section because this report served only as a compilation of existing regulations, and no results or recommendations were provided in the report.

The purpose of each report presented in this section differs from the others, and the types of findings in each report likewise differ from the other reports. The Phase I report presents a summary of an assessment of MSW landfill environmental performance by various site characteristics and identifies key findings from the assessment, but does not make any definitive recommendations. The Phase II report presents results of an analysis performed to assess regulatory effectiveness in protecting the environment over time. The Task 6 report identifies other states' and countries' regulations that could possibly improve or enhance California's multimedia regulations. Both the Phase II report and the Task 6 report provide conclusions and make recommendations that could improve California's multimedia regulations. The Task 7 report presents results of an analysis performed to identify and evaluate emerging technologies that could possibly improve or enhance the operation of California's MSW landfills and identifies those that could have a considerable potential for successful implementation in California.

3.1 Phase I Report—Screening Analyses of 224 MSW Landfills

The purpose of the Phase I report was to assess the environmental performance of 224 MSW landfills that were inventoried under Task 2. In accordance with the Task 2 scope of work, GeoSyntec compiled a relational database inventory of 224 California MSW landfills for the CIWMB, also called the Task 2 cross-media inventory. The 224 California MSW landfills included as part of Task 2 were those that have accepted waste since October 9, 1993. This date was chosen as the cutoff date since it was the effective date for Subtitle D regulations, the first comprehensive federal standard for MSW landfills.

The information on the 224 MSW landfills in the database includes general site characteristics (for example, owner type, age, size, social setting, and liner type) and environmental performance information collected during the period from January 1, 1998 through December 31, 2001. The database included information gathered by GeoSyntec during file reviews at each RWQCB, EA, and AQMD/APCD office from September 2000 through May 2001. In accordance with the approved scope of work and budget, the time allotted to collect all information was limited and had to be divided between the RWQCB office, the EA office, and the AQMD/APCD office. GeoSyntec submitted the first draft database to the CIWMB in September 2001.

[**] Bibliographical information on the reports produced for the Landfill Facility Compliance Study is listed in Section 5, "References."

Recognizing the limitations of the relatively brief file review period, the CIWMB forwarded the database information first to the respective landfill owners and operators and later to regulators, requesting verification, comments, and corrections regarding each site, as appropriate. These comments were incorporated into the final database as appropriate.

While substantial efforts were made to ensure the correctness and completeness of the data within the database, there were still undoubtedly errors in the dataset. As with any undertaking of this magnitude, some errors in measurement, interpretation, and data entry are inevitable. However, as the findings of the screening analyses presented in the Phase I report do not depend upon any single record but represent statistical analyses of a larger body of data, these findings are considered reliable with a relatively high level of confidence.

The remainder of this section provides a summary of the key findings of the Phase I report that were derived from a review of the Task 2 cross-media inventory and a screening analysis of environmental performance using statistical methods.

3.1.1 Current State of MSW Landfill Practice

The three primary regulatory agencies (EAs, RWQCBs, and AQMDs/APCDs) regulate and oversee the landfills differently. These differences are necessitated by the goals of each agency.

The EAs regulate the landfills based on MSW operational units—generally on a site-wide basis—whereas the RWQCBs regulate the landfills based on individual waste management units (WMU). EAs do not recognize the individual WMUs that may comprise the landfill. All of the information is kept for the site as a whole and is not broken down into individual WMUs. For example, information on capacity, compliance, final cover type, and site status is reported for the entire landfill and not broken down according to specific WMUs. As a result, it is difficult to determine where a problem with performance or compliance has occurred at a landfill. Also, there are cases where two adjacent operational units are regulated separately as individual landfills, when they should be regulated as one landfill.

RWQCBs issue site-wide permits that can include both MSW and non-MSW WMUs (for example, Class II surface impoundments). For purposes of this study, environmental performance and compliance records for each site were determined for MSW WMUs and did not include the non-MSW WMUs.

The AQMDs/APCDs regulate the landfills primarily based on the equipment in operation. In some cases, there are adjoining landfills with shared gas collection systems. For purposes of this study, performance and compliance issues then become difficult to assign to one landfill vs. the other. As a result, it was difficult to determine which landfill actually had a problem with performance or compliance.

Additionally, within each type of agency, there are differences in the information available. Even seemingly simple pieces of data can become complex. As an example, the EAs issue a solid waste facility permit (SWFP) for each landfill that lists, among other things, the design capacity of the site. However, “design capacity” may have a range of meanings depending on the landfill. In some cases, it refers to the total volume of the landfill as measured from the base grades to the final grades. In others, it refers to the actual MSW volume (total airspace minus daily cover and final cover volumes). Still others refer to the remaining capacity, rather than total capacity.

These observed inconsistencies most likely have little, if any, effect on the enforcement of the regulations for any given site. All parties involved presumably understand the site-specific requirements. The difficulty comes only when comparing a group of sites where these differences affect the consistency of the data. In a study such as this one, a cross-media evaluation becomes increasingly difficult with this type of added complexity.

As described in the Phase I report, the 224 landfills contained within this study vary greatly. The following highlights were derived from comparing the site characteristics of all 224 MSW landfills studied:

1. At the time of the study, 75 percent of the landfills studied were publicly owned, while 25 percent were privately owned.

2. Sixty-two percent of the landfills studied (138 landfills) were fully unlined, while 1.8 percent (4 landfills) were fully lined with Subtitle D liners. The remaining landfills had a combination of liner types. Figure 3A presents the distribution of liner types for all 224 landfills. Note that if closed and inactive sites are excluded from this tally, fully unlined sites are reduced to approximately 52 percent of the total. The distribution of liner type for the active landfills is included in Figure 3B.

3. The permitted maximum daily tonnage for the active landfills ranged from 1 ton to 13,200 tons. The median tonnage was 385 tons. For the entire state, the permitted maximum daily tonnage was approximately 195,500 tons, which equates to approximately 11.5 pounds of MSW per person per day.

4. The permitted remaining capacity for the MSW landfills during the timeframe of the study ranged from approximately 2,000 cubic yards to approximately 95 million cubic yards. For the entire state, the total remaining capacity was approximately 1.5 billion cubic yards, which equates to approximately 44 cubic yards per person. This is roughly equivalent to a cube that is 11 feet by 11 feet by 11 feet. In general, California's remaining capacity for the time frame of the study was concentrated around the population centers (may include surrounding counties) of Los Angeles, San Francisco, Sacramento, and San Diego.

Table 3-A: Distribution of Liner Types (All 224 Landfills)

Liner Type	Number of Landfills	Percent of Total
Fully Subtitle D	4	1.8
Fully Lined—Partially non-Subtitle D	12	5.4
Partially Unlined	70	31.3
Fully Unlined	138	61.6
Total	**224**	**100**

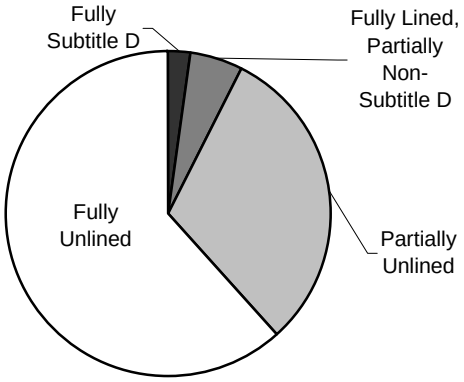
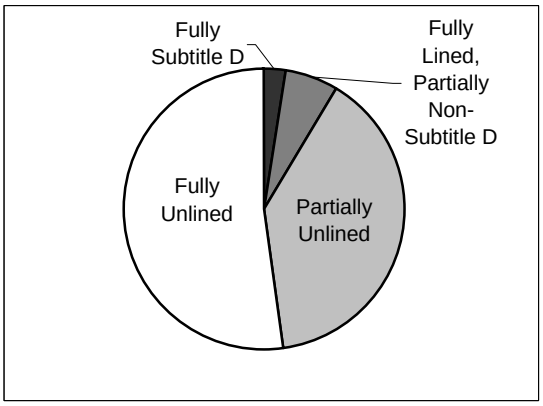


Table 3-B: Distribution of Liner Types (Active Sites Only)

Liner Type	Number of Landfills	Percent of Total
Fully Subtitle D	4	2.5
Fully Lined—Partially Non-Subtitle D	10	6.3
Partially Unlined	62	39.3
Fully Unlined	82	51.9
Total	**158**	**100**



5. Based on the information gathered for the period from January 1, 1998 through December 31, 2001, the following eight counties had no remaining MSW capacity: Alpine, Mendocino, Modoc, Nevada, San Francisco, Sutter, Tehama, and Trinity. Between 2001 and the date of the Phase I report, additional landfills have closed or become inactive. This created an additional three counties with zero remaining MSW capacity: Del Norte, Humboldt, and Tuolumne.

6. Of the 224 landfills in the study, 103 landfills (46 percent) have engineered landfill gas collection systems in place to collect landfill gas, and 121 landfills (54 percent) do not. Landfill gas collection systems are required by federal regulations based on capacity or by state regulations in response to landfill gas

migration. Federal regulations (40 CFR, Part 60, Subpart WWW: "Standards of Performance for New Stationary Sources" and 40 CFR Part 60, Subpart Cc: "Emission Guidelines for Control of Existing Sources") require that when an operating landfill is larger than 2.5 million cubic meters or 2.5 million megagrams in capacity or when the landfill has non-methane organic compound emissions in excess of 50 million grams per year, the discharger must install a system to extract and control the gases generated at the landfill.

7. Based on the results of a statistical evaluation, the "typical" MSW landfill in California at the time of the study was publicly owned, active, located inland, either fully unlined or partially unlined (in the case of active sites), fully uncovered, and has no gas collection system. The typical landfill has a permitted disposal area of 55.5 acres and a permitted disposal volume 2.7 million cubic yards. The typical landfill is underlain by sand and/or gravel, has a minimum depth to underlying groundwater of 34.5 feet, and receives an average annual precipitation of 16 inches.

3.1.2 Indicators of Environmental Performance

Generally, the environmental performance of a landfill can be assessed based on the measured properties of the groundwater, leachate, air, soil, and surface water relative to some standard. The standard may be the background levels, historical values, or regulatory limits. Measurements for any given site, when observed over time, can be compared against a standard to evaluate the site's performance.

As discussed in the Phase I report, each site in this study has a unique physical and operating environment, so that examining the performance of all 224 sites with respect to each other would represent an extremely complex analysis. Monitoring frequency, monitoring point location, background characteristics, historic measurements, constituents of concern, and reporting formats can vary greatly from site to site. Recognizing that quantifying environmental performance is complex and difficult for any given site, much less 224 sites at once, an alternative measure of environmental performance was necessary to achieve the objectives of the study. For the analyses conducted as part of Task 3 (the Phase I report), the actions taken by the various regulators were used as indicators of environmental performance. Three principal assumptions were made in order to use these types of regulatory actions as reliable indicators of environmental performance. The assumptions were:

1. The monitoring systems at each site (such as groundwater wells and gas probes) are located, monitored, and reported in such a way that the site regulators have an adequate picture of the actual environmental performance.

2. The actions the regulators take are appropriate responses for actual environmental impacts. This assumption requires that when presented with the site-specific data, the regulator draws an appropriate conclusion and takes an appropriate action. For example, if there is strong groundwater monitoring evidence that a landfill is impacting the underlying groundwater, then it is assumed that the RWQCB would issue a cleanup and abatement order or would require a corrective action program.

3. The actions that regulators take are relatively uniform across the state. For example, if leachate seeps are observed by one EA in northern California and a

leachate control violation is issued, then an EA in southern California observing identical seeps would also issue an identical leachate control violation.

Information regarding the actions of each of the three primary regulators was used to derive five environmental response variables that served as indicators of environmental performance. One variable was developed to serve as an indicator for groundwater impacts, two for gas impacts, one for surface water impacts, and one for air quality impacts.

The experiences of Phase I demonstrate that this type of simplified approach can provide a relatively uniform and effective measure of environmental performance that allows for the rapid analysis of a wide range of site characteristics with respect to environmental performance. While this approach was found to be very useful in Phase I, Phase II of the landfill study (discussed in Section 3.2) demonstrated that the complexities of environmental performance and compliance are not fully captured with these five simple indicators. Regardless, as indictors, they serve the purpose of screening a broad set of data. These types of variables, as described in detail in the Phase I report, could be used for future studies of statewide landfill environmental performance.

3.1.3 California MSW Landfill Environmental Performance

Using logistic regression analyses, the relationships between the site characteristics and the environmental response variables described in Section 3.1.2 were evaluated for statistically significant correlations. As a result, common characteristics were identified that were correlated to environmental performance or compliance problems. While a particular site characteristic may be more common among sites with certain regulatory actions, it does not necessarily mean that the site characteristics were the underlying cause for the actions taken by the regulators, but only that a correlation exists. Phase II of the study involved a more detailed analysis of individual sites to better understand the underlying reasons that a landfill is not in compliance and if it is related to current regulation.

The following key findings were made from the environmental performance analyses by landfill site characteristics:

1. The landfills most likely to have groundwater impacts are larger, located in urban areas, at least partially unlined, and located in areas of higher-than-average precipitation. These sites also tend to be privately owned and have landfill gas collection systems. In contrast, small, rural, unlined sites in dry climates tend to have a lower occurrence of groundwater impacts. These sites also tend to be publicly owned and are not required to have landfill gas collection systems. These findings suggest that if all else is equal, a larger volume of waste spread over a larger area with higher precipitation results in a higher potential for a release into groundwater. These larger, urban sites may also tend to be more intensely monitored and attract greater regulatory scrutiny, thus leading to a higher relative occurrence of regulatory actions. However, the data collected in this study can neither support nor refute this hypothesis.

2. Landfills in drier climates tend to have fewer surface water impacts such as including leachate seeps and excessive erosion. It is logical to conclude that greater precipitation leads to greater potential for both erosion and leachate generation.

3. Landfills that have undergone closure have a significantly lower occurrence of surface water actions. This suggests that construction of an approved final cover system can reduce the potential for surface water impacts.

4. Larger urban landfills that are greater than 60 years old, with higher annual precipitation, a combination of liner types, and that are partially closed are more likely to have landfill gas violations or notices to comply than other sites. These findings suggest that if all else is equal, a larger volume of waste in areas of higher precipitation results in more landfill gas with a higher potential for gas compliance issues. These larger, urban sites may tend to be more intensely monitored and attract greater regulatory scrutiny, thus leading to a higher relative occurrence of gas-related violations. However, the data collected in this study can neither support nor refute this hypothesis.

3.2 Phase II Report—Evaluation of Regulatory Effectiveness Based on a Review of 53 MSW Landfills

The purpose of Tasks 4 and 5 was to evaluate the effectiveness of the current California MSW landfill regulations in protecting the environment by using 53 selected MSW landfills as case studies. These 53 MSW landfills were identified previously in the Phase I report (GeoSyntec, *Phase I Report,* 2003, pp. 74–77). The following actions were taken to satisfy the requirements of the Task 4 and 5 scopes of work:

1. Assessed the Task 2 cross-media inventory and the results of the Task 3 multi-variable analyses to identify the environmental performance of the 53 landfills.

2. Reviewed documentation available through the Task 2 cross-media inventory to gain a better understanding of the environmental performance of the landfills.

3. Contacted landfill owners/operators and regulators (RWQCB, EA, and AQMD/APCD) to collect more detailed information regarding the environmental performance of the 53 landfills and the application of the existing MSW regulations at those landfills.

4. Reviewed the results of the Task 4 in-depth review of 53 MSW landfills' environmental performance, looking across all environmental media, for use in cross-site comparisons.

5. Evaluated the in-depth information and identified recurring issues related to unsatisfactory environmental performance that may be associated with deficiencies in the existing California landfill regulations.

6. Developed recommendations for changes to the existing California MSW landfill regulations based on the results of these evaluations that could lead to greater environmental protection.

A list of general findings from the in-depth landfill review was presented in the Phase II report, and six regulatory topics were developed from these findings for detailed evaluation. From the six topics, four changes to existing landfill regulations or practices are recommended for implementation in California that could result in greater environmental protection. These changes fall under three regulatory categories, including water quality monitoring, gas monitoring and control, and other control systems. A description of each of the recommended changes to the regulations or practices within a

given category and a brief summary of the basis for the recommendation is provided in the following paragraphs.

3.2.1 Water Quality Monitoring

Regulatory Topic: Subsurface Landfill Gas Monitoring as Part of Water Quality Detection Monitoring

The existing water quality monitoring regulations allow for, but do not require, monitoring for releases of landfill gas. It is recommended that landfill gas monitoring be either explicitly incorporated into the regulations as part of the detection monitoring program for water quality or more widely encouraged by the RWQCBs. This change is recommended because:

1. The migration of landfill gas is a precursor to impacts to groundwater.
2. Landfill gas is typically easier to control than groundwater.
3. Fifty-nine percent of the 53 landfills that have had impacts to groundwater have attributed those impacts at least in part to landfill gas migration.

If such an approach is adopted, the location of such monitoring points and the constituents evaluated should be carefully considered. All landfills with active decomposition will generate landfill gas, and should require landfill gas monitoring as part of the monitoring program—ideally, as part of unsaturated zone monitoring. Monitoring points located within or very close to the waste will likely have higher volatile organic compound (VOC) concentrations than those located farther away. Site-specific conditions including the location and age of the waste, presence of a liner system, subsurface geology, and proximity to groundwater should be used in designing a monitoring network. Any additional landfill gas monitoring should be coordinated with the EA in order to complement any ongoing explosive gas monitoring.

Note that there are added complexities with respect to monitoring gas migration that would make monitoring gas more complex than it is for water. For example, molecular diffusion through even a composite liner will result, in time, in the presence of detectable concentrations of VOCs in soil-pore gas immediately exterior to the landfill liner. This is not a release, given that it is not being driven by a pressure gradient, yet such a “hit” could result in a regulatory response. A means for avoiding false-positive indications resulting from molecular diffusion would need to be developed prior to its implementation.

Provided that the above-listed issues are addressed, incorporating landfill gas monitoring into the groundwater monitoring program has the potential to improve environmental performance by identifying conditions that could lead to groundwater impacts before they occur. If the release of landfill gas is identified and mitigated prior to impacts to the groundwater, the groundwater contamination would be reduced. From a cost perspective, such a change would have significant impacts to the landfill operators, as another level of monitoring and reporting would be required. Time and money for sampling, testing, and reporting could be significant. Additionally, such a change would increase costs to the RWQCBs to review additional monitoring information. However, for landfills where a release of landfill gas impacts groundwater and a corrective action is required, the cost to install and operate a landfill gas collection system can be large. Controlling landfill gas is often less expensive than remediating a groundwater impact, so for these landfills there

could be a net cost savings to the operator for monitoring for landfill gas releases as part of groundwater monitoring.

3.2.2 Landfill Gas Monitoring and Control

Regulatory Topic: Landfill Gas Monitoring and Control at Active Landfills

The existing regulations for landfill gas monitoring and control are significantly more comprehensive for the post-closure care period than they are for the active life of a landfill. It is recommended that the landfill gas monitoring and control regulations for the active life of the landfill be changed so that they are as comprehensive as the regulations for gas monitoring and control during the post-closure care period. This change is recommended because:

1. The generation of landfill gas starts as soon as waste is placed.
2. Active landfills are more likely to have gas-related compliance issues than closed landfills.

Based on the statistical analysis of the cross-media inventory described in the Phase I report, fully covered sites were found to be 7.3 times less likely than fully uncovered sites to be in the category "Has Gas Enforcement Action" [††] (GeoSyntec, *Phase I Report*, 2003, p. 50). This finding suggests that landfills that have undergone closure and have installed a final cover are less prone to violating the State minimum standards for gas-related performance. While the performance standards for landfill gas control are the same for active and closed sites, it should be noted that under the current regulations, the regulatory requirements for landfill gas control and monitoring for active sites are less rigorous than those for closed sites

The anticipated environmental protection benefit of implementing the same landfill gas monitoring and control requirements for the active life of the landfill as is currently required for post-closure care is that the potential for landfill gas to migrate off-site undetected through the subsurface is reduced prior to closure. The cost impact of these changes are expected to be associated with the installation and monitoring of multi-depth probes at the active landfills in the state, which are more expensive than the shallow probes that have been used during the active life at some landfills. Because multi-depth probes are already required at the time of closure, the installation costs would be incurred sooner than required by the current regulations.

Regulatory Topic: Vadose Zone Monitoring for Landfill Gas Near the Waste Limit

No change to the regulations is recommended per se, since current landfill regulations already allow alternative monitoring locations on a site-specific basis. However, it is recommended that the EAs promote monitoring for explosive gases in the vadose zone closer to the landfill mass than simply at the property boundary at sites with large buffers. This would not include any changes to the existing regulations, and the compliance point for explosive gas concentrations remains at the property boundary.

This change in practice is recommended because:

1. The migration of landfill gas is a precursor to impacts to groundwater.

[††] Findings were based on a 90 percent significance level.

2. The distance to the property boundary may be so large that monitoring at that boundary my not effectively identify the migration of explosive gases.

To simplify landfill monitoring, it would be preferable for gas monitoring systems that detect landfill gas prior to impacting groundwater (recommended in Section 3.2.1) be combined with explosive gas monitoring systems, with the monitoring results provided both to the EA and to the RWQCB. The depth and location of the monitoring locations (somewhere between the refuse boundary and the property boundary) would be defined on a site-specific basis, considering site subsurface conditions and depth and potential uses of groundwater. Approval of the system would require concurrence of both the local EA and the RWQCB.

There is, however, a difficulty if both systems are combined. The lower explosive limit (LEL) for methane is five percent by volume in air; however, the trace gases commonly found in landfill gas may reach toxic or carcinogenic levels in gas at a much lower concentration of methane than five percent. Therefore, a monitoring location may be in compliance for methane, but out of compliance for trace gases (compliance with trace gas requirements is currently required only during post-closure care). The appropriate remediation would need to be selected to address the compliance issue, again with the concurrence of both the local EA and the RWQCB.

Performing explosive gas monitoring closer to the waste mass allows the detection of landfill gas migration closer to the source, so that the landfill may implement the necessary controls to avoid landfill gas impacts to groundwater, human health and the environment. In terms of construction and monitoring costs, locating the gas monitoring probes closer to the waste mass may reduce the number of monitoring points and therefore reduce the total costs. The maximum allowable spacing (without a regulatory variance) is 1000 feet. For sites with a large buffer, the number of monitoring points at 1000-foot spacing that are installed close to the waste mass could be much fewer than if they were installed at the property boundary.

3.2.3 Other Control Systems

Regulatory Topic: Regulatory Requirement for Winterization

The existing regulations have no explicit requirement for the submission of an annual winterization plan. It is recommended submission of an annual winterization plan be either explicitly incorporated into the regulations or be more widely encouraged by the regulatory agencies. It is recommended that this plan be reviewed and approved by the EA with the concurrence of the RWQCB. This change is recommended because:

1. Winterization plans have been indicated to be helpful in complying with surface water and leachate control requirements at sites with different climatic conditions.

2. Storm-related surface water and leachate control compliance issues have occurred at sites with different climate conditions.

3. The cost to implement and enforce the plans may be lower than the cost of responding to storm-related impacts to surface water.

The potential environmental protection benefit associated with requiring a winterization plan is that landfills may be better prepared to handle winter storms. This could reduce the potential for erosion of cover, inundation of drainage features, and leachate control

problems. The potential cost impacts associated with the addition of this regulation would be associated with the development of the plan by the owners and the review and approval of the plan by the regulatory agency. Potential cost benefits may be experienced by regulators, by simplifying the approval of erosion and drainage control systems with the submission of an annual plan, and by owners, by reducing the likelihood of storm-related erosion and drainage control and leachate control violations.

3.3 Task 6 Report—Review of MSW Landfill Regulations From Selected States and Countries

The purpose of Task 6 was to identify those elements of other state and country MSW regulations that, if adopted in California, could improve or enhance California's multimedia regulation of MSW landfills. In accordance with the contract scope of work, the method for developing the Task 6 report included the following activities.

1. Review current MSW landfill regulations from all 50 states and selected countries to identify those jurisdictions that will be most relevant to this study.
2. Select up to eight states and five countries for comparison of their current MSW landfill regulations with those from California.
3. Review and compare the federal regulations to those from the selected states, since the states must meet, at a minimum, the federal regulations and many of the individual states include the federal regulations by reference in their regulations.
4. Identify those elements that, if applied in California, could possibly improve or enhance California's multimedia regulation of MSW landfills.
5. To the extent possible, compare the incremental cost and potential environmental protection benefit of the selected states' and countries' regulations to California's current state of practice.

The diverse nature of California's geology, hydrogeology and climate sets it apart it from most other states with respect to evaluating regulations that can be most effective in providing environmental protection. When comparing California to most of the eight selected states, regulations that may have been developed for a more homogenous environment may only be applicable to portions of California. In general, California regulations allow for the diversity of the state in all the factors considered for design, and for that reason are likely to provide the most environmentally protective and cost-effective disposal for the people of California.

In comparison to the five countries reviewed, California's regulations appear to be similar in that they are all attempting to accommodate highly variable site conditions across the governed area. However, in some instances these countries' regulations tend to be more prescriptive than California's, either by including additional requirements (such as for waste pre-processing) or by defining a range of minimum requirements to accommodate varying conditions across the country (such as with a tiered structure for defining minimum requirements based on site conditions).

With these general observations in mind, a brief assessment of the applicability of each regulatory topic in California was conducted and several recommendations were developed for changes to landfill practice and the existing California landfill regulations, as presented below. Those topics that were evaluated and found not to require any changes to current landfill practice or existing regulations are not discussed here.

3.3.1 Regulations for Special Handling of Waste

Waste Pre-Processing: It is expected that introducing a requirement for pre-processing and/or pre-treatment of waste into the California regulations would have a significant benefit for both environmental protection and waste handling and disposal costs. The European Union (EU) requirement for waste pre-processing has been praised as a significant step toward developing a sustainable waste management cycle. By reducing the volume of degradable waste landfilled, the generation of leachate and landfill gases is expected to decline. Less airspace is used, thus extending landfill resources. However, significant economic impacts (both positive and negative) are anticipated in conjunction with a regulation to require pre-processing of waste.

A review of the cross-media inventory has identified five of the 224 studied MSW landfills in California that have proposed or implemented some form of waste pre-processing. Of the five sites, one has water-related compliance issues, no sites have been issued gas-related enforcement actions, three sites had gas-related compliance issues, and two sites have had surface water- or leachate-related compliance issues. Many materials recycling facilities (MRF) and incineration facilities in California are not associated with a specific landfill and are not included in the inventory.

The specific benefits of various methods of pre-processing (summarized in Section 5 of the Task 6 report and discussed in detail in the Task 7 report), especially with respect to their applicability to California's physical and social setting and the associated cost implications, should be thoroughly investigated to enable the development of an appropriate regulation for California. It is recommended that a regulatory requirement for the pre-processing and/or pre-treatment of waste be considered for implementation in California, if a detailed cost-benefit analysis indicates that it is appropriate.

3.3.2 Siting Regulations

Distance From Wetlands: The applicability of a more stringent requirement for the siting of landfills near wetlands should be based on the need to protect California's wetlands. The anticipated environmental protection benefit of implementing a landfill siting restriction based on proximity to wetlands is additional protection of California's existing wetlands.

Imposing this restriction on landfill siting may result in increased cost to procure a landfill site that is not within a wetlands area. Additional cost may also be incurred to replace wetlands if the landfill site does not comply with the minimum allowable distance requirement. It is expected that this cost would be incurred by the landfill owner and passed on to the public. However, it is GeoSyntec's understanding that existing wetlands regulations enforced in California (which were not reviewed as part of this study) may require special operations and monitoring for sites near wetlands. Therefore, an economic benefit in the form of fewer restrictions may be realized by the landfill owner if the landfill is not in a wetlands area.

A review of the cross-media inventory indicates that at least 10 of 158 existing active MSW landfills in California (approximately 6 percent) are in the vicinity of a wetlands area. Of the 10 sites located near wetlands, 3 (30 percent) have had water-related compliance issues, 3 (30 percent) have been issued gas-related enforcement actions, 7 (70 percent) have had gas-related compliance issues (without enforcement actions), and 3 (30 percent) have had surface water or leachate control compliance issues. The introduction

of a landfill siting restriction based on proximity to a wetlands area could preclude the construction of any future disposal units at these sites.

The actual environmental impact of existing landfills that comply with California's current siting regulations on California's wetlands should be thoroughly reviewed prior to the development of new regulations restricting landfill siting. It is recommended that more stringent requirements for siting near wetlands only be considered for adoption into the California regulations if it is warranted by the results of that review.

Distance From Water Supply Wells: The applicability of a more stringent requirement for the siting of landfills near water supply wells should be based on the need to protect California's water sources. The perceived environmental protection benefit of implementing a landfill siting restriction based on proximity to a water supply source is additional protection of human health through protection of drinking water. However, distance may not be the most appropriate parameter for controlling the affect of a landfill on the quality of a water supply well because the impact is also dependent on the permeability of the strata, the direction and rate of flow, and the depth to the aquifer.

Imposing this restriction on landfill siting may result in increased cost to procure a landfill site that is not in proximity of a water source or, alternatively, the cost to relocate the water supply wells. It is expected that this cost would be incurred by the landfill owner and passed on to the public. However, it is expected that an economic benefit may be realized by the landfill owner in the form of less stringent groundwater monitoring requirements than if the landfill were in proximity of a water supply source.

A review of the cross-media inventory indicates that at least eight of 158 existing active MSW landfills in California have been sited in the vicinity of one or more water supply wells. Of the eight sites, five (63 percent) have had water-related compliance issues The introduction of a landfill siting restriction based on proximity to a water supply source could preclude the construction of any future disposal units at these sites.

The actual environmental impact of existing landfills (where the prescriptive minimum base liner system has been installed) on water supply wells should be thoroughly reviewed prior to the development of new regulations restricting landfill siting. It is recommended that more stringent requirements for siting in proximity to water supply wells be considered for adoption into the California regulations only if they are warranted by the results of that review.

3.3.3 General Design Regulations

Design Requirements and Submittals: Because the current practice in California allows for additional submittals to be requested by the permitting agency when warranted by site-specific conditions, it may not be an improvement to the landfill regulations to require more design submittals. In addition, the development of general guidance documents for landfill design and construction, such as have been developed in several other states, may be an appropriate alternative to imposing new regulations. Guidance documents can help provide consistency and reliability across the state, but since they are not enforceable, they may be adjusted to account for site-specific conditions. Therefore, it is recommended that non-enforceable general guidance documents be developed in lieu of changing the existing California landfill regulations. Therefore, no change to the existing California landfill regulations is recommended.

Liner Performance Evaluation: Existing California regulations do not require a performance evaluation for the prescriptive single composite liner (or engineered

alternatives), but allow permitting agencies to require one. This approach seems to be appropriate for California, given the variability of both the physical setting and the potential environmental impact of landfills across the state. Therefore, it is not recommended that liner performance evaluations be required in the California landfill regulations. However, if the recent trend toward requiring liner performance evaluations continues, a prescriptive standard for evaluating landfill performance should be developed, if feasible, and criteria for acceptable performance should be defined.

3.3.4 Base Liner System Regulations

Design and Construction of Liner Components (Clay and Geosynthetics): While imposing design and construction standards in the regulations may provide consistency and reliability in liner systems, the efficiency and performance of some sites may be hampered. Because of the variability in site conditions across the state, it may not be appropriate to stipulate specific design and construction criteria for all sites. The development of non-enforceable general guidance documents for liner design and construction, such as have been developed in several other states, may be an appropriate alternative to imposing new regulations because they can provide consistency and reliability across the state. Since they are not enforceable, they may be adjusted to account for site-specific conditions. Therefore, it is recommended that non-enforceable general guidance documents be developed in lieu of changing the existing California landfill regulations.

Double Liner Systems: Recent studies (U.S. EPA, 2002) have found that Subtitle D-compliant single composite liner systems can have a very high hydraulic efficiency and are capable of preventing adverse impacts on the environment. Existing California regulations do not include any provisions for when a double liner may be required, but allow permitting agencies to require one. This approach seems appropriate for California, given the variability across the state of both the physical setting and the potential impact of landfills on the environment. No change to the existing California landfill regulations is recommended. However, if the recent trend of permitting agencies considering double liners continues, a prescriptive standard for evaluating landfill performance should be developed, if feasible, and criteria for acceptable performance should be defined in the regulations.

Multiple Prescriptions for Base Liners Based on Site Conditions: Providing a tiered structure for prescriptive base liner requirements based on the physical and social setting of the landfill site may be an appropriate alternative to California's current prescriptive single composite liner requirement. Defining the appropriate prescriptive liner system based on the physical and social setting of the site would allow site-specific conditions to be considered and would provide efficiency in the design and installation of liners. It would also give more direction to the local agency in regulating their jurisdiction, while still allowing the flexibility to require more protective systems if warranted.

The concept that different levels of protection may be appropriate at different landfill sites is widely acknowledged. Current Subtitle D regulations allow for the exemption of small landfills based on their low waste acceptance rate and low potential to impact groundwater. Findings from the Phase I report similarly suggest that small, rural, unlined landfills in "dry" climates are less likely to have had water-related compliance issues than other landfills. By contrast, the North Coast and Central Valley regions of the RWQCB are trending toward requiring liner performance evaluations to demonstrate the

effectiveness of the prescriptive single composite liner system, and in some cases have required the installation of a double composite liner system.

It is expected that the implementation of a tiered structure for prescriptive base liner systems would pair the level of environmental risk with the level of protection required. It would have a positive environmental impact by prescribing more protective liners at sites where the potential for environmental impact is greatest. Less protective liners would be required at sites where the environmental risk is less, suggesting no net environmental impact for these sites.

A tiered structure for base containment requirements has the potential to reduce the economic burden on small communities with low population growth that intend to construct a landfill solely for their own use. However, as the population of California continues to grow and spread out from the metropolitan areas, this classification will apply to fewer and fewer communities. It is expected that no economic relief would be experienced by medium to large landfills.

A review of the cross-media inventory results in the following breakdown of 158 existing active California MSW landfills included in the database, based on waste acceptance rate and site climate.

Climate	Number of Sites			
	Community Sites (accept less than 27.5 tpd of waste)	**Small Sites (accept 27.5 to 165 tpd of waste)**	**Medium (accept 165 to 550 tpd of waste)**	**Large (accept more than than 550 tpd of waste)**
Dry	12	14	10	15
Wet	9	11	28	59

Dry sites: Desert or high desert (high deserts sites have less then 10 inches precipitation per year).
Wet sites: All other climate designations.
Tpd= tons per day.

Of the dry sites, no community or small sites have had water-related compliance issues, three (30 percent) of the medium sites have had water-related compliance issues, and four (27 percent) of the large sites have had water-related compliance issues. Of the wet sites, three (39 percent) of the community sites have had water-related compliance issues, no small sites have had water-related compliance issues, 11 (39 percent) of the medium sites have had water-related compliance issues, and 31 (53 percent) of the large sites have had water-related compliance issues. These percentages can be compared to existing active California landfill sites as a whole, of which approximately 33 percent have had water-related compliance issues.

To apply this type of regulatory structure to the existing California landfill regulations, a further breakdown of landfill categories would need to be defined based on the range of social and physical characteristics found across the state. In addition, the prescriptive liner requirements for each of the categories would need to be defined so that each liner requirement will be appropriately protective of the environment of California**.** It is recommended that a tiered structure for multiple prescriptive base liner systems based on site conditions be considered for application to California landfill regulations if it can be shown to be more environmentally protective than the current regulatory system.

3.3.5 Post-Closure Regulations

Post-Closure Land Use: Several states stipulate specific exclusions for post-closure land use activities. However, because of the variability in site conditions and social setting of landfills across the state, it may not be appropriate to stipulate all-encompassing land use exclusions criteria. It is recommended that post-closure land use recommendations be set forth in non-enforceable general guidance documents without making a change to regulations.

Site-Specific Post-Closure Period: Two of the countries included in this study specifically define the end of the post-closure care period based on site-specific consideration of environmental performance. California's current regulations and statutes state that a landfill operator may be released from post-closure maintenance after a minimum period of 30 years, upon demonstration to and approval by regulatory agencies that the waste in the landfill no longer poses a threat to groundwater quality, public health and safety, and the environment. Although there are no definitive criteria to pre-determine the end of the post-closure maintenance period, an operator can, at any time, provide evidence to document that post-closure maintenance should be discontinued because the waste no longer poses a threat. Alternatively, even if the operator cannot provide sufficient evidence to discontinue post-closure maintenance, the operator might still be able to justify a significant decrease in the level of post-closure maintenance, thus lowering post-closure maintenance costs.

Adding components to the regulations to consider leachate, landfill gas and water quality performance, and the level of degradation of the waste mass, when determining when to end the post-closure period would allow the end of the post-closure care period to be considered on a site-specific basis, while providing an equitable standard by which to compare all sites. It is recommended that the current regulatory 30-year minimum period may stay the same if prescriptive standards are added for leachate quality, landfill gas quality, water quality, and level of waste degradation, to evaluate the potential future environmental impact of a site.

Because the existing California regulations do not address specific criteria for releasing sites from the post-closure care period, it is unclear how long beyond 30-years

monitoring and maintenance will be required at a particular site. Therefore, the introduction of components to the regulations to address waste stabilization, leachate, landfill gas quality and water quality in defining the end of the post-closure care period may serve to add consistency in evaluating landfills and has the potential to significantly decrease post-closure costs where it is appropriate. Landfill owners that to date have been able to demonstrate no potential for future impact have realized a substantial cost savings.

The cross-media inventory generally includes sites that have been operational after 1993, and thus does not include many sites that have begun the post-closure care period. However, 40 of the 224 California MSW landfills included in the inventory are listed in the database as being closed, and 36 sites are listed as being inactive (pending closure). Six of 224 sites have had their waste discharge requirements rescinded by the RWQCB (post-closure care for water quality impacts has ended). All six of these sites are less than 10 acres in size and are located in the same county. Five are owned by the federal government, and one is owned by a local government. Therefore, of the sites included in the inventory, the six that have been released from post-closure care do not have site characteristics typical of most California MSW landfills. The "typical" California landfill was defined in Section 3.1.1.

There are several ongoing research projects looking at the concept of ending post-closure maintenance, but this work is very preliminary. One difficulty in developing standards is that dry tomb landfills (favored by Subtitle D) indefinitely suspend and/or retard the decomposition process such that a breach in containment (such as caused by extreme climate, earthquake event, inappropriate land use, or long-term aging of geosynthetics) could trigger uncontrolled production and release of landfill gas and leachate, and public contact with waste. Should these research projects result in standards that can effectively determine when the waste in Subtitle D landfills no longer poses a threat, then California should consider them and pursue the development of quantifiable standards for defining the end of post-closure, if the standard can be shown to achieve greater environmental protection than current regulations.

3.3.6 Landfill Gas Control Regulations

Performance Requirements: The applicability of a more stringent requirement for the concentration of explosive gases at the facility boundary should be based on the need for additional protection of human health and the environment. The potential environmental protection benefit of requiring no detection of explosive gases (such as methane) at the landfill boundary is increased protection of human health and the environment.

The potential economic impact of requiring no detection of explosive gases is associated with increased costs to the landfill owner to provide:

1. Additional gas extraction facilities.
2. Additional gas control features (such as cut-off walls).
3. Additional buffer from surrounding populations by extension of the property boundary.

It is expected that the cost of implementing these protections may outweigh the perceived benefit of no detection of explosive gases. A more cost-effective alternative may be to require enhanced protection (above the current requirement) only in the vicinity of sensitive receptors.

The actual environmental impact of existing landfills that comply with California's current landfill gas control regulations should be thoroughly reviewed prior to the development of new regulations restricting explosive gases. It is recommended that more stringent requirements for explosive gases only be considered for adoption into the California regulations if warranted by the results of that review.

3.4 Task 7 Report—Study of Emerging Technologies in Waste Management for MSW Landfills

The purpose of Task 7 is to identify new, emerging, and advanced technologies, as well as new approaches that if applied in California could possibly improve and/or enhance the operation of California's MSW landfills. The Task 7 report also identifies those California landfill sites included in the Task 2 cross-media inventory where these emerging technologies have been implemented.

Four categories of emerging technologies are evaluated in this study: pre-treatment technologies; landfill design technologies; landfill remediation technologies; and industry standards, certification, and guidance documents. Fifteen individual technologies within these four categories are discussed in the Task 7 report and also listed in Table 3-C. These technologies were selected based on their potential to improve or enhance the operation of California's MSW landfills.

Table: 3-C: Emerging Technologies Evaluated in Task 7

Category	Technology
Pre-Treatment Technologies	• Mechanical Pre-Processing (separation, size reduction/shredding, washing/ flushing, baling) • Biological Pre-Treatment (aerobic, anaerobic) • Thermal Pre-Treatment (incineration, pyrolysis)
Landfill Design Technologies	• Anaerobic Bioreactor • Aerobic / Semi-Aerobic Landfill • Alternative Base Containment Systems (double liners, electrically-conductive liners, white liners, tensioned liners, encapsulated GCLs, inward gradient landfill) • Alternative Final Cover Systems (Monolithic ET Cover Systems, Capillary Break Cover System, Phytoremediation Cover System, Exposed Geomembrane Cover System, Delayed Closure)
Remediation Technologies	• Landfill Gas Applications (destruction, electricity, medium Btu fuel, high Btu fuel, leachate evaporation, industrial products) • Passive Aeration • Air Injection • Leachate Recirculation • Landfill Mining/Waste Recycling
Industry Standards, Certifications, and Guidance Documents	• Standards • Certifications • Guidance Documents

The discussion of each technology in the Task 7 report includes the following, where applicable:

1. A description of the technology.
2. Identification of where the technology has been implemented and presentation of a case history (where available).
3. Identification of research topics pertinent to the technology.
4. An evaluation of the viability of applying the technology in California.
5. A summary of the benefits and barriers to successful implementation of the technology.

There are many factors that affect the applicability of a particular technology at a given site. Likewise, the technologies presented in this report represent a wide range of waste management activities, making it difficult to provide an across-the-board assessment of which technologies are most applicable to California. However, several of the technologies discussed in this report are recognized to have considerable potential for successful implementation in California due to ease of implementation, successful past experiences, appropriate conditions in California, compatibility with existing regulations, and so on. These technologies include:

1. **Mechanical Pre-Processing:** A mechanical pre-processing system comprised of separation and shredding may be found to be cost effective and to preserve landfill space, as it may serve to both increase compaction (reduce the volume of material to be disposed) and enhance stabilization (accelerate degradation) of the waste mass following disposal.
2. **Anaerobic Bioreactors:** This technology may be particularly applicable in less arid parts of California, in which a new cell is designed for the recirculation of leachate (or other liquid) and the collection of landfill gas for the primary goal of enhancing waste stabilization (accelerating waste degradation) with the added benefit of generating additional disposal capacity.
3. **Alternative Base Containment Systems:** An electrical leak detection testing is probably the most cost-effective means of enhancing the reliability (in other words enhancing environmental protection) of Subtitle D liner systems. Encapsulated GCLs can significantly increase the shear strength of the GCL and may be particularly applicable to canyon landfills.
4. **Alternative Cover Systems:** Non-barrier cover systems (such as monolithic evapotranspirative cover systems, capillary break cover systems, and phytoremediation cover systems), have been developed primarily with arid and semi-arid climates in mind, as are found in most parts of California, and are expected to provide equivalent or superior infiltration control compared to the prescriptive cover system in these climates. These non-barrier cover systems may also ultimately prove to be beneficial in more temperate climates due to enhancement of waste stabilization by letting the waste breathe (i.e., mitigation of the “dry tomb” effect of a geomembrane cover) if infiltration concerns can be addressed. In addition, delayed closure may be found to be applicable in many areas of California, especially in cases where there is still significant ongoing

degradation of the waste mass following the active life of the landfill due to climatic conditions.

5. **Landfill Gas Applications:** The most viable emerging LFG application discussed in this report is the collection and re-use of LFG as a medium-Btu fuel, because minimal processing is required, capital cost is relatively low, and economic incentives may be available.

6. **Leachate Recirculation:** The recirculation of leachate in an existing landfill cell for the primary purpose of improving leachate quality, but with the added benefit of enhanced waste stabilization, may be applicable throughout California if properly designed to minimize head (the pressure exerted by a column of liquid) on the liner system and minimize the potential for seeps and stability problems.

7. **Industry Standards, Certification and Guidance Documents:** The standards and certifications described in this study are generally applicable in California, and can simplify regulatory compliance and oversight. Non-prescriptive general guidance documents can provide the owner with a framework for design and assist regulators in ensuring quality through consistency in design methods.

It should be recognized that each of technologies presented in the Task 7 report may be applicable under certain circumstances, and should not be ruled out because they have not been included in this list.

Additional information regarding the applicability of the 7 recommended technologies and approaches is provided in the following paragraphs.

3.4.1 Mechanical Pre-Processing

Waste separation has been implemented in many communities in California in the form of MRFs. These facilities are used primarily for separation of recyclable materials prior to disposal and generally do not incorporate additional mechanical pre-processing steps such as size-reduction (shredding, crushing).

Size-reduction has been found to both increase capacity due to increased initial disposal density and accelerate the degradation of waste after disposal, increasing the potential for enhanced revenue from landfill gas to energy projects. It has not been incorporated into MRFs primarily due to the added cost and the lack of a perceived benefit. If the MRF is not owned by the same company or municipality that operates the landfill, the additional cost of shredding does not provide any additional benefit to the MRF owner because landfill tipping fees are typically based on weight. Therefore, the current structure of the waste industry may limit the economic feasibility of incorporating size-reduction at MRFs, unless the shredding facility is owned by the landfill company or municipality.

Baling of waste is planned or being used at several California landfills. Baling allows for increased compaction of waste prior to landfilling, reducing demand for airspace. The bales can be stacked higher and at a steeper angle. Landfilling baled waste allows for a cleaner operation, by reducing the need for daily cover. However, placement of baled wastes in landfills may adversely affect the time required for environmental stability of the landfill as it prolongs degradation of wastes.

Current regulations place no barriers to implementation of mechanical pre-processing.

It is widely recognized that the various methods of pre-treatment are the most effective when used in combination. For instance, anaerobic or aerobic pre-treatment is greatly

enhanced when mechanically pre-processed (separation and/or shredding) waste is used. In Europe, mechanical and biological pre-treatment technologies are being used in combination to create a soil-like, low permeability, high density, low emission potential material, called mechanically-biologically processed (MBP) waste, for final disposal in a landfill. Essentially, MBP technologies achieve prior to landfilling what bioreactors attempt to achieve after landfilling. The physical characteristics of MBP waste result in reduced leachate and gas generation compared to untreated MSW and allow for the immediate re-development of a landfill site following its closure.

A review of the cross-media inventory developed as part of a previous phase of the Landfill Facility Compliance Study identifies the following landfills as having planned or implemented some form of mechanical pre-processing:

1. Fort Irwin Sanitary Landfill.
2. Edwards AFB Main Base Sanitary Landfill.
3. West Miramar Landfill.
4. Potrero Hills Landfill.
5. West Contra Costa Sanitary Landfill.

However, it is likely that some form of mechanical pre-processing is performed at other landfills in California

3.4.2 Anaerobic Bioreactors

Anaerobic technology is most advantageous with wastes with high organic content and requires relatively large quantities of liquid (generally water). The anaerobic bioreactor method can enhance the degradation of waste prior to closure of the landfill, increasing air space, the recovery and reuse of “green” energy (in the form of methane), and reducing degradation potential of the material following closure, thereby reducing the long-term effects on the environment. Due to the need for an ample liquid supply source, typically in the form of water or leachate, this technology may not be applicable in arid environments. In semi-arid conditions, a feasible alternative may be the construction of a single anaerobic bioreactor cell which is operated in tandem with traditional landfill cells, using leachate from all cells combined with surface water runoff as the liquid for injection in the bioreactor cell.

Various regulatory constraints may limit the applicability of anaerobic bioreactors. Current regulations do not allow the construction of an anaerobic bioreactor cell with any base containment system other than the Subtitle D prescriptive liner system, which may result in additional cost for the construction of a compacted clay liner on the cell side slopes. Current federal regulations further restrict recirculation to leachate that originates within the landfill, though a recent interpretation of an existing rule expanded this to include water from non-contaminated sources. In addition, existing waste management regulations require the application of a final cover system within 180 days of the closure of the landfill. Depending on the details of the individual bioreactor design, the enforcement of this regulation may limit optimization of the bioreactor system unless leachate and “make-up” water may continue to be injected beneath the final cover.

Due to the inherent heterogeneity of MSW, which can limit the effectiveness of anaerobic bioreactor landfills, it has been suggested that MSW be mechanically pre-processed prior to disposal in a bioreactor. Aerobic pre-treatment of waste prior to disposal in an

anaerobic bioreactor landfill allows for accelerated degradation of the waste mass and a shorter stabilization period after the waste has been landfilled. Anaerobic bioreactor landfills have been successfully implemented in combination with air injection, creating an aerobic landfill condition. Delayed closure of a landfill may be particularly applicable if the landfill incorporates an anaerobic bioreactor landfill. By delaying closure, the waste mass is allowed to continue to degrade and stabilize, without excessive settlement of the final cover or accumulation of landfill gas below the cover system.

A review of the cross-media inventory developed as part of a previous phase of the Landfill Facility Compliance Study identifies the following landfills as having planned or implemented anaerobic bioreactors:

1. San Onofre Landfill (proposed).
2. Yolo County Central Landfill.
3. Las Pulgas Landfill (proposed).

3.4.3 Alternative Base Containment Systems

Experience with the field performance of single composite liner systems (Bonaparte et al., 2002) indicates that liner leakage rates will be very small for MSW landfills with a single-composite liner system properly designed and constructed to minimum state and federal criteria with good construction quality assurance (CQA) practices. Therefore, enhancements to the prescriptive single composite liner system (for example, double liners or white liners) should only be necessary for MSW landfill sites in California with exceptional conditions (such as karst geological features, sites over sole source aquifers without geological barriers beneath the waste unit, or sites where groundwater cannot be monitored).

Electrically conductive geomembranes are probably the most cost-effective means of enhancing the reliability of the prescriptive single composite liner system.

Encapsulation of a GCL can significantly increase the shear strength of the GCL, and may be particularly applicable to canyon landfills, where use of a GCL is necessary because the construction of a low permeability soil liner is either cost-prohibitive or technically infeasible. Encapsulated GCLs have already been used at over a half-dozen landfills in California.

For sites with high groundwater, one alternative base containment system that may be applicable is the inward gradient landfill. The premise behind an inward gradient landfill is that by constructing the landfill cell below the surrounding groundwater table and providing a higher conductivity flow path, groundwater is directed inward toward the waste, protecting the surrounding environment from leachate contamination. However, implementation of an inward gradient landfill without construction of a base liner system, as has been implemented at sites in Canada, is precluded by state and federal regulations that require a 5-foot separation between groundwater and waste. Notwithstanding, when constructed in conjunction with a base liner, inward gradient landfill technology may be applicable to sites in California with high groundwater conditions.

The cross-media inventory developed as part of a previous phase of the Landfill Facility Compliance Study identifies the following landfills where alternative base containment system have been planned or implemented:

1. Azusa Land Reclamation Company Landfill (double liner system).

2. CWMI Kettleman Hills Facility (double liner system).
3. Rock Creek Solid Waste Facility (double liner system).
4. Woodville Disposal Site (white geomembrane).

3.4.4 Alternative Cover Systems

In general, non-barrier cover systems (such as monolithic evapotranspirative cover systems, capillary break cover systems, and phytoremediation cover systems) have been developed with arid and semi-arid climates in mind, as are found in many parts of California. However, regulatory limitations (such as conditional long-term approvals) may dissuade owners from employing them. Studies are ongoing to evaluate the performance of these types of alternative cover systems in arid and semi-arid climates. These studies generally employ conditional approvals, wherein the owner is prohibited from withdrawing money from financial assurance funds until after several years of post-construction monitoring has been completed. While regulations that allow for engineered alternatives to the prescriptive cover system facilitate the application of alternative cover systems in California, long-term conditional approvals may dissuade some owners from employing alternative covers even in cases where it is recognized that the prescriptive cover (including a clay barrier layer) will not perform satisfactorily.

Monolithic Evapotranspirative Soil Cover System

The monolithic evapotranspirative (ET) soil cover is the most common alternative cover system installed in arid and semi-arid regions of the western United States. Over a dozen ET covers have been granted conditional approval in southern California. An ET cover relies on the storage capacity, evaporation and transpiration characteristics of the cover soil. Infiltrating surface water is stored in the cover soil during the wet periods and released to the atmosphere through evaporation and transpiration during the dry season.

A review of the cross-media inventory developed as part of a previous phase of the Landfill Facility Compliance Study identifies 22 landfills where monolithic soil covers have been proposed or implemented. However, the cross-media inventory does not specify whether these covers have been designed as monolithic ET soil covers and thus are not listed here.

Capillary Break Cover System

A capillary break cover system is an ET cover system that uses a layering sequence that inhibits infiltration by fully utilizing capillary suction within the cover soils. A capillary break cover system is similar to a monolithic ET cover in that it is dependent upon the evaporation and transpiration characteristics of the cover soil to minimize infiltration. However, proper design of a capillary break cover system allows the storage capacity of the cover soil to be maximized. In addition, the capillary break cover facilitates the collection of landfill gas from the capillary break layer (which the ET cover does not include).

Phytoremediation Cover System

Similar to an ET cover system, a phytoremediation cover system uses a monolithic soil cover and relies on the storage capacity and evaporation and transpiration characteristics of the cover soil to minimize percolation into the waste mass. However, unlike an ET cover system, a phytoremediation cover system is designed to incorporate a variety of vegetative types, from grasses to trees, which minimize infiltration and enhance

degradation of the waste mass. A phytoremediation cover may actually rely upon intrusion of the root system into the waste or contaminated soil to facilitate degradation.

Use of a phytoremediation cover system may not be applicable in conjunction with some technologies for enhanced degradation of the waste, such as leachate recirculation, air injection, or passive aeration. The build-up of landfill gas under this type of cover system is detrimental to its effectiveness.

Exposed Geomembrane Cover System

An exposed geomembrane cover system (EGCS) generally consists of a geomembrane overlaying a foundation soil layer without drainage, topsoil or vegetation layers that may be included in a typical cover system. An EGCS may be considered as a viable alternative to a typical cover system in certain special situations where aesthetics are not a significant issue, infiltration control is critical, or stability concerns preclude placement of a vegetative cover soil layer.

In general, exposed geomembrane cover systems are applicable to sites in California for limited term applications (up to 10 to 20 years). However, sites with high winds or aesthetic requirements may not be suitable for application of this technology. There are no barriers in the current regulations to the application of this technology.

Use of exposed geomembrane cover systems as sites where landfill mining is planned can reduce costs and simplify operations. Use of an exposed geomembrane cover system may not be applicable in conjunction with some technologies for enhanced degradation of the waste such as leachate recirculation, air injection, or passive aeration. The build-up of landfill gas under this type of cover system is detrimental to its effectiveness.

A review of the cross-media inventory developed as part of a previous phase of the Landfill Facility Compliance Study identifies one landfill in California where an exposed geomembrane cover system is proposed: Azusa Land Reclamation Company Landfill.

Delayed Closure

As suggested by the U.S. EPA (*Design and Construction of RCRA/CERCLA Final Covers*, 1991), it may be appropriate to propose the installation of an intermediate cover instead of a final cover for two to five years following the end of waste placement to allow anticipated settlement of the waste mass to occur. This concept is not new, but it has not yet been widely implemented. Sites continue to be closed soon after waste placement. This practice reduces the generation of leachate and may allow the site to be redeveloped quickly, but dramatically slows the degradation process. By allowing a delay in closure, the waste continues to degrade, reducing the potential for long-term impacts on the environment.

Delayed closure is generally applicable to sites throughout California, depending on the characteristics of the waste, the local climate, and the type of base containment system. Delayed closure may not be applicable in areas where urban development has encroached upon a site, as such sites are generally pressured to close shortly after waste acceptance is ceased, in order to mitigate nuisance concerns such as odors and vectors.

Delayed closure of a landfill may be particularly applicable if the landfill incorporates a technology for enhanced degradation prior to closure, such as an anaerobic bioreactor landfill or an aerobic/semi-aerobic landfill. By delaying closure, the waste mass is

allowed to continue to degrade and stabilize, without excessive settlement of the final cover or accumulation of landfill gas below the cover system.

No sites have been identified where delayed closure has been approved by a regulatory agency to allow enhanced degradation of the waste mass prior to closure. One site, Millikin Landfill in California, is reportedly nearing the end of a four-to-five-year delayed closure, though the purpose of this delay has not been identified and regulatory approval of the delay has not been verified.

3.4.5 LFG Use as Medium-Btu Fuel

One of the simplest and most direct ways to use LFG is through direct use as a medium-Btu fuel. Common medium-Btu fuel uses include industrial boiler fuel, wastewater treatment plant sludge incinerators, and steam space heat. A recent innovative use is to provide heat for greenhouses. Utilization of LFG as a medium-Btu fuel should not face significant implementation hurdles in California from either a regulatory or economic standpoint.

The collection of LFG for use as a medium Btu fuel (as opposed to destruction by flaring) may reduce the potential environmental impact of accelerated LFG production expected with waste shredding, anaerobic bioreactor landfills and leachate recirculation.

A review of the cross-media inventory developed as part of a previous phase of this Landfill Facility Compliance Study identifies four landfill sites in California that have planned or implemented landfill gas medium-Btu projects:

1. Bradley Landfill West and West Extension.
2. Cold Canyon Landfill Solid Waste Disposal Site.
3. Lopez Canyon Sanitary Landfill.
4. University of California Davis Sanitary Landfill.

3.4.6 Leachate Recirculation

Leachate recirculation is most beneficial with wastes with high organic content, and its successful application is dependent on the composition of waste at the site, local climate conditions, and local site conditions. It should generally be applicable at all lined landfill sites to reduce leachate management costs and improve leachate quality. Leachate recirculation accelerates stabilization of waste, decreasing long-term environmental risk, while increasing the potential for increased revenue from the sale of landfill gas as an energy source. Because low-permeability daily cover soil can inhibit the penetration of liquid and the distribution of moisture within the waste mass, alternative daily covers may be advisable at sites where the daily cover soil is low-permeability in nature. However, there do not appear to be any other barriers to leachate recirculation at lined landfill sites, and many lined sites within California recirculate leachate over lined areas for dust control.

Existing waste management regulations require the application of a final cover system within 180 days of the closure of the landfill. Unless leachate is reinjected under the final cover, the enforcement of this regulation may limit optimization of the leachate recirculation system for improving leachate quality.

Due to the inherent heterogeneity of MSW, which can limit the effectiveness of leachate recirculation systems, it has been suggested that MSW be mechanically pre-processed prior to disposal in a landfill cell where leachate recirculation is practiced. In addition, aerobic pre-treatment of waste prior to disposal in a leachate recirculation system allows for increase moisture content of the waste as well as accelerated improvement of leachate quality. Leachate recirculation systems have been successfully implemented in combination with air injection, creating an aerobic landfill condition. To achieve proper moisture conditions within the landfill, lower temperatures and enhance degradation, leachate recirculation may be used in conjunction with passive aeration for remediation of an existing landfill or landfill cell.

A review of the cross-media inventory developed as part of Task 2 of the Landfill Facility Compliance Study identifies six landfill sites in California that have planned or implemented leachate recirculation:

1. Central Landfill.
2. Keller Canyon Landfill.
3. Vasco Road Landfill.
4. Acme Landfill.
5. Badlands Sanitary Landfill.
6. Potrero Hills Landfill.

3.4.7 Industry Standards, Certifications, and Guidance Documents

Adherence to industry standards and self-certification can simplify regulatory oversight. The standards and certifications described in this study are generally applicable in California on a voluntary basis. Methods to provide incentives for owners to voluntarily adopt these programs may be one way to encourage further implementation of these programs.

Non-enforceable general guidance or training documents can be beneficial in that they provide the owner with a framework for design, and they assist regulators in ensuring quality through consistency in design methods. However, care must be taken so that the document is not too prescriptive, rigid, or inflexible.

4 Comprehensive Recommendations

This section considers collectively the findings of the Phase I, Phase II, Task 6, and Task 7 reports to identify those recommendations that are expected to have the most immediate tangible benefits to the environmental performance of landfills if implemented in California. These recommendations may include changes to industry practices or California's existing regulations. Many of the recommendations from the previous tasks, all of which are presented in Section 3 of this report, are not included in this section. A recommendation is not included in this section if the potential environmental protection benefit associated with the change is not readily apparent when compared to current practices or regulations. Likewise, a recommendation is not included in this section if substantial additional study is required prior to implementation of the change.

Previous studies of the environmental impact of landfills, as well as the environmental protection benefit of landfill regulations, have placed considerable emphasis on leachate leaks from landfills and base containment systems (base liner and leachate collection and removal system [LCRS]). For example, at the State level, California's Solid Waste Assessment Test was performed in the 1980s and 1990s to identify leaking landfills and to address the impacts of leakage from solid waste disposal sites on the waters of the state.

More recently, on the national level, the U.S. EPA's 2002 "Technical Resource Document: Assessment and Recommendations for Optimal Performance of Waste Containment Systems" (Bonaparte et al., 2002) evaluated the performance of base containment system components using laboratory tests and field data. This emphasis on base containment is not surprising, since landfill leakage is a direct pathway for impacting the waters of the state. As such, considerable attention has been given to the development and performance of base containment systems through research, field tests and landfill regulations; and all new MSW waste disposal units constructed since 1993 have some degree of base containment included in the design and an LCRS for removing leachate before it impacts the environment.

Because base liners and leachate removal have been addressed diligently in research and regulation to date, this report does not focus on changes to California's base containment regulations. Rather, the Landfill Facility Compliance Study finds that the potential for negative impacts on the environment due to landfill gas migration is significant, and is inadequately addressed in the existing regulations. The issues associated with the migration of landfill gas have been addressed in every stage of this study. As such, landfill gas monitoring and control is given first priority in Section 4.1, with respect to proposed changes to the existing regulations and current practices. These recommendations for changes with landfill gas monitoring and control, as well as surface water control, are detailed in the remainder of this section.

4.1 Landfill Gas Monitoring and Control

Landfill gas generation begins as soon as waste is placed. Landfill gas is highly mobile, and can move out of the landfill in any direction (by comparison to leachate, which generally moves downward). The installation of a base containment system helps to contain landfill gas from migrating downward, but it can still migrate upward and horizontally from the landfill unless gas controls are installed.

The status of landfill performance with respect to landfill gas compliance and control was defined in the Phase I report. Recurring issues associated with landfill gas were defined in the Phase II report. Other states' landfill gas monitoring and control regulations were reviewed in the Task 6 report. Emerging technologies for landfill gas control were identified in the Task 7 report.

Existing Regulatory Requirements

The monitoring and control of gas at active and closed landfill sites is currently addressed in California's landfill regulations in 27 CCR, sections 20919 though 20937. There are also federal Title V Clean Air Act requirements[‡‡] for landfill gas monitoring and control at landfills with certain size and emissions characteristics. The primary intent of California's landfill gas related regulations is to protect public health and the environment at adjacent properties from the hazards associated with explosive gas. These regulations address monitoring and control of methane inside structures and at the property boundary, providing monitoring criteria, concentration limits, and gas control requirements, with some additional consideration given to the migration of "trace gases" during post-closure care.

Regulatory Deficiencies

In the course of the Landfill Facility Compliance Study, deficiencies in the existing regulations for the monitoring and control of landfill gas have been identified, as follows.

1. The existing regulations do not explicitly require monitoring for landfill gas for the purpose of protecting the waters of the state (Phase II report).
2. The existing regulations for monitoring and control of landfill gas at the property boundary are more stringent and better defined during the post-closure care period than during the active life of a landfill (Phase II report).
3. The concentration limit for methane at the property boundary is the LEL, which is less stringent than several other states' requirements (Task 6 report).

Changes to the existing regulations are recommended to address the first two deficiencies and are discussed further below Section 4.1. The concentration limit for methane at the property boundary is discussed further in Section 3.3.9, and additional study is recommended before the regulations are changed.

Status of California MSW Landfills

The current status of California MSW landfills, as identified in the Phase I report (GeoSyntec, *Phase I Report*, 2003), finds that 46 percent of the 224 existing landfills included in the study have engineered landfill gas collection systems. Based on the existing regulations, gas control systems may be required under the following conditions:

1. If a "hazard or nuisance" has been identified during the active life of the landfill.
2. During the post-closure care period to control the migration of explosive gases.

‡‡ Title 40, of the Code of Federal Regulations, Part 70 provides for the establishment of comprehensive state air quality permitting systems consistent with the requirements of Title V of the Clean Air Act (Title 42, U.S. Code, section 7401, et seq.). These regulations define the minimum elements required by the Clean Air Act for state operating permit programs and the corresponding standards and procedures by which U.S. EPA will approve, oversee, and withdraw approval of state operating permit programs.

3. If the landfill has certain size and emissions characteristics to require one under the federal Title V Clean Air Act regulations.

Some of the sites that have installed landfill gas control systems may have done so as a proactive measure to prevent the migration of landfill gas, without being required by the regulations.

As identified in the Phase II report, at least 19 of 53 landfills included in the Phase II study have had impacts to groundwater due to landfill gas. Of these 19 sites, 9 (47 percent) are fully unlined, 8 (42 percent) are partially unlined, and 2 (11 percent) are fully lined.

Based on a review of the Task 2 cross-media inventory, of the 19 landfills with landfill gas impacts to groundwater, the median depth to underlying groundwater was 26 feet.

Based on the statistical analysis of the cross-media inventory described in the Phase I report (GeoSyntec, 2003, p. 50), fully covered sites were found to be 7.3 times less likely than fully uncovered sites to "Have Gas Enforcement Actions." [§§] This finding suggests that landfills that have undergone closure and have been covered with a final cover are less prone to violating the State minimum standards for gas-related performance.

As identified in the Phase II report, at least four of the 53 landfills included in the Phase II study are performing monitoring of the vadose zone near the waste limit to detect releases of landfill gas as early as possible, protecting against explosive gas migration and potential impacts to groundwater due to trace gases.

Recommended Changes to Existing Regulations and Landfill Practices

To address the recurring issue of landfill gas impacts to groundwater, it is recommended that landfill gas monitoring be either explicitly incorporated into the regulations as part of the detection monitoring program for water quality or more widely encouraged by the RWQCBs. Incorporating landfill gas monitoring into the unsaturated zone monitoring program has the potential to improve environmental performance by identifying conditions that could lead to groundwater impacts before they occur. If the release of landfill gas is identified and mitigated prior to impacts to the groundwater, the groundwater contamination would be reduced.

In addition, to address the issue of landfill gas impacts to groundwater as well as the migration of explosive gases, it is recommended that the regulatory agencies promote monitoring for explosive gases in the vadose zone closer to the waste mass at sites with larger buffers. Performing explosive gas monitoring closer to the waste mass allows the detection of landfill gas migration closer to the source, so that the landfill may implement the necessary controls to avoid landfill gas impacts to groundwater, human health, and the environment.

To address the potential for explosive gas impacts during the active life of a landfill, it is recommended that the landfill gas monitoring and control requirements for the active life of the landfill be as comprehensive as is currently required for post-closure care. The anticipated environmental protection benefit of implementing the same requirements for the active life of the landfill as is currently required for post-closure care is that the

[§§] Findings were based on a 90 percent significance level.

potential for landfill gas to migrate off-site undetected through the subsurface is reduced prior to closure.

4.2 Surface Water Controls

The purpose of surface water controls at landfills is to prevent impact to the waters of the state through the off-site discharge of sediment and leachate to surface water. Therefore, the performance of the surface water controls is instrumental in protecting the waters of the state.

Surface water controls have been considered mostly in the Phase I and Phase II reports. The status of landfill performance with respect to surface water controls was presented in the Phase I report. Recurring issues associated with surface water controls, namely winterization issues, were defined in the Phase II report. No emerging technologies for control of surface water were identified in the Task 7 report.

Existing Regulatory Requirements

The regulations in 27 CCR, section 20365 for design and construction standards of surface water controls are enforced by the RWQCB. The regulations in 27 CCR, sections 20820 and 21150 for design and maintenance of surface water controls are enforced by the EA, and regular inspections of these systems are performed by the EA.

Regulatory Deficiencies

The existing regulations have no requirement for the submission of an annual winterization plan. However, the RWQCB or EA can require them as part of permit conditions.

Status of California Landfills

The current status of California landfills, as identified in the Phase I report, finds that impacts to surface water (such as leachate seeps and excessive erosion) are less in dry climates than in wet ones, and that impacts to surface water are generally less after a site has been closed.

However, the Phase II report found that the seven of 53 landfills that were identified with storm-related and surface water related compliance issues have different precipitation conditions. The average rainfall range for these sites is from 5 to 35 inches per year with a mean value of 15 inches per year.

Of the 237 California landfills included in the cross-media inventory, 96 (less than half) have a rainfall greater than 15 inches per year.

In addition, as presented in the Phase II report, four (of 53) sites indicated that winterization plans had helped comply with surface water requirements. These sites also have very different precipitation conditions. The average rainfall is 6, 16, 18, and 40 inches per year for these four sites. The waste discharge requirements (WDR) for the two sites with the most rainfall require a winterization plan.

It should be recognized that it is not always the total volume of precipitation that is the problem but the intensity of the precipitation. Some desert sites with less than 6 inches of rain per year can get one-third to one-half of the yearly total in one short-duration storm.

Recommended Changes to Existing Regulations

It is recommended that all landfills be either explicitly required to submit a winterization plan annually for review and approval by the EA with the concurrence of the RWQCB, or that the regulatory agencies promote this practice. Winterization plans have been indicated to be helpful in complying with surface water and leachate control requirements at sites with a variety of climatic conditions. In addition, surface water and leachate control compliance issues have occurred at sites with different climate conditions. The potential environmental protection benefit associated with requiring a winterization plan is that landfills may be better prepared to handle winter storms. This could reduce the potential for erosion of cover, inundation of drainage features, and leachate control problems.

5 References

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