County Sanitation Districts of Los Angeles County
Whittier, California

Radioactivity Sampling Report
for
Calabasas Landfill
Agoura, California
(File No. 60-118)

January 2003

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Authorization Certification

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Executive Summary

The Regional Water Quality Control Board, Los Angeles Region (RWQCB) has required that the County Sanitation Districts of Los Angeles County (Sanitation Districts) perform testing for radioactive constituents in liquid samples from the Calabasas Landfill. Concerns have been raised that the Calabasas Landfill took building debris from Rocketdyne's Santa Susana Field Laboratory in Simi Valley that contained traces of radioactivity. This report presents the results of radioactivity sampling and analysis of liquid samples at the Calabasas Landfill.

The Calabasas Landfill is a Class III municipal solid waste disposal facility located in western Los Angeles County near the Ventura County border. The geologic materials beneath the site store and transmit limited quantities of groundwater and natural groundwater quality is poor. Therefore, there are no significant uses of groundwater in the areas surrounding the landfill. A number of water quality protection facilities have been installed at the site including composite liner systems, subsurface barriers, and groundwater extraction wells. Older areas of the landfill are unlined or lined with compacted clay, while newer areas are underlain with composite liner systems. Areas downgradient of older unlined areas of the site have detections of volatile organic compounds (VOCs) from the landfill, while areas downgradient of the newer lined areas of the site are unaffected by the landfill. Corrective actions have been implemented to address landfill affects on groundwater.

The hydrogeology of the site is complex. The site is underlain by unconsolidated materials and folded and faulted bedrock formations. Groundwater occurs in shallow canyon alluvial deposits, in the permeable bedrock units, in the fractured fine-grained bedrock units, and in surface seeps. Generally, shallow groundwater flow appears to mimic the surface topography with preferential groundwater flow toward the historic alluvial canyons that have been severed by subsurface barriers. Because of the various different geologic materials encountered at the site and the different travel paths and residence times of groundwater within those formations, natural water quality at the site can vary considerably over relatively short distances.

Groundwater samples were collected from four downgradient VOC-affected monitoring wells (downgradient monitoring wells), from three unaffected monitoring wells (background monitoring wells), and from four liquid collection and recovery systems (LCRSs) and analyzed for specific conductance, gross alpha/beta particle activity, tritium, isotopic uranium (i.e., uranium-234, uranium-235, and uranium-238), radium-226, radium-228, and strontium-90. One LCRS sample was also analyzed for potassium, potassium-40, and cesium-137. The radioactive constituents tested by the Sanitation Districts exceed minimum sampling requirements specified by the RWQCB.

All downgradient monitoring well sample results were within the range of results found in background samples. LCRS samples have alpha activity, beta activity, and uranium detections that overlap with, and in some cases slightly exceed the range of the results found in background samples. The LCRS results for alpha activity and uranium are likely the result of naturally-occurring uranium found in onsite shales used for daily cover. The slightly elevated beta activity results for the LCRS samples indicate that low levels of radioactivity associated with household wastes may be found in the landfill LCRS liquids, with a significant portion being likely related to naturally-occurring radioactive potassium-

40. Additional beta activity may be related to beta-emitting daughter products derived from the natural uranium-234 and uranium-238 also present in LCRS liquids.

While uranium and alpha particle activity concentrations in the downgradient monitoring wells exceed their respective maximum contaminant levels (MCLs) for drinking water, these levels appear to reflect natural sources rather than a release from the landfill, since background well and some DHS drinking water sources in Los Angeles and Ventura Counties also exceed MCLs.

The radioactivity data collected for the Calabasas Landfill indicate no evidence of radioactive waste disposal from the Rocketdyne facility. However, slightly elevated levels of alpha and beta activity, and uranium in LCRS samples indicate that low levels of radioactivity associated with household products and food, and uranium-bearing shales used for daily cover have been detected in the landfill LCRS liquids. This radioactivity is contained by the various landfill containment systems and does not impact groundwater beneath the site. Levels of radioactivity in monitoring wells are consistent with natural sources.

1 Introduction

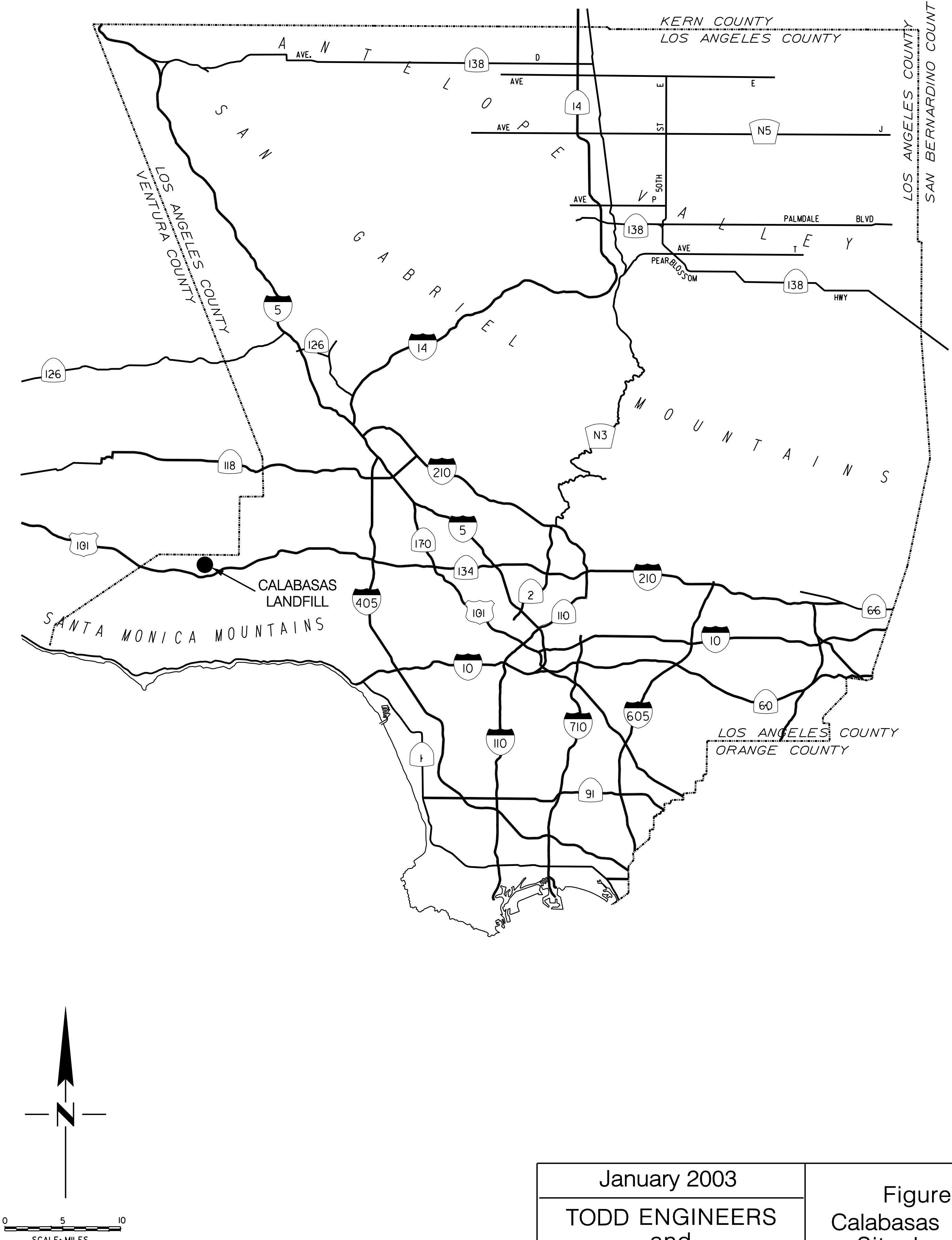
The Regional Water Quality Control Board, Los Angeles Region (RWQCB) has required that the County Sanitation Districts of Los Angeles County (Sanitation Districts) perform testing for radioactive constituents in liquid samples from the Calabasas Landfill (RWQCB, August 2002). The RWQCB has also required similar sampling at the Sanitation Districts' Puente Hills Landfill. A number of additional landfills across the state have been required to perform such sampling with the purpose of establishing basic information on radioactivity characteristics of LCRS liquids and groundwater beneath active landfills in the state.

It is believed that the Calabasas Landfill was selected for inclusion in the statewide radioactivity sampling program because of concerns that building debris with traces of non-regulated radioactive constituents from Rocketdyne's Santa Susana Field Laboratory in Simi Valley may have been disposed at the Calabasas Landfill. The Sanitation Districts have reviewed several hundred Rocketdyne documents to determine the disposition of this debris. These documents included regulatory agency correspondence, remediation and radiological survey reports, and waste hauler and disposal records. The Sanitations Districts have found no evidence of any radioactive materials from Rocketdyne at the Calabasas Landfill (Sanitation Districts, December 2002). This report presents the methodology and results of the radioactivity sampling conducted by the Sanitation Districts at the Calabasas Landfill. Interpretation and conclusions regarding the data are also presented.

2 Background

The Calabasas Landfill is a Class III municipal solid waste disposal facility located on Lost Hills Road near the Ventura Freeway (U.S. 101) in Western Los Angeles County near the Ventura County border (Figure 1). There are no significant uses of groundwater in the areas surrounding the landfill. The area of landfilling at the site is shown in Figure 2. A number of water quality protection facilities have been installed at the site including composite liner systems, subsurface barriers, and groundwater extraction wells. Older areas of the landfill are unlined or lined with compacted clay, while newer areas are underlain with composite liner systems.

Landfill effects on groundwater have been observed downgradient of the older, unlined areas of the site. The Sanitation Districts have implemented an evaluation monitoring program and a corrective action program to address these landfill effects. Generally, monitoring results indicate that low-level volatile organic compounds (VOCs) detected downgradient of the unlined areas have stabilized or are decreasing as a result of corrective actions. No landfill effects on groundwater have been detected downgradient of the newer, lined areas of the landfill.



Source: Sanitation Districts of Los Angeles County, 2001

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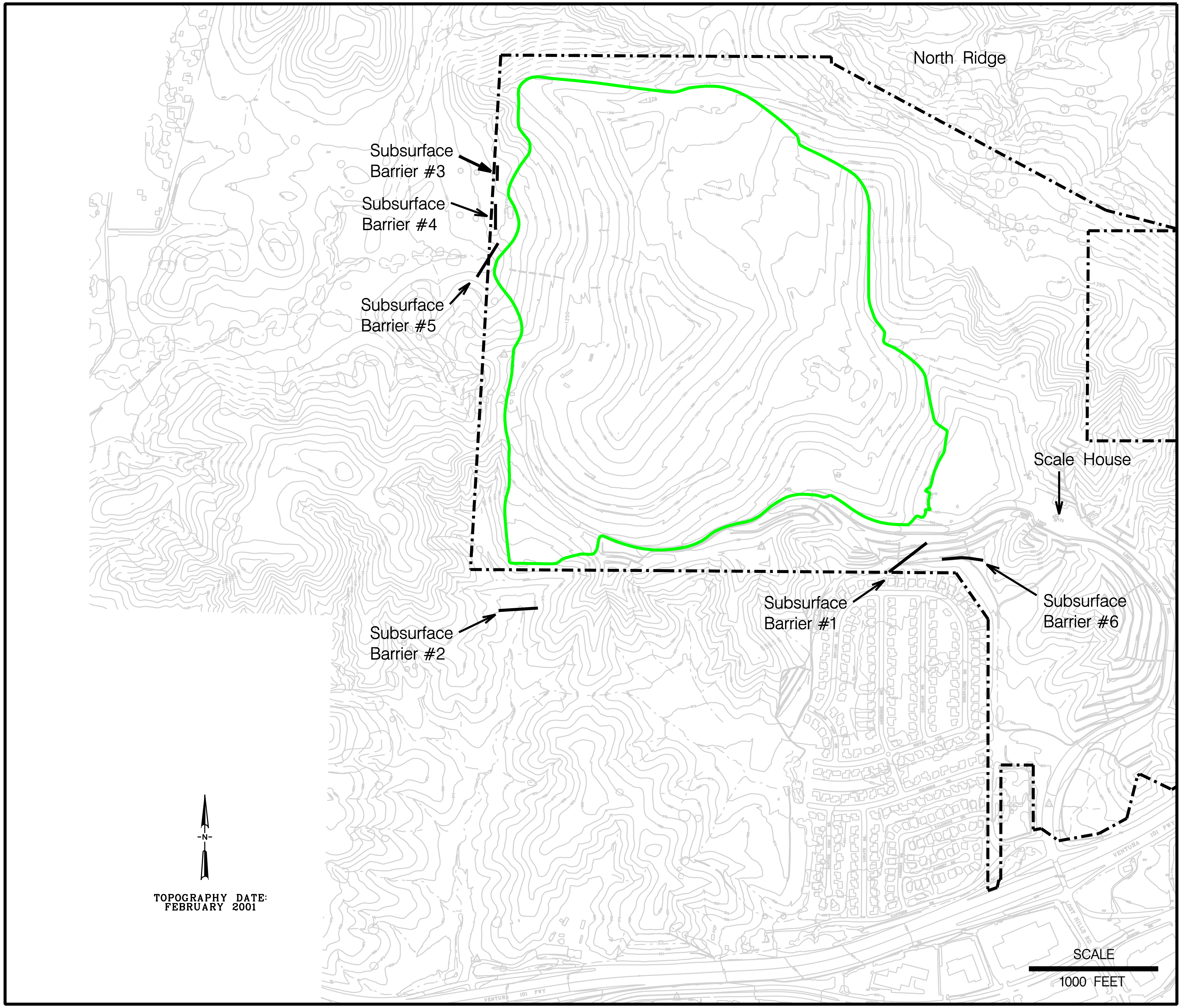
Figure 1
Calabasas Landfill
Site Location



LEGEND

- ‒·‒·‒ PROPERTY LINE
- 🟩 LIMIT OF REFUSE
- ── EXISTING SUBSURFACE BARRIER

Figure 2
Areas of Landfilling
at Calabasas Landfill

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3 Containment Facilities

Groundwater containment facilities installed at the site include subsurface barriers, extraction wells, clay liners, and composite liner systems. Six subsurface low permeability (cement/bentonite) barrier walls have been constructed to impede the movement of shallow groundwater from the site. The barriers have been constructed across historic canyon areas, where groundwater flow that would otherwise leave the site is focused. Figure 2 shows the locations of the barriers. Barriers 1, 2 and 5 are oriented perpendicular to three canyons that historically drained the unlined portion of the landfill and are located on the south and west sides of the site. Barriers 3, 4, and 6 are located across canyons downgradient of lined areas of the landfill.

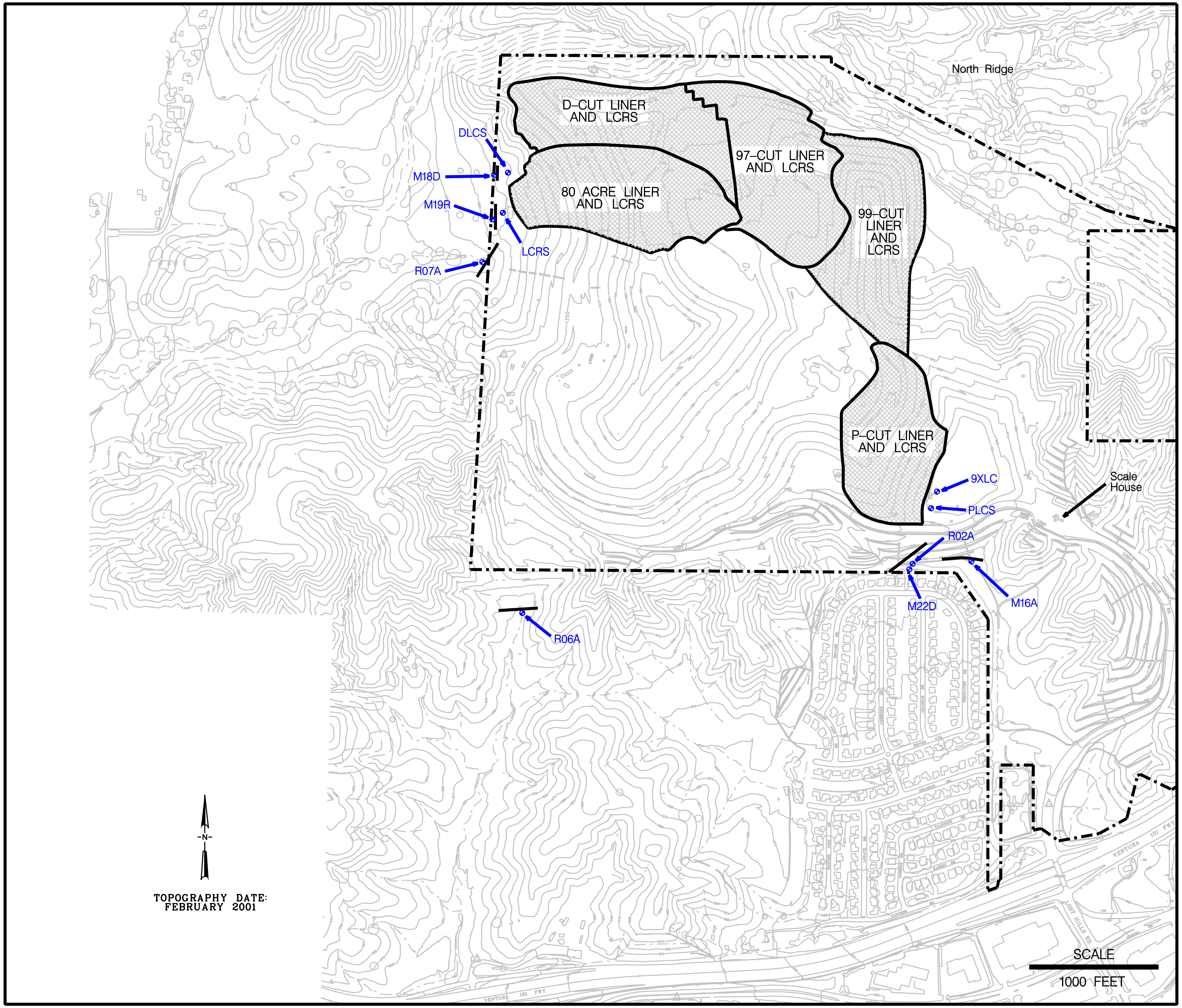
Extraction wells have been installed at all of the barriers to provide hydraulic containment of groundwater. There are three to four extraction wells upgradient of each of the six barriers.

Five composite liner systems have been installed at the Calabasas Landfill. The older southwestern area of the landfill is unlined. Newer areas of the landfill site have been underlain with composite liner systems as shown in Figure 3. A Liquid Collection and Removal System (LCRS) is an integral part of a composite liner system. Composite liners are composed of three essential elements: (1) low permeability clay liner, (2) synthetic liner and (3) an LCRS. The LCRS is located immediately above the liner elements and consists of a high permeability gravel drainage layer and collection pipes to collect any fluids generated from the landfill. The five composite liner systems include the 80-Acre Liner, the D-Cut Liner, the 97-Cut Liner, the 99-Cut liner, and the P-Cut liner.

4 Hydrogeologic Setting

The Calabasas Landfill is located in the south central portion of the Western Transverse Range in the Santa Monica Mountains. The Transverse Range Province is characterized by east-west trending faults and mountains of uplifted and folded Tertiary sedimentary rocks with intervening valleys. The Simi Hills are located to the north of the site, Las Virgenes Canyon to the east and Cheeseboro Canyon to the west. The geologic materials beneath the site store and transmit limited quantities of groundwater. The adjacent hydrologic areas also produce limited amounts of groundwater. In addition, water quality in adjacent subareas is poor due to elevated dissolved solids. At present, there is no municipal use of groundwater in the area of the landfill since all residents in the area use imported water provided by the Las Virgenes Metropolitan Water District. Thus, there are no significant uses of groundwater in the areas surrounding the landfill, and this condition is unlikely to change in the future.

The geology of the site includes unconsolidated materials and bedrock. Unconsolidated materials at the site include solid waste refuse, engineered fill, landslide deposits, colluvium, and alluvium. Landslide deposits have been identified along north facing slopes near the northern border of the property. Colluvial deposits occur as thin loose debris on hillside slopes. Alluvium occurs in several shallow canyon drainages. Bedrock includes units of the Modelo, Lindero Canyon, and Topanga Formations. Bedrock units include shale, claystone, siltstone, sandstone, and conglomerate. Of particular interest to this study is the occurrence of black shales in the Modelo Formation, which historically



LEGEND

-·-·-	PROPERTY LINE
●	MONITORING LOCATION (Radioactivity Sample Collected)
—	EXISTING SUBSURFACE BARRIER
▨	LIMIT OF COMPOSITE LINER

Figure 3
Location of Containment Features and Monitoring Locations

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outcropped along the base of the north ridge (Figure 2). Black shales are known to contain elevated uranium concentrations (Quinby-Hunt, et al., 1989).

The structural geology at the Calabasas Landfill is complex. Bedrock in the vicinity of the Calabasas Landfill has undergone two episodes of regional deformation resulting in folding and faulting. During the first event, the area was compressed in an east-northeast syncline whose axis is located north of the site. Hence, the site is located on the southern limb of the syncline. Subsequently, smaller scale folds trending northwest were superimposed on the syncline. Generally, bedrock strata at the Calabasas Landfill strike southeast-northwest and dip to the northeast. In the northern and northeastern area of the site, the upper Topanga and the Modelo Formations strike northeast and dip to the northwest. The southern area of the site is more structurally complex with shale/siltstone beds of the Topanga Formation complexly and tightly folded and faulted.

Several faults have been identified at the site, although there are no known active faults (i.e., inactive for at least 11,000 years) onsite or within 200 feet of the site. Investigations have identified several faults in the southwest corner of the site. In addition, northeast trending faults near the scale house and on the south side of the north ridge have been located (Figure 2). Faulting near the P-Cut area has been inferred based on a shear zones.

Groundwater occurs at the Calabasas Landfill in a variety of hydrogeologic settings. Groundwater occurs in the shallow canyon alluvial deposits, in the sandstone and conglomerate units of the Modelo, Lindero, and Topanga Formations, and in the fractured shale/siltstone units of the Topanga and Modelo Formations. Groundwater has also been encountered as surface seeps.

Generally, shallow groundwater flow appears to mimic the surface topography. Groundwater in the fractured Topanga shale/siltstone which underlies most of the southern portions of the landfill, flows toward the southeast canyon area at Barriers 1 and 6 and toward the southwest canyon area at Barrier 2. In the northern and central portion of the landfill, groundwater occurs in the Modelo Formation sandstones and conglomerates. Groundwater elevation data indicate that groundwater flows toward the west near Barriers 3, 4, and 5.

Because of the various different geologic materials encountered at the site and the different travel paths and residence times of groundwater within those formations, natural water quality at the site can vary considerably over relatively short distances.

5 Sampling

To assess the concern that wastes containing radioactivity may have been disposed at the Calabasas Landfill, groundwater monitoring wells and LCRSs were sampled for alpha and beta particle activity and selected radioactive isotopes. The sampling locations, parameters, and methods are presented below.

5.1 Locations and Rationale

The RWQCB (August 2002) requested that liquid samples be collected from the following:

1. All LCRSs;
2. For landfills that have not experienced a release of waste constituents to groundwater, at least one sample from a potentially unimpacted monitoring well;
3. For landfills that have experienced a release of waste constituents to groundwater, at least one sample from an impacted monitoring well; and
4. At lease one sample from a monitoring well representative of ambient background conditions.

In accordance with RWQCB's requirements, samples from these monitoring facilities were collected and analyzed for radiochemicals. This suite of radioactive constituents analyzed by the Sanitation Districts exceeds the minimum list of parameters required by the RWQCB.

5.1.1 LCRS Sampling

The Sanitation Districts obtained four LCRS samples and seven groundwater samples at the Calabasas Landfill for the purpose of determining whether wastes containing low-level radioactivity may have been disposed of at the site. The Calabasas Landfill has been equipped with five composite liners: 80-Acre, D-Cut, P-Cut, 97-Cut and 99-Cut liners, as indicated in Figure 3. These composite liner systems have effectively prevented landfill affected liquids from entering underlying formations. Consequently, monitoring wells downgradient of these liners have not been affected by the landfill. Each of these LCRSs was sampled separately with the exception of the 97-Cut and 99-Cut. The LCRS piping from these liners were combined for operational necessity in 2002. Hence, LCRS samples were obtained from the 80-Acre LCRS (sample name: LCRS), D-Cut LCRS (sample name: DLCS), P-Cut LCRS (sample name: PLCS), and the 97-Cut and 99-Cut LCRSs (sample name: 9XLS).

5.1.2 Landfill-Affected Monitoring Well Sampling

Unlined areas at the Calabasas Landfill are underlain by low permeability geologic formations. These areas commenced landfill activities before composite liners were developed. Because these areas are not underlain by a composite liner, VOCs have been detected in downgradient groundwater monitoring wells. An evaluation monitoring program was conducted to determine the nature and extent of the VOCs in the groundwater; and a corrective action program has been implemented to remediate these unlined areas.

As described in Section 4, preferential groundwater movement from the site could occur within historic canyons beneath the unlined portions of the site. These potential pathways were severed by three subsurface cement bentonite barriers that were installed in the mid-1980s (Barriers 1, 2 and 5). A representative groundwater monitoring well, downgradient of each of these barriers, was sampled for radiochemical analysis (R02A, R06A and R07A). These wells are referred to as "downgradient monitoring wells" throughout the text. These downgradient monitoring wells have historically detected the highest levels of VOCs for each respective unlined area. An additional monitoring well, M22D, located downgradient of R02A, was inadvertently sampled for radiochemistry and those results are also included herein.

5.1.3 Background Monitoring Well Sampling

Radioactive isotopes occur naturally in the environment and are found at some level in all sources of water. In order to interpret the results from downgradient monitoring wells affected by VOCs from the landfill and LCRSs, it is necessary to have reference data that represent background levels of radioactivity. Ideally, background wells located upgradient of refuse disposal area would provide information on regional background conditions. However, due to the complex hydrogeology at the Calabasas Landfill, natural groundwater quality is highly variable both temporally and spatially. Thus, there are no upgradient areas which could provide groundwater quality results representative of unaffected downgradient groundwater. Therefore, to obtain data representative of local background conditions, the Sanitation Districts sampled monitoring wells M16A, M18D and M19R. These wells are located downgradient of composite liners or areas that have not yet received refuse (i.e., monitoring well M16A). M18D and M19R are downgradient of the 80-Acre area, which is lined for the purpose of groundwater protection. These monitoring wells have not been affected by the landfill. Consequently, results obtained from these wells can be utilized to provide a general indication of background groundwater quality. M16A is located at the mouth of a native canyon on the southeast portion of the site. The groundwater flow received at M16A originates to its northeast, away from unlined disposal areas. Because the groundwater flow at M16A is hydraulically isolated from all waste disposal areas, the data at this location is also representative of local background conditions.

5.2 Sampling Procedures and Analysis

5.2.1 Sampling Procedure

Monitoring facilities were sampled in accordance with the following procedure described in *Calabasas Landfill Water Quality Monitoring System Report*, dated August 7, 1995. The sampling procedure for groundwater monitoring wells utilizes the low-flow micropurge method described in the literature (Puls and Barcelona, 1996). LCRS samples were collected directly from respective storage tanks. Field water quality monitoring forms are used by sampling personnel to record field data from monitoring wells. These forms are included in Appendix A.

Sample Bottles

All sample containers used for the radioactivity samples were pre-cleaned by the manufacturers to meet United States Environmental Protection Agency (USEPA) *Specifications and Guidelines for Contaminant Free Sample Containers*, and come with a certificate of analysis. One-liter high density polyethylene (HDPE) containers were used for gross alpha, gross beta, uranium, and strontium-90 and two-liter HDPE containers were used for radium-226 and radium-228 samples. Tritium samples were collected in 1/2-liter amber glass containers.

Groundwater Sampling

Groundwater sample collection for radioactivity analysis followed the standard sampling procedures established for groundwater sampling as specified in *Calabasas Landfill Water Quality Monitoring System Report*, dated August 7, 1995. In accordance with these sampling programs, groundwater wells were purged using dedicated bladder pumps prior to sample collection. During the purging process, groundwater was monitored for pH, conductivity, temperature, dissolved oxygen, and turbidity until specified stabilization criteria was achieved. When the groundwater reached stabilization, sampling personnel rinse each container three times with groundwater prior to collecting the samples. Sample bottles were properly labeled to identify each specific sample. For each sample, a chain-of-custody/sample request form was filled out by sampling personnel. These forms are included in Appendix A.

LCRS Sampling

LCRS samples were obtained at the outlet of each respective LCRS storage tank. Samples are collected by opening a sampling spigot, purging the spigot for approximately one minute, rinsing sample bottles three times, and filling sample bottles. As with the groundwater samples described above, sample bottles are labeled to identify each sample. A chain-of-custody/sample request form was also completed for each LCRS sample.

Sample Preservation

No field preservation was performed for these samples. Within five days, the laboratory filtered the sample through a 0.45-µm filter, and then acidified the sample with ultrapure nitric acid to a pH of less than 2.

Sample Handling

Immediately after sample collection, samples were placed in ice chests and transported to the Sanitation Districts' San Jose Creek Water Quality Laboratory (SJCWQL). The SJCWQL then packed the samples for overnight shipping to Severn Trent Laboratories Inc. (STL), in St. Louis, Missouri for analysis.

5.2.2 Sample Analysis

Severn Trent Laboratories Inc. (STL) was retained to perform the sample analysis. STL is a California State Department of Health Services (DHS) certified laboratory for all the radiochemical analyses required by the RWQCB. All samples were analyzed for specific conductance, gross alpha/beta particle activity, tritium, isotopic uranium (i.e., uranium-234, uranium-235, and uranium-238), radium-226, radium-228, and strontium-90. One LCRS sample was also analyzed for potassium, potassium-40, and cesium-137. Analytical methods used for the above parameters are summarized in Table 1.

Detection Limits

Radiochemical parameter results reported as part of this program are reported in terms of “activity” which is defined as the number of nuclear transformations (i.e., decay) of a radioactive substance which occur in a specific time interval (USEPA, 1991). Results are expressed in terms of activity because it is not the mass of the radiochemical parameter that is of interest but the radioactive emissions. Activity can be related to half-life, which is defined as the length of time required for a radionuclide to lose 50 percent of its activity by decay. A radionuclide with a shorter half-life (e.g., radium-226 at 1,600 years) emits higher activity whereas a radionuclide with a longer half-life (e.g., uranium-238 at 4,500,000,000 years) emits lower activity (EPA, 2000). Half-lives can range from a millionths of a second to billions of years (NRC, 2001).

Table 1

Analytical Methods of Radiochemical Analyses for Calabasas Landfill

PARAMETER	ANALYTICAL METHOD
Gross Alpha activity by coprecipitation	SM 7110
Gross Beta activity	EPA 900.0
Tritium	EPA 906.0
Isotopic Uranium	NAS/DOE 3050
Radium-226	EPA 903.0
Radium-228	EPA 904
Strontium-90	EPA 905
Potassium-40	901.1
Cessium-137	901.1
Potassium	SW846 6010B
Specific Conductance	MCAWW 120.1

References:

EPA	"Eastern Environmental Radiation Facility Radiochemistry Procedures Manual", USEPA, EPA 520/5-84-006, August 1984.
MCAWW	"Method for Chemical Analysis of Water and Wastes", USEPA, EPA 600/4-79-020, March 1983 and subsequent revisions.
SM	"Standard Methods for the Evaluation of Water and Wastewater", 18th edition
SW846	USEPA Methods for Evaluating Solid Waste Physical/Chemical Methods
NAS/DOE	National Academy of Science "DOE Methods for Evaluating Environmental and Waste Management Sample", US Department of Energy, October 1994

The specific activity concentration unit reported for data presented herein is picocuries per liter (pCi/L). One curie is equal to a nuclear transformation rate of 3.7 x 10^{10} decays per second. One picocurie is equal to 10^{-12} curies, which equates to one decay per 27 seconds or 2.2 decays per minute. Analytically, the laboratory measures the minimum detectable activity (MDA) for a specific analytical procedure; the MDA is the smallest amount of activity that can be measured given the conditions of a specific sample. The MDA is affected by various factors, including the amount of sample, the count duration, and the detector efficiency. The MDA is reported at the 95 percent confidence level, meaning that there is a 5 percent chance that a false signal was reported as activity, and a 5 percent chance that true activity went undetected (STL, Standard Operating Procedures).

The MDA, which is purely a measure of activity (e.g., picocuries), is converted to activity concentration units (i.e., picocuries per liter) by calculating the activity (i.e., picocuries) per unit volume (i.e., liters of aqueous sample). The minimum activity concentration is designated the “MDC” (minimum detectable concentration) on the laboratory reports and can be viewed as a traditional analytical reporting limit. All results are reported in activity concentration units (i.e., pCi/L) and expressed with an error term that expresses uncertainty in the form of +/- two standard deviations. Results can be expressed as negative values since the activity measurement incorporates the subtraction of background radioactivity encountered at the laboratory. The reporting of a negative value is not unusual given the uncertainties associated with both the measurement of natural radioactivity in the actual sample as well as in the laboratory background sample.

For purposes of this report, results are presented in a manner typical of environmental analyses. That is, numerical results are reported without an error term and non-detected values are simply expressed as less than the MDC. The Certified Analytical Reports (CARs) included in Appendix B, include the numerical error terms and numerical results below the MDC for interested reviewers.

Analytical Protocols and MCLs

Brief descriptions of the radiochemical methods of analysis used in this study (see Table 1) are presented below. In addition, drinking water maximum contaminant levels (MCLs) developed by the USEPA are noted for each radiochemical method or parameter as these methods are typically used by community water systems to assess compliance with MCLs.

Gross Alpha/Beta Particle Activity (EPA Method 900.0)

EPA Method 900.0 is a screening test to determine the presence of alpha- and beta-emitting radioisotopes. The method involves the evaporation of a small aliquot of liquid until a small liquid concentrate remains. The liquid concentrate is then placed on a stainless steel planchet and further evaporated to dryness. The alpha and beta emissions from the residual solids on the planchet are measured using a gas-flow proportional counter (GFPC).

The method does not provide information on specific radioisotopes emitting alpha and/or beta radiation. However, in natural groundwater, uranium-238, radium-226, and polonium-210 are the principal alpha emitters in the dissolved phase (USEPA, 2000). Radon-222 is an alpha emitter in gaseous phase and is not measured as part of gross alpha particle activity in water.

The MCL for gross alpha particle activity is 15 pCi/L, which excludes any contribution from radon and uranium (USEPA, November 2002), both of which have specific MCLs, as noted below.

In natural groundwater, radium-228 and potassium-40 are the principal beta emitters (USEPA, March 2000; Welch et al., 1995). Tritium and carbon-14 are low-level beta emitters that are not measured (in the case of tritium) or partially measured (in the case of carbon-14) as part of the gross beta particle activity analysis (STL, personal communication, December 27, 2002). EPA notes that a total of 168 individual beta particle and photon emitters may be use to calculate compliance with the beta/photon MCL of 4 millirems per year (mrem/yr), which allows a 50 pCi/L MCL screening level (USEPA, June 2001). However, the MCL excludes any beta particle activity contribution by potassium-40. According to the final Radionuclide Rule for public water supplies, only when the beta particle activity minus the naturally occurring potassium-40 activity in a drinking water supply sample exceeds 50 pCi/L must the system speciate the beta emitters (USEPA, June 2001).

Gross Alpha by Co-precipitation (SM 7110)

Method SM 7110 is a screening test to determine the presence of alpha-emitting radioisotopes in water samples with high dissolved solids content (i.e., >500 mg/L). Alpha emitting isotopes are co-precipitated with an iron hydroxide carrier, thereby removing interferences caused by residue mass (described in further detail in the Analytical Problems/Limitations section below). The precipitate is then counted using a GFPC. Similar to EPA Method 900.0, Method SM7110 does not provide information on specific alpha-emitting isotopes.

Radium-226 (EPA Method 903.0)

EPA Method 903.0 is a co-precipitation method followed by counting of alpha-emitting radium (i.e., radium-226) with a GFPC. Barium and lead are used to co-precipitate radium as the sulfate. Following chelation with EDTA, Radium-Barium sulfate is precipitated, purified, and counted.

The MCL for radium-226 is 5 pCi/L when combined with radium-228 (USEPA, June 2001).

Radium-228 (EPA Method 904)

EPA Method 904 determines radium-228 by direct measurement of its beta-emitting progeny, actinium-228, using a GFPC. Radium isotopes are collected by co-precipitation with barium and lead sulfate and purified by precipitation from EDTA solution. After a suitable ingrowth period, actinium-228 is separated and carried on yttrium oxalate, purified and counted for the presence of total beta radiation. The precipitation and counting are performed in a manner consistent with the time requirement of the 6.13-hour half life of actinium-228. By applying correction factors for ingrowth and decay and appropriately calibrating the beta counter, radium-228 is quantified mathematically from the actinium-228 activity.

The MCL for radium-228 is 5 pCi/L when combined with radium-226 (USEPA, June 2001).

Isotopic Uranium (NAS/DOE 3050)

Uranium isotopes (i.e., uranium-234, uranium-235, and uranium-238) are counted using alpha spectroscopy. A liquid sample is evaporated or co-precipitated and alpha emitters (e.g., americium, thorium, uranium, etc.) are sequentially separated by elution from anion exchange resin columns, based on the differences in their absorption and chemical properties. The uranium isotopes are removed from the resin columns using hydrochloric acid; the samples placed in alpha detector chambers and counted.

The MCL for uranium is 30 micrograms per liter (ug/L) (USEPA, June 2001). However, uranium activity is reported as pCi/L, which is required in order to evaluate the contribution of uranium to the gross alpha particle activity. The conversion of uranium from pCi/L to ug/L is not straightforward and is subject to interpretation based on the activity relationships of the various uranium isotopes. In the USEPA's summary of its response to comments, it set a conversion factor of 0.67 pCi/ug "because it is a conservative factor that is based on the 1:1 activity ratio of uranium-234 to uranium-238 characteristic of naturally-occurring uranium". This conversion factor translates to an MCL of 20 pCi/L for uranium.

Tritium (EPA Method 906.0)

Tritium is determined by first distilling a liquid sample to obtain pure water and then analysis by liquid scintillation. An unpreserved sample is steam distilled and the condensate collected. A scintillation cocktail is added and the sample counted using a liquid scintillation counter. Tritium is the weakest beta emitter. The range of the most energetic tritium beta particles is only about 5 mm in air or 0.005 mm in water (U.S. Department of Energy, 1994).

Strontium-90 (EPA Method 905)

EPA Method 905 determines strontium-90 by direct measurement of its beta-emitting progeny, yttrium-90, using a GFPC. Strontium-89 is precipitated from a liquid sample as insoluble carbonates. The yttrium-90 daughter of strontium-90 is then removed by hydroxide precipitation. Yttrium-90 is then allowed to re-grow, is separated and then precipitated as yttrium oxalate and counted for beta activity. The yttrium-90 activity represents the strontium-90 activity. The MCL for strontium-90 is 8 pCi/L (USEPA, June 2001).

Potassium-40 and Cesium-137 (EPA Method 901.1)

Potassium-40 and cesium-137 were counted using gamma spectroscopy. A liquid sample is acidified with nitric acid and counted directly using Hyperpure Germanium gamma ray detectors able to detect isotopes with gamma ray energies between 40 thousand electron volts (KeV) and 2 million electron volts (MeV). Although both potassium-40 and cesium-137 are principally beta emitters, they both emit small proportions of gamma radiation at 1.46 MeV and 1.18 MeV, respectively (Friedlander, 1964).

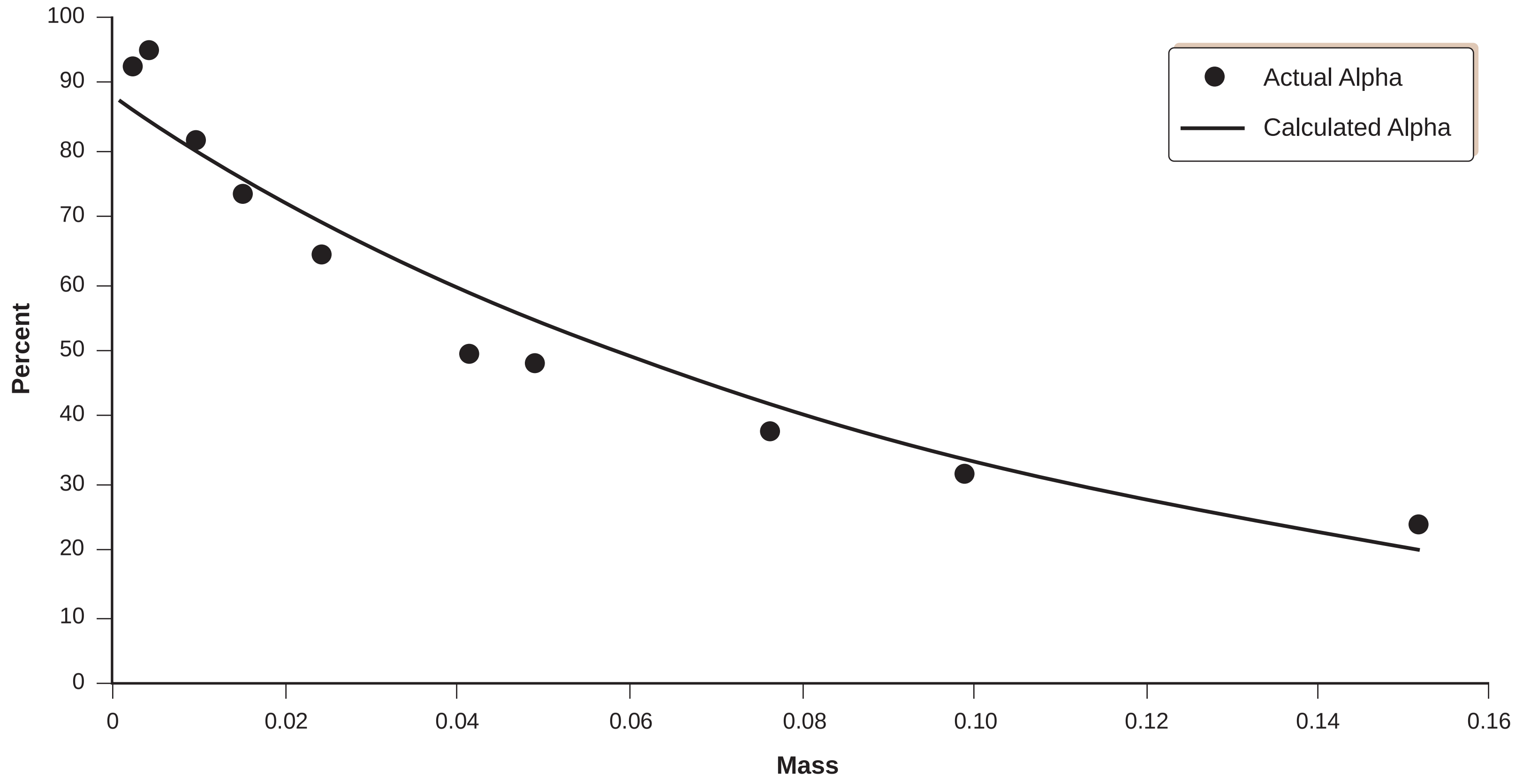
Potassium-40 and cesium-137 do not have MCLs. They are both beta emitters that would be included in the MCL for gross beta particle/photon emitter activity.

Analytical Problems/Limitations

High concentrations of dissolved solids in several samples resulted in increased detection limits for those samples, particularly for the analysis of gross alpha particle activity. This situation occurred for LCRS samples, as well as many groundwater samples. As discussed previously, the Calabasas Landfill is situated in an area of naturally poor water quality, with elevated concentrations of dissolved solids.

The primary non-radioactive interference for the gross alpha/beta analysis using a GFPC is residue mass (derived from dissolved solids). As the sample aliquot is concentrated under acidic conditions, the solid material contained in the sample, as well as any crystallization of salts, is deposited on the stainless steel planchet. This mass effectively blocks a portion of the alpha particles and, to a lesser degree, beta particles. This blocking effect is referred to as “self-absorption of attenuation”.

During calibration of a GFPC, an attenuation calibration is performed. This measures the effect of increasing mass to the efficiency of the detector. Figures 4 and 5 show attenuation charts for alpha and beta, respectively. The alpha attenuation curve shows a significant reduction in counting efficiency as the mass increases. This is due primarily to the relatively large size of alpha particles and their resulting inability to escape from the residue mass. The beta attenuation curve demonstrates a reduced effect because the relatively higher energy and smaller size of beta particles are less inhibited by the residue mass, relative to alpha particles.



$\alpha\ r^2 = 0.946302$

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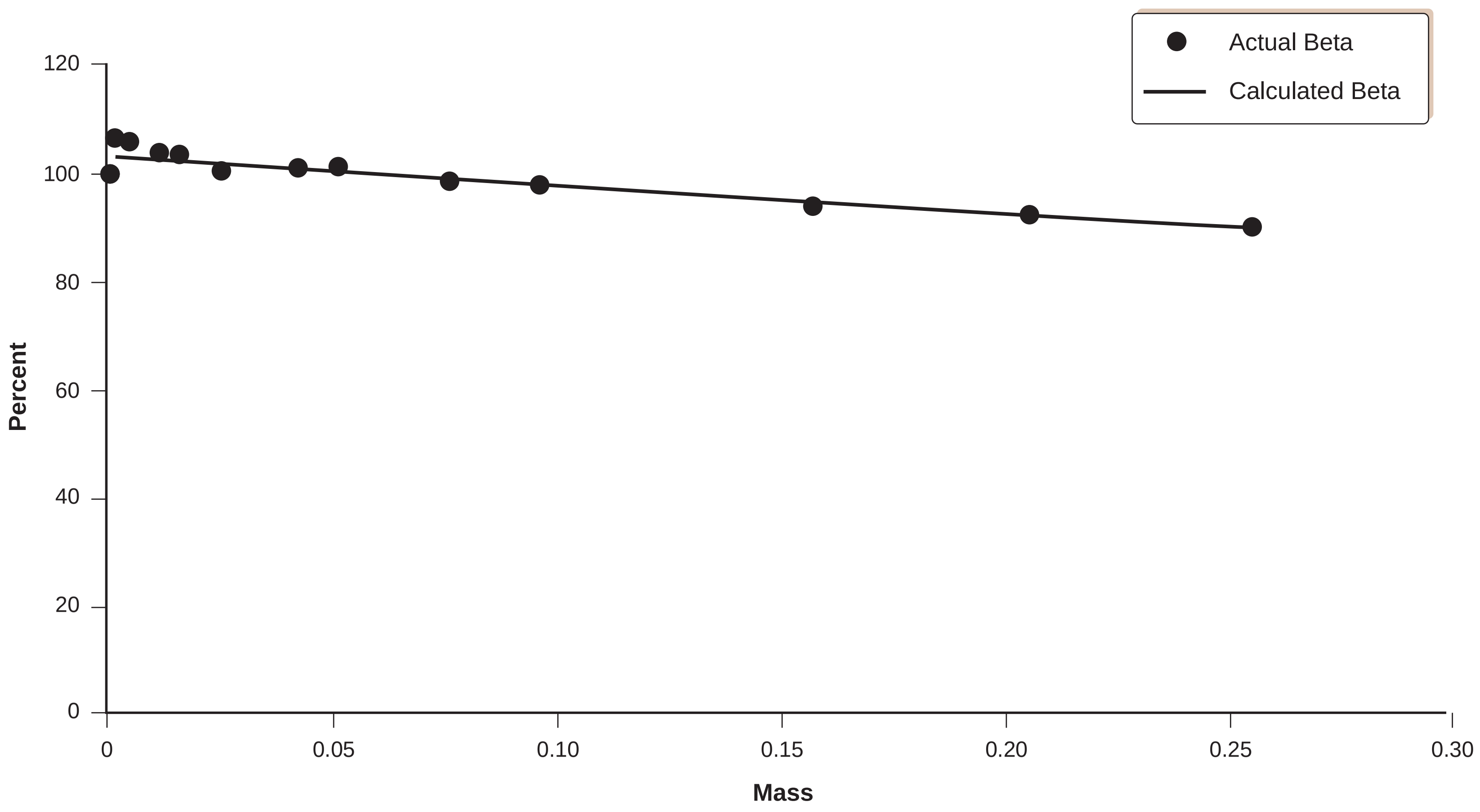
Figure 4
Alpha
Attenuation Chart



B $r^2 = 0.923559$

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Figure 5
Beta
Attenuation Chart

The internal standards for the analysis of samples for gross alpha/beta require a maximum residual mass of 100 mg. At this point, the laboratory concludes that the reduction in counting efficiency no longer permits an accurate assessment of sample activity (STL, personal communication, December 8, 2002). During the preparation of samples for analysis, a pre-screen is performed to determine the aliquot size that would approximate a 70 mg residual mass. In samples with high solids content, this aliquot can be only a few milliliters. This reduction in aliquot size also increases the uncertainty (2 sigma error) and detection limit. A copy of the equations used for the generation of gross alpha/beta results is provided in Appendix C for verifying the effect of the reduced aliquot to final results.

Problems related to elevated MDCs for gross alpha particle activity were resolved by use of the Gross Alpha by Co-precipitation Method (SM 7110), described above, in lieu of EPA method 900.0.

6 Results

6.1 QA/QC Data

Three duplicate samples were collected in the field and submitted to the laboratory for analysis for selected parameters in order to test the reproducibility of the laboratory results. In addition, the laboratory analyzed method blanks, laboratory control samples, matrix spike samples, and duplicate samples. The laboratory included a case narrative that discussed QA/QC results in each report (Appendix B). The applicable quality control procedures met method-specified acceptance criteria except as noted in the case narratives.

Field-collected duplicate sample results are presented in Table 2. Duplicate samples were collected for monitoring well M22D, LCRS, and background monitoring well M16A. The duplicate from M22D was analyzed for alpha particle activity, strontium-90, tritium, radium-226, and radium-228 with a good correlation with the original sample. The percentage difference (PD) is a calculation of the difference between the original and duplicated sample. Alpha activity was the only parameter detected above the detection limit in the duplicate (alpha PD = 7). Strontium-90, tritium, radium-226, and radium-228 were detected in both original and duplicate at concentrations below the detection or reporting limit. The LCRS duplicate sample was analyzed for beta activity with a good correlation (PD = 10) with the original sample. The duplicate of M16A was analyzed for tritium and showed a reasonable correlation (PD = 29) with the original sample.

6.2 Sampling Data

The radioactivity sampling program results are presented in Table 2. An electronic copy of this table in Excel format is included in Appendix D. The table is separated into monitoring wells that have been affected by VOCs from the landfill, LCRS samples, and background well not affected by the landfill. MCLs are also listed in the table for comparison purposes only. The range of detections in background monitoring wells is presented in Table 3.

Table 2

Radioactivity Results

Calabasas Landfill - WDRs: 00-077, 93-062, and 89-053

			Downgradient Monitoring Well					LCRS Sample				
		Sample ID Well or LCRS Date Sampled	SJ-72555 **R02A** 30-Sep-02	SJ-72134 **R06A** 23-Sep-02	SJ-72174 **R07A** 23-Sep-02	SJ-72126 **M22D** 23-Sep-02	SJ-72126-DUP **M22D** 23-Sep-02	SJ-72135 **PLCS** 23-Sep-02	SJ-72136 **DLCS** 23-Sep-02	SJ-74671 **9XLC** 14-Nov-02	SJ-72175 **LCRS** 26-Sep-02	SJ-72175-DUP **LCRS** 26-Sep-02
Parameter	**Units**	**MCL**										
Conductivity	umhos/cm		5,190	7,030	5,910	5,460		7,040	5,910	5,720	6,630	
RL			1.0	1.0	1.0	1.0		1.0	1.0	1.0	1.0	
Gross Alpha	pCi/L	15	**38.0**	**19.2**	7.5	**31.5**	**33.7**	7.3	**70.3**	**91.3**	**41.5**	
MDC			0.7	0.5	0.6	0.6	0.9	0.6	0.6	0.5	0.7	
Gross Beta	pCi/L	50	27.2	20.8	5.5 U	8.4		22.1	19.3	**63**	**97**	**88**
MDC			5.6	11	6.9	6.1		7.4	5.7	12	9	9
Potassium	ug/L										68,100	
RL											5,000	
Potassium-40	pCi/L										24 U	
MDC											65	
Cesium-137	pCi/L										0.5 U	
MDC											3.5	
Strontium-90	pCi/L	8	0.5 U	-0.1 U	1.08 J	0.53 U	-0.52 U	-0.02 U	1.7 U	1.09 U	1.48 J	
MDC			3.0	2.3	0.97	1.3	1.6	0.79	3.8	1.3	0.88	
Tritium	pCi/L	20,000	-130 U	-150 U	640	-80 U	-20 U	3,310	200 U	930	210 U	
MDC			400	410	410	420	420	410	400	440	410	
Radium-226	pCi/L	5*	0.15 U	0.31 J	1.27	0.24 J	0.26 J	0.37 J	0.24 U	0.17 J	0.36 J	
MDC			0.31	0.21	0.30	0.18	0.21	0.24	0.30	0.17	0.21	
Radium-228	pCi/L	5*	0.15 U	0.23 U	0.76 U	0.42 U	0.36 U	0.16 U	0.1 U	1.26	0.65 U	
MDC			0.86	0.81	0.98	0.61	0.67	0.97	1.3	0.63	0.80	
Uranium-234	pCi/L		**29.4**	12.7	4.6	**24.8**		6.0	**63**	**68**	**41.9**	
MDC			0.2	0.2	0.07	0.2		0.2	0.4	0.2	0.2	
Uranium-235	pCi/L		1.64	0.85 J	0.09 U	1.48		0.25 J	3.3	2.68	2.30	
MDC			0.22	0.28	0.15	0.13		0.25	0.5	0.23	0.28	
Uranium-238	pCi/L		**25.7**	10.6	3.90	**21.4**		5.7	**58**	**64**	**39.5**	
MDC			0.2	0.2	0.19	0.2		0.2	0.4	0.09	0.2	
Total Uranium	pCi/L	20	**56.7**	**24.2**	8.6	**47.7**		12.0	**124.3**	**134.7**	**83.7**	

umhos/cm - micromhos per centimeter
pCi/L - picocuries per liter
RL - reporting limit
MDC - minimum detectable concentration (determined by instrument performance only)
MCL - maximum contamination level
* - total Radium-226 + Radium-288
J - Result is greater than sample detection limit but less than the stated reporting limit.
U - Result is less than sample detection limit.
Concentrations above MCLs are shown in bold
WDRs - Waste Discharge Requirements

Table 2
Radioactivity Results
Calabasas Landfill - WDRs: 00-077, 93-062, and 89-053

			Background Monitoring Well			
		Sample ID Well or LCRS Date Sampled	SJ-72180 **M19R** 23-Sep-02	SJ-72179 **M18D** 23-Sep-02	SJ-72127 **M16A** 23-Sep-02	SJ-72127-DUP **M16A** 23-Sep-02
Parameter	**Units**	**MCL**				
Conductivity	umhos/cm		3,380	947	5,070	
RL			1.0	1.0	1.0	
Gross Alpha	pCi/L	15	4.6	**68.0**	**49.4**	
MDC			0.8	0.7	0.8	
Gross Beta	pCi/L	50	36.4	31.7	35.1	
MDC			3.5	1.2	5.4	
Potassium	ug/L					
RL						
Potassium-40	pCi/L					
MDC						
Cesium-137	pCi/L					
MDC						
Strontium-90	pCi/L	8	-0.4 U	1.1 U	0.45 U	
MDC			2.0	2.2	1.2	
Tritium	pCi/L	20,000	-140 U	9 U	-30 U	-40 U
MDC			400	400	400	410
Radium-226	pCi/L	5*	0.18 U	0.53 J	0.42 J	
MDC			0.23	0.23	0.21	
Radium-228	pCi/L	5*	0.70 U	0.20 U	0.73 U	
MDC			0.72	0.74	0.83	
Uranium-234	pCi/L		0.04 U	**46.2**	**36.0**	
MDC			0.34	0.2	0.3	
Uranium-235	pCi/L		0.047 U	2.34	1.75	
MDC			0.21	0.19	0.29	
Uranium-238	pCi/L		-0.011 U	**41.4**	**29.5**	
MDC			0.15	0.2	0.2	
Total Uranium	pCi/L	20	0.08	**89.9**	**67.3**	

Table 3

Range of Detections in Background Monitoring Wells

Parameter	Concentration Range
Gross Alpha Activity	4.6 to 68 pCi/L
Gross Beta Activity	31.7 to 36.4 pCi/L
Strontium-90	BDL to 1.1 pCi/L
Tritium	BDL
Radium-226	BDL
Radium-228	BDL
Uranium-234	BDL to 46.2 pCi/L
Uranium-235	BDL to 2.34 pCi/L
Uranium-238	BDL to 41.4 pCi/L

BDL – below detection or reporting limits

Alpha activity, uranium-234 and uranium-238 were detected in background samples above the MCL indicating that naturally-occurring background levels of these radioactive parameters exceed drinking water standards. All downgradient monitoring well sample results were within the range of results found in background samples. LCRS samples have alpha activity, beta activity, and uranium detections that overlap with and in some cases slightly exceed the range of the results found in background samples. In order to more fully understand the source of the apparently elevated beta activity result in the LCRS sample, that sample was also analyzed for potassium, potassium-40, and cesium-137 (the latter two being beta emitters) as shown in Table 2. Interpretation of the data is presented in Section 8.

7 Radioactivity in the Environment

Naturally-occurring levels of radioactivity are found in rocks, soils, groundwater, and foods. Naturally-occurring radiation is the result of primordial sources from before the creation of the earth and cosmogenic sources formed as a result of cosmic ray interaction. Background radioactivity now includes the impact of cumulative deposition from fallout from nuclear testing and nuclear accidents such as Chernobyl. Finally, radioactivity is also concentrated in certain man-made or anthropogenic products that may be disposed of in landfills. In this analysis we attempt to differentiate the naturally-occurring and background radiation from that radioactivity that is potentially the result of the disposal of radioactive wastes that may have been placed in the landfill.

When radionuclides decay they emit emissions or particles of three different types called alpha, beta, and gamma. The types of particles emitted by some common radionuclides are presented in Table 4. Table 4 also lists the half-life and source(s) for each radionuclide.

Table 4

Radionuclide Half-Lives and Emission Type

Radionuclide or Isotope	Half-Life (years)	Radiation Type		
		Alpha	Beta	Gamma
Americium-241	432	*		*
Carbon-14	5,730			
Cesium-137	30.2		*	*
Cobalt-60	5.27		*	*
Iodine-129	1.57×10^7		*	*
Iodine-131	8.04		*	*
Plutonium-238	87.7	*	*	*
Plutonim-239	2.41×10^4	*	*	*
Potassium-40	1.28×10^9		*	
Radium-226	1,599	*		*
Radium-228	5.8		*	
Radon-222	3.82	*		
Strontium-90	28.8		*	
Technetium-99	2.1×10^5		*	*
Tritium	12.3		*	
Thorium-232	1.41×10^{10}	*		*
Uranium-234	2.47×10^5	*		*
Uranium-235	7.04×10^8	*		*
Uranium-238	4.5×10^9	*		*

7.1 Naturally-Occurring Radioactivity in Rocks and Soil

Naturally-occurring radioactivity originates from extraterrestrial sources (cosmic) and from radioactive elements found in the Earth's crust (primordial). Primordial nuclides include uranium-235, uranium-238, thorium-232, and potassium-40. For example, trace amounts of the long-lived isotopes (e.g., uranium-238, which has a half life of almost five billion years) have been present in the earth's crust since the crust first formed. Most of the naturally-occurring radionuclides are alpha emitters (e.g., the uranium isotopes and their daughter products, e.g., radium-226), but naturally occurring beta particle emitters do also occur (radium-228 and potassium-40). Certain rock types contain trace amounts of radioactive isotopes of radium, uranium, thorium, potassium, and/or actinium (USEPA, November 2000) (Eisenbud, 1987). Uranium, thorium, and potassium radionuclides are also found at high concentrations in coal (Eisenbud, 1987).

Cosmic radiation permeates all of space. The upper atmosphere interacts with the cosmic radiation and produces radioactive nuclides. Cosmogenic nuclides include carbon-14, tritium, and berryllium-7.

Uranium, radium-226, potassium-40, and thorium-232 are found in all rocks and soils. Table 5 lists the average radium-226, uranium-238, potassium-40, and thorium-232 activity of various rock types. Concentrations of uranium-238 range from 400 pCi/kg in sedimentary and metamorphic rocks to 1,300 pCi/kg in igneous rocks. Uranium concentrations in phosphate rocks found in Florida and Idaho, and neighboring areas range to 81,600 pCi/kg[1] (Clegg and Foley, 1958; NCRP, 1975). The high uranium content of phosphate rocks is reflected in the correspondingly high uranium content of commercial phosphate fertilizers.

Table 5

Average Radium, Uranium, Potassium, and Thorium In Various Rock Types

Rock Type	Radium-226 (pCi/kg)	Uranium-238 (pCi/kg)	Potassium-40 (pCi/kg)	Thorium-232 (pCi/kg)
Igneous	1,300	1,300	22,000	1,300
Sedimentary	710 - 1,080	400	8,800 - 22,000	650 - 1,110
Limestones	420	400	2,200	140

pCi/kg - pico curies per kilogram
From UNSCEAR (1958)

Radium-226 concentrations range from 420 pCi/kg in limestones and to 1,300 pCi/kg in igneous rocks. Potassium-40 concentrations range from 2,200 pCi/kg in limestones to 22,000 pCi/kg in igneous rocks. Radium-226 and potassium-40 levels are also high in phosphate-bearing rocks used for fertilizers. Thorium-232 concentrations range from 140 pCi/kg in limestones to 1,300 pCi/kg in igneous rocks. Overall, radioactivity levels tend to be somewhat higher in igneous rocks compared with sedimentary and metamorphic rocks (Table 5).

Commercially exploitable deposits of uranium are found in the Wyoming Basin, Colorado Plateau, California, Belgian Congo, Canada, and Czechoslovakia. Many relatively more concentrated deposits of uranium- and thorium-bearing minerals are known in eastern and southern California. Most of the enriched uranium deposits are found in the southern Sierra Nevada, Mojave Desert Region, and western Kern County (Troxel, et al., 1957). Thorium deposits are found primarily in the Mojave Desert Region. While uranium occurs in all lithologic rock types, the principal sources of uranium ores are hydrothermal veins in igneous and metamorphic rocks, and disseminated deposits in sedimentary rocks. Uranium also occurs in coal, petroleum, and asphalt. Large, low-grade

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[1] The concentration is presented in parts per million (ppm) in the cited reference. An activity mass ratio of 0.68 pCi/ug (USEPA, March 2000) was used to convert ppm to pCi/kg. Cited concentrations given in ppm have been converted to pCi/kg or pCi/L throughout the text of this report for consistency.

concentrations of uranium are present in marine black shales, phosphorites, and locally in some igneous rocks (CDMG, 1966).

A U.S. Geologic Survey (USGS) study of black shales found them to have significant uranium concentrations. The average concentration of 287 samples tested was 10,336 pCi/kg with a maximum concentration of 300,968 pCi/kg (Quinby-Hunt, et al., 1997). Black shales in the Monterey Formation here in California are also known to have elevated uranium concentrations. The USGS calculated the average uranium concentration in Monterey Formation black shales at 14,144 pCi/kg. The Monterey Formation is broadly distributed in the southern San Joaquin Valley, San Francisco Bay area, central Coast Range, and Los Angeles Basin (USGS, July 2002). Black shales are known to exist in the Modelo Formation at the Calabasas Landfill. The Monterey and Modelo Formations were deposited contemporaneously and rocks of the Monterey Formation are assigned to the Modelo Formation in some areas of the Santa Monica Mountains (Troxel, September 1954).

Prospective uranium ore deposits have been identified approximately 20 miles from the Calabasas Landfill in the Grimes Canyon area near Filmore in Ventura County. In this deposit, the radioactive ore is found in Tertiary age sedimentary and volcanic rocks. The uranium ore in the deposit occurs at three times background concentrations (Walker, et al., 1956).

7.2 Naturally-Occurring Radioactivity in Groundwater

As naturally-occurring radioactive rocks weather, they can become a source of naturally-occurring radioactivity in groundwater. Most groundwater has very low levels of radioactivity, levels low enough not to be considered a public health concern. Uranium-238, thorium-232, and uranium-235, which exist naturally, give rise to most of naturally-occurring radioactivity in groundwater. Alpha-emitting substances in natural water are mainly isotopes of radium and radon. Beta and gamma activity is characteristic of potassium-40, rubidium-87, strontium-89, strontium-90, iodine-131, phosphorus-32, and cobalt-60 (Hem, 1992).

Tritium, a beta emitter, forms in the upper atmosphere through the interaction of cosmic rays and the gases comprising the atmosphere. Tritium can be carried from the atmosphere into precipitation, surface water and groundwater. The natural concentration of tritium in lakes, rivers, and potable waters was reported to have been between 5 to 25 pCi/L prior to the advent of atmospheric nuclear weapons testing (UNSCEAR, 1982). The use of tritium for timing processes and/or other processes in hydrology has been extensive since the 1950s but with the cessation of atmospheric nuclear testing tritium concentrations in precipitation are once again approaching natural background conditions.

Uranium is present in concentrations between 0.067 and 6.7 pCi/L in most natural waters. However, some western states have elevated uranium levels compared to the national average (USEPA, November 2000). High concentrations of uranium have been detected in groundwater associated with uranium-bearing minerals present in igneous rocks (Hem, 1992).

Radium-223, radium-224, radium-226, and radium-228 are naturally-occurring isotopes. It has been widely assumed that radium-226 is normally the dominant form in natural water; however, a relatively high proportion of radium-228 has been detected in groundwater in South Carolina (Hem, 1992). The concentration of radium in most natural water is mostly below 1.0 pCi/L (Hem, 1992). Several areas of the country have groundwater that contains radium that exceeds the MCL for drinking water (Piedmont and Coastal Plain areas of the Middle Atlantic states; and the North Central states of Minnesota, Iowa, Illinois, Missouri, and Wisconsin) (USEPA, November 2000; Eisenbud, 1987).

To determine a range of reasonable background concentrations for radioactivity in groundwater, the Department of Health Services (DHS), Drinking Water Sources, water quality database for Los Angeles and Ventura Counties was summarized for radiochemistry data. Table 6 presents the minimum, maximum, mean, and median for the radioactivity parameters tested in this program, along with the number of samples used in the statistical calculations. The DHS database includes drinking water wells, surface water sources, and springs used for water supply. The statistics are based on sampling results reported between 1994 and 2002. As shown in the table, maximum concentrations detected in Los Angeles and Ventura Counties were above MCLs for gross alpha activity, uranium, and radium. Three wells at Agua Dulce near Santa Clarita in Los County were not included in Table 6 due to unusually high alpha (190, 170, and 212 pCi/L) and uranium (211, 155, and 285 pCi/L) activity.

Table 6

Los Angeles and Ventura Counties
Drinking Water Sources Radiochemistry Data
1994 through November 2002

	Units	Gross Alpha	Gross Beta	Total Uranium	Radium 226	Radium 228	Strontium 90	Tritium
Los Angeles County								
Maximum	pCi/L	44.5	19.4	50.0	4.8	6.2	2.5	886
Minimum	pCi/L	BDL	BDL	BDL	BDL	BDL	BDL	0.74
Mean	pCi/L	3.5	5.2	6.1	0.36	0.43	0.16	131
Median	pCi/L	2.8	5.0	4.4	0.11	0.00	0.01	17.9
No. Samples		7,420	1,519	1,531	186	60	28	40
Ventura County								
Maximum	pCi/L	56.7	23.0	24.6	4.9	4.7	1.1	176.6
Minimum	pCi/L	BDL	BDL	BDL	BDL	BDL	BDL	69.1
Mean	pCi/L	5.2	6.7	5.8	0.4	1.20	0.3	122.9
Median	pCi/L	4.0	6.0	5.0	0.2	0.90	0.28	122.9
No. Samples		1,126	115	251	233	10	13	2

Source: California Department of Health Services - Drinking water sources data base, 1994 through November 2002

BDL - Below the method detection limit

Values reported as less than the method detection limit (MDL) were assumed to equal the MDL for mean and median calculations.

7.3 Global Background Radiation

Background radiation includes the fallout from nuclear testing and nuclear accidents such as Chernobyl. Atmospheric nuclear testing, which began in the late 1940s and continued at an accelerated pace until 1962, resulted in the widespread distribution of radioisotopes in the atmosphere, soil, and food chain (Eisenbud, 1987). Artificial nuclides that have been produced as a result of nuclear testing and accidents include tritium, iodine-131, iodine-129, cesium-137, strontium-90, and plutonium-239 (ISU).

7.4 Radioactivity in Food

Naturally-occurring radioactive isotopes can be absorbed from the soil by plants. Every food has some small amount of radioactivity in it. Potassium-40 is the predominant radioactive component in most foods, while radium-226, and uranium-238 and its daughter products are also found. Phosphate fertilizers are widely used everywhere in the world. The United States is a major user of phosphate rocks for fertilizers. Phosphate ores used for fertilizer contain elevated levels of uranium (5,440 pCi/kg to 272,000 pCi/kg), radium-226, and potassium-40. It is estimated that 3×10^{15} pCi of potassium-40 is added to soils annually in the U.S. in the form of fertilizers (Guimond, 1978). Potassium-40, radium-226, and uranium-238 associated with the application of phosphate fertilizer to arable land and the inclusion of phosphate rock in cattle feed can increase the radioactivity levels in food stuffs. Measurable alpha radioactivity thought to be primarily related to radium-226 ranges from 1 pCi/kg in fruits to 14,000 pCi/kg in Brazil nuts as shown in Table 7 (Mayneord, 1958). The potassium-40 concentration in milk is about 2,000 pCi/L (ANL, 2001) and in bananas is about 3,500 pCi/kg (ISU). Carrots, Brazil nuts, white potatoes, red meat and lima beans all contain potassium-40 concentrations above 1,000 pCi/kg (ISU). Salt substitutes made from natural potassium chloride (KCl) emit activities on the order of 450,000 pCi/kg, or more than 20 times background soil levels, due to its potassium-40 content. A salt shaker containing 100g of KCl salt substitute would exhibit a total activity of approximately 45,000 pCi. Though such levels can be a significant contributor to both internal and external beta-particle exposure, potassium-40 is generally not of environmental concern because the absorption of potassium by the human body is under strict homeostatic control and, therefore, not influenced by variations in environmental levels (Canada Department of National Health, 1995).

Table 7

Alpha Activity in Foods

Foodstuff	Maximum Alpha Activity (pCi/kg)
Brazil nuts	14,000
Cereals	600
Teas	400
Liver and kidneys	150
Flours	140
Peanuts and peanut butter	120
Chocolates	80
Biscuits	20
Milk (evaporated)	10-20
Fish	10-20
Cheeses and eggs	9.0
Vegetables	7.0
Meats	5.0
Fruits	1.0

pCi/kg picocuries per kilograms
From Mayneord, et al. (1958)

7.5 Radioactivity in Household Wastes

Table 8 shows the many foods, household and construction products that contain radionuclides that may be introduced to a landfill in the form of household wastes. Prior to 1970, radium was used in luminous paints used for timepieces and other products. Tritium mostly replaced the use of radium in luminous paints after 1970. A significant source of tritium is thought to be the gaseous tritium used in glow-in-the-dark light devices such as exit signs (Hicks, et. al., 2000). For example, a luminous exit sign, watch, and electron tube can contain 2.02×10^{12} pCi, 1.96×10^{11} pCi and 1.3×10^{7} pCi of tritium, respectively (Buckley, et al., 1980; Harding, 1992). It was estimated that the disposal of several luminescent exit signs could generate high levels of tritium (325,400 pCi/L) for many years at the Ness Landfill in Scotland (Hicks, et al., 2000). Uranium can be found in certain types of ceramics and glassware. Alpha emitters including thorium-232 and americium-241 are used in gas mantles for camper's lamps and smoke detectors, respectively. The products listed in Table 8 may be components of the waste stream that is directed to municipal landfills.

Table 8

Radiation in Household Products and Wastes

Contaminant	Alpha	Beta	Sources	
	Emitter		Naturally-Occurring	Household Products and Wastes
Alpha Radiation	X		Yes (radon, radium, uranium-bearing rocks)	Smoke detectors (americum-241), glow in the dark products, gas lamp mantles (thorium-232), electronic filaments and television picture tubes (thorium), welding rod (thorium-232)
Beta Radiation		X	Yes (potassium-40 and thorium-232-bearing rocks)	Gas lamp mantles, welding rod, building materials. and optical glass (thorium-232), smoke detectors (americum-241), lead crystal glassware (lead-210)
Radium-226	X		Yes (uranium ore, phosphate rocks, various foods including vegetables, fruits, grains, nuts, dairy products, eggs, meats, and fish)	Glow in the dark products containing luminous paint manufactured before the 1970's (clocks and watches, compasses, religious artifacts, and aircraft instruments), quack medicines, phosphate fertilizers, building materials, food wastes
Radium-228		X	Yes (uranium ore, phosphate rock)	
Uranium	X		Yes (uranium ore mostly uranium -238, phosphate rocks, coal, most foods)	Ceramics (Fieataware), canary or vaseline glass, ceramic glazed jewelry and cloisonne enameled jewelry, fertilizer, pre-World War II steel, photographic emulsions and other photographic materials, building materials, optical glass, porcelain teeth
Tritium		X	Yes (cosmic rays)	Many glow in the dark products which contain either gaseous tritium or luminous tritium-bearing paints (watches, clocks, aisle markers, bell pushes, bubble levels, circuit breakers, compasses, depth gauges, telephone dials, exit signs, fire extinguishers, fishing floats and lures, house numbers, instrument dials, light wands, street signs, weapon sights), electron tubes
Potassium-40		X	Yes (potassium-bearing rocks, major radioactive component in most foods, coal)	Ceramics (Fiestaware), fertilizer, food, salt substitute (potassium chloride), building materials, porcelain teeth, food wastes

Eisenbud, 1987
Fisenne and Keller, 1970
Mayneord, et al, 1958

7.6 Fate and Transport of Radioactivity in Groundwater System

Most natural radioactivity in groundwater is generated through the progressive decay of naturally-occurring uranium and thorium via three decay series, beginning with uranium-238, thorium-232, and uranium-235 (referred to as the “Uranium Series”, the “Thorium Series”, and the “Actinium Series”, respectively). Water-rock reactions release the natural uranium and thorium found in concentrated amounts in granite, metamorphic rocks, lignites, monazite sand and phosphate deposits, as well as in the uranium-rich minerals of uraninite, carnotite, and pitchblende (USEPA, March 2000). The Uranium Series (i.e., uranium-238) is the most predominant contributor to radioactivity in groundwater (Hem, 1992). Other potentially significant sources of natural radioactivity in groundwater include tritium and potassium-40, the latter decaying directly to stable calcium (ANL, October 2001). Strontium-90 is not a naturally-occurring radioisotope, being introduced into the environment through atmospheric testing of nuclear weapons. With a half-life of 28 years, most environmental strontium-90 has decayed (USEPA, 2002).

Uranium

Natural uranium in rock contains three isotopes: uranium-234 (0.006% by weight), uranium-235 (0.72%) and uranium-238 (99.27%). The activity to mass ratio of the sum of the three radioisotopes in rock is 0.68 pCi/ug (EPA, March 2000). These crustal abundances of uranium are not duplicated in groundwater. Uranium-234 is enriched in water relative to rock when standardized to uranium-238 in the water. The USEPA uses a uranium-234/uranium-238 ratio of approximately 1.0 to indicate the presence of natural uranium in groundwater; this natural uranium isotopic ratio may vary regionally, as well as seasonally, with uranium-234/uranium-238 ratios ranging from 0.9 to 1.3 (USEPA, March 2000).

Uranium concentrations in groundwater are predominantly redox controlled. Uranium forms soluble complexes under oxygen-rich conditions, particularly with carbonates, causing higher concentrations in zones of recharge due to the relatively high solubility of the oxidized uranium (VI) species (USEPA, March 2000; Clark and Fritz, 1997). Alternatively, uranium precipitates from groundwater under oxygen-poor conditions and can be concentrated in secondary deposits (Cothern and Rebers, 1990). Consequently, uranium concentrations in water can be expected to range widely with different geologic environments. USGS studies show that uranium is preferentially concentrated in wetland environments where uranium-rich rocks and soils occur (USGS, February 1994).

Radium

Radium-226 and radium-228 are derived from uranium and thorium, respectively. Radium-226 is the sixth member of the uranium series, has a half-life of approximately 1,600 years, and decays by alpha-particle emission. Radium-228 is the second member of the thorium-232 series, has a half-life of about 5.7 years, and decays by beta-particle emission. Because uranium and thorium are ubiquitous components of rocks and soils, radium radionuclides are also ubiquitous trace elements in rocks and soils. However, the chemical behavior of the radium isotopes differs significantly from their parent radioisotopes. As noted above, uranium solubility is primarily redox controlled with uranium concentrations higher in zones of oxidation. Alternatively, thorium is extremely insoluble (Cothern and Rebers, 1990) and thus is not subject to mobilization in most groundwater environments. Groundwater with high radium levels tends to have low uranium levels and vice-versa, even though uranium-238 is the parent of radium-226 (EPA, November 2002).

Radium isotopes tend to be most mobile in reducing groundwater that is chloride-rich with high concentrations of total dissolved solids (Zapecza and Szabo, 1986, Kramer and Reid, 1984). Radium-228 activities tend to be the highest in arkosic sand and sandstone aquifers (Cothern and Rebers, 1990). Radium behaves similarly to other divalent cations such as calcium, strontium, and barium. Therefore, in aquifers with limited sorption sites, radium solubility can be enhanced by the common ion effect in which competing cations are present in abundance and occupy sorption sites keeping the radium in solution (USEPA, March 2000). For example, relatively high concentrations of radium were found to be associated with groundwater that was geochemically affected by agricultural practices in the recharge areas by strongly enriching the water with competing ions such as hydrogen, calcium, and magnesium (Szabo and dePaul, 1998).

Tritium

Tritium in groundwater is highly mobile because the tritium atom becomes part of the water molecule. As part of the water molecule, tritium movement in the groundwater system is unimpeded by chemical reactions or other physicochemical processes that are known to affect other radionuclides. The relatively short half-life of tritium (12.3 years) is the most limiting aspect of tritium mobility in the groundwater system; approximately 75 percent of tritium in groundwater would decay in 25 years.

Potassium-40

Potassium-40 comprises 0.012% by mass of naturally-occurring potassium and has a half-life of 1.27 billion years (Friedlander, et. al., 1964). The mobility of potassium, and hence potassium-40, in the groundwater system is controlled primarily by the dissolution of potassium-bearing silicate minerals and cation exchange reactions involving the adsorption of potassium ions. Although potassium is a major crustal element it seldom occurs in high concentrations in groundwater due primarily to the general stability of potassium silicates and irreversible cation exchange reactions with clay minerals (Hem, 1992).

Alternatively, potassium concentrations in a LCRS can reach high concentrations relative to groundwater (i.e., >100 mg/L) due to the dissolution of highly soluble potassium salts present in organic matter, including food and green waste, as well as fertilizers. Over 90 percent of the world's output of potassium salts is used for the manufacture of fertilizers (Fairbridge, 1972). The most common potassium salt, KCl, is highly soluble in water and would be expected to be present in most landfill LCRS samples in measurable concentrations and, therefore, act as a potentially significant source of natural radioactivity. Mass-activity calculations indicate that approximately 0.8 pCi/L of activity can be expected for every 1 milligram of dissolved potassium in water (or LCRS liquids); with the vast majority of that activity being beta particle activity (potassium-40 decay is 89 percent beta emission). This mass-activity relationship is observed in nature; seawater, which contains approximately 390 mg/L dissolved potassium (Hem, 1992), exhibits potassium-40 activity of approximately 300 pCi/L (NAS, 1971).

8 Interpretation and Conclusions

8.1 Data Interpretation

As expressed in a letter to the State Water Resources Control Board (SWRCB), the absence of a meaningful standard against which the radiochemical data collected will be compared is a primary concern for this sampling program (Allied Waste, et al., 2002). Because all of the radiochemical parameters measured as part of the SWRCB program occur naturally, it is difficult to assess whether the reported values are anomalous with respect to natural background levels. As noted above "background" groundwater samples collected from background wells at the Calabasas Landfill may not be representative of the full range of temporal and spatial variability found beneath the site and cannot be used to accurately establish true background concentrations in groundwater everywhere beneath the site.

MCLs developed by the USEPA can be used to assess risk for drinking water, but are not particularly relevant to non-potable groundwater found beneath the Calabasas Landfill and in LCRS fluids. Exceedance of a water quality standard (without a thorough understanding of natural background conditions) cannot be used to identify potential impacts to the environment resulting from operations at a landfill or any other type of facility. In addition, exceedance of an MCL in LCRS samples would be of no significance, since landfill LCRS liquids typically contains chemicals in excess of water quality standards. For that reason, engineering controls are installed to contain these fluids and prevent them from being discharged into waters of the State.

In spite of the above limitations, certain empirical observations can be made. In particular, comparison of the site data with data observed in the public water supply provides a useful basis for determining, on a gross scale, whether the data collected are anomalous. If samples from the DHS database exceed downgradient groundwater and LCRS samples, then it can be concluded that landfill-related samples are not particularly unusual with respect to radioactivity levels. Also, certain interrelationships in isotopic ratios provide insight on the natural component of observed radioactivity. The following interpretations of the data are presented.

Uranium

While uranium concentrations in the downgradient monitoring wells and LCRS samples exceed the 20 pCi/L uranium MCL, these levels appear to reflect a natural uranium source since similar concentrations are detected in the background monitoring wells (see Table 2). Another indication that the detections are naturally-occurring is that all of the uranium results show uranium-234/uranium-238 ratios between 1.05 and 1.22 (Table 9). As explained in Section 7.6, natural uranium in groundwater reaches equilibrium with uranium-234/uranium-238 ratios ranging from 0.9 to 1.3 (USEPA, March 2000).

The source rock for the uranium detections at Calabasas is likely the black shales of the Modelo Formation which underlie the site. These shales remain beneath portions of the site and would contributing uranium to groundwater. In addition, the black shales have been excavated and incorporated into the daily cover contained in the landfill itself and would also contribute uranium to LCRS liquids.

Table 9

Uranium-234/Uranium-238 Ratios in Water Samples

Calabasas Landfill

Sample	Uranium-234 (pCi/L)	Uranium-238 (pCi/L)	^{234}U/^{238}U Ratio
M22D	24.8	21.4	1.16
R02A	29.4	25.7	1.14
M16A	36.0	29.5	1.22
R06A	12.7	10.6	1.20
R07A	4.6	3.9	1.18
M18D	46.2	41.4	1.12
M19R	ND	ND	Not calculated
PLCS	6.0	5.7	1.05
DLCS	63	58	1.09
LCRS	41.9	39.5	1.06
9XLC	68	64	1.06

Radium

Radium isotope detections are not of radiological significance. Radium-228 is not detected in any samples above the detection or reporting limit. Radium-226 is detected in seven samples but only slightly above the method detection limit and in all cases well below the 5 pCi/L MCL. Radium-226 and radium-228 levels are consistent with natural background concentrations.

Strontium-90

Strontium-90 detections are not of radiological significance. There were only two detections slightly above the method detection limit; however, both samples were well below the 8 pCi/L MCL.

Tritium

Tritium detections are not of radiological significance. The highest tritium concentration is 3,310 pCi/L, which is well below 20,000 pCi/L MCL and below the maximum level found in drinking water sources in Los Angeles County (Table 6).

Gross Beta Particle Activity

Beta particle activity in downgradient monitoring wells is below the range seen in background monitoring wells. Beta activity in two of the four LCRS samples was slightly above the level seen in background wells. Upon receiving this data, the Sanitation Districts had one of the LCRS samples analyzed for potassium, potassium-40, and cesium-137 to determine if potassium-40 might be the source of the slightly elevated beta results (Table 2). Because of time limitations, MDCs low enough to determine the suspected potassium-40 content in the sample were not obtained. However, as shown on Figure 6, a statistically significant positive correlation exists between concentrations of potassium and beta particle activity in Calabasas Landfill groundwater and LCRS samples. The correlation coefficient (R^2) value of 0.7 indicates that the relationship is reasonably strong, and generally supports the information presented in Section 7.6 herein on the predicted mass-activity relationship between natural potassium and beta particle activity. An analysis of the much larger DHS database for groundwater sources also supports this conclusion. The DHS database contains over 600 pairs of gross beta and potassium values. Linear regression shows the same correspondence between potassium and gross beta in the DHS database as found at Calabasas. The slope and intercept confidence intervals for the Calabasas data shown on Figure 6 (0.55 to 1.89 and -3.79 to 29.83, respectively) bracket the slope and intercept for the DHS dataset (0.93 and 1.74, respectively). Therefore, the slightly elevated beta activity results for the LCRS samples indicate that low levels of radioactivity associated household wastes may be found in landfill LCRS liquids, with a significant portion being likely related to naturally occurring radioactive potassium-40. Additional beta activity may be related to beta-emitting daughter products derived from the natural uranium-234 and uranium-238 also present in LCRS samples.

Gross Alpha Particle Activity

Gross alpha activity was detected above the 15 pCi/L MCL in downgradient monitoring wells and LCRS samples. However, the alpha particle activity in downgradient monitoring wells is below the range seen in background monitoring wells. The alpha detections in downgradient monitoring wells were below the maximum value observed in drinking water sources in Los Angeles County (Table 6). Alpha activity in two of the four LCRS samples was slightly above the level seen in background wells. It appears that alpha activity is the result of naturally-occurring conditions, with natural uranium as the primary source of alpha activity (both uranium-234 and uranium-238 are alpha emitters and were measured at levels above the gross alpha particle activity).

8.2 Conclusions

The radioactivity data collected for the Calabasas Landfill indicate no evidence of radioactive waste disposal from the Rocketdyne facility. Levels of radioactivity in monitoring wells appear consistent with natural sources. Results are not unusual when compared to DHS database of drinking water sources in Los Angeles County. Uranium-234 / uranium-238 ratios in all water samples are consistent with a naturally-occurring uranium associated with the black shales which underlie the site.

Slightly elevated levels of alpha and beta activity and uranium in LCRS samples indicate that low-levels of radioactivity associated with household products and food, and uranium-bearing shales used for daily cover have been detected in the landfill LCRS liquids. This radioactivity is contained by the various landfill containment systems and does not impact groundwater beneath the site.

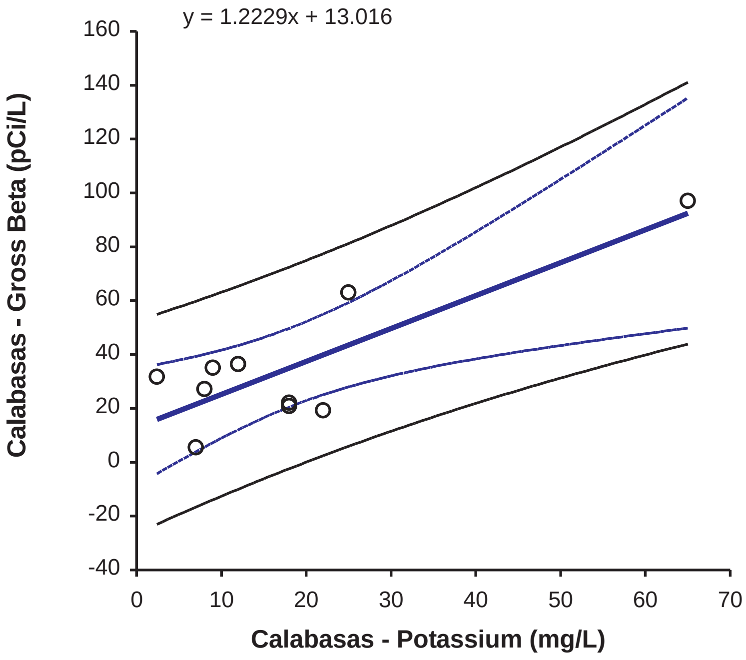
Test	**Linear Regression**
Site	Calabasas Landfill
Parameters	Gross Beta (pCi/L) v Potassium (mg/L)
Performed by	GeoChem Applications
Date	9 January 2003

n	10

R^2	0.69
Adjusted R^2	0.65
SE	15.4765

Term	Coefficient	SE	p	95% CI of Coefficient
Intercept	13.0159	7.2897	0.1120	-3.7943 to 29.8261
Slope	1.2229	0.2898	0.0029	0.5545 to 1.8912

Source of variation	SSq	DF	MSq	F	p
Due to regression	4263.740	1	4263.740	17.80	0.0029
About regression	1916.189	8	239.524		
Total	6179.929	9			



January 2003	**Figure 6**
TODD ENGINEERS and GeoChem Applications	**Linear Regression of Potassium versus Beta Activity**

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