SUMMARY REPORT FOR THE DEL RIO LANDFILL

Presented to:
CITY OF PHOENIX
Street Transportation Department
200 West Washington Street, 5th Floor
Phoenix, Arizona  85003

Presented by:
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City of Phoenix Street Transportation Department  
200 West Washington Street, 5th Floor  
Phoenix, AZ 85003  

Subject: Summary Report  
Del Rio Landfill  
Phoenix, Arizona  

Dear James:  

SCS Engineers is pleased to provide this Summary Report for the Del Rio Landfill. SCS appreciates the opportunity to work with the City on this exciting project. If you have any questions regarding this document, please contact Brad Johnston at (602) 910-0547.  

Sincerely,  

Bradley F. Johnston, RG  
Vice President  
SCS ENGINEERS  

Michael W. McLaughlin, PE (VA)  
Principal  
SCS ENGINEERS  

Enclosure  

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EXECUTIVE SUMMARY

The Del Rio Landfill (DRL), also known as the 16th Street Landfill, is located on the south bank of the Salt River between 7th and 16th Streets in Phoenix, Arizona. The site is owned by the City of Phoenix (City) and is approximately 156 acres in size, of which an estimated 103 acres have been landfilled.

Prior to the 1970s, the DRL was used for sand and gravel excavation. It was then operated as a landfill from 1971 until November 1980, during which time it accepted an estimated 2.5 million tons of municipal and industrial solid wastes at a rate of about 30,000 tons per month. The thickness of refuse has been estimated to range from approximately 25 to 49 feet. Wastes were reportedly compacted into 8-foot lifts, resulting in an estimated soil-to-refuse ratio of 1:3.5 (one ton of soil for every 3.5 tons of refuse). Test excavations of the landfill cover soil indicated that the thickness of cover soil ranged from 4 inches to over 60 inches, with the majority of locations exceeding 60 inches.

A Consent Agreement was entered between the City and the Arizona Department of Health Services (ADHS) in 1979 to characterize and close the site, and an injunction was issued in 1981 for failure to comply with the consent agreement. These instruments were vacated by the court in November 2000. A landfill gas (LFG) and groundwater monitoring agreement was then implemented until it was certified as complete in 2009. The City voluntarily continues annual groundwater measurement and sampling until 2013 when the monitoring wells went dry. The City continues to measure groundwater levels annually to determine whether sampling is possible, and will perform sampling when possible. LFG monitoring continues to take place.

An LFG migration control system was installed in 1982 and includes 31 LFG extraction wells installed along the west, south, and east sides of the landfill; two perimeter LFG header pipelines; and a flare station located in the central portion of the site. The system is operated and monitored under a Maricopa County Air Quality Division permit. The City also voluntarily monitors 28 LFG monitoring probes located along the west, south, and east site boundaries to verify that subsurface methane at the property boundary does not exceed 5% methane. Monitoring records reviewed for this report indicate that perimeter probes have not exceeded 5% methane due to LFG since 2012.

A 1991 Remedial Action Plan concluded that the DRL was not adversely impacting groundwater quality, and that a source other than the DRL appeared to be responsible for degradation of inorganic water quality immediately west of the landfill. Between 2001 and 2013, there were no exceedances of Aquifer Water Quality Standards (AWQS) in the monitored groundwater wells.

Based on a site visit performed on February 10, 2017, the site is currently vacant. A park formerly occupied the central portion of the site, but has been closed for several years. A paved entrance road and parking areas are located in the south-central portion of the site, and a few maintenance roads on the site have been surfaced with asphalt millings. Previous park structures such as restrooms and ball courts have been removed, and the only remaining structures on the site are chain link fences, a maintenance building, and the LFG flare station in the central portion of the site. LFG wells and control system piping are present on the west, south, and east edges of the site, and groundwater monitoring wells and utility boxes were observed in several locations.
Soil and asphalt millings have been stockpiled on the site. In 2010, an estimated 250,000 cubic yards of soil were present on the west and central portions of the site. It does not appear that significant amounts of soil have been added or removed from these piles since 2010. It appears that additional asphalt millings have been added on the eastern portion of the site since 2010. The amount of asphalt millings or other materials that may have been placed since 2010 has not been quantified.

The DRL is classified as “a closed solid waste facility” per A.R.S. 49-701. Therefore, the Arizona Department of Environmental Quality (ADEQ) will allow redevelopment of the site so long as the DRL remains a closed solid waste facility by meeting certain conditions relating to leachate, LFG, landfill cover, and regulatory notification.

This report is intended to provide a summary of site conditions as well as examples of environmental and development issues and mitigation alternatives. These examples are provided for information only and should not be considered an exhaustive analysis of all environmental, development, and mitigation alternatives or solutions for all types of potential land uses at the site. The examples presented in this report were prepared specifically for a conceptual master plan of a regional municipal park facility. Any proposed future land uses should ensure that required regulatory requirements are met and that human health and the environment are protected.
1.0 INTRODUCTION

1.1 PURPOSE

The City of Phoenix (City) requested this report for the City-owned Del Rio Landfill (DRL) site that was closed in 1980. The purpose of this report is to provide a summary of site conditions (background, history, and environmental and geotechnical conditions), potential environmental/development issues, and mitigation alternatives based on existing data.

This report includes the following:

- A summary of site conditions
- Maps showing the location and thickness of waste, cover thickness, proposed redevelopment features, and other relevant information
- A description of the methodology and findings of settlement estimates
- A summary of issues that may need to be addressed
- Alternatives and, where possible, associated preliminary cost estimates for addressing these issues
- Preliminary recommendations for mitigation of potential settlement, landfill gas, and irrigation infiltration issues
- Recommendations for additional investigation to address data gaps and refine conceptual design and costs

1.2 LIMITATIONS

Existing information summarized in this report, specifically regarding potential issues and mitigation alternatives, is based primarily on previous plans to develop the site as a golf course and a large park facility. Therefore, this report should not be considered an exhaustive analysis of all potential redevelopment issues and mitigation alternatives for all types of land uses at this site. Furthermore, any cost estimates provided in this report are from 2010 (unless otherwise noted) and they should not be considered accurate for current conditions.

The services of a qualified environmental consultant and licensed professional engineer should be retained to guide additional investigation and design of mitigation measures specific to any land use planned for the DRL site.
2.0 SITE CONDITIONS

2.1 BACKGROUND

The DRL, also known as the 16th Street Landfill, is located at 1150 East Elwood Street on the south bank of the Salt River, between 7th and 16th Streets, and north of Elwood Street in Phoenix, Arizona (see Figure 1). The DRL site is approximately 156 acres in size, and landfilled areas occupy approximately 103 acres of the site.

The DRL was owned by the City and operated as a landfill from 1971 until November 1980. Municipal solid waste was reportedly received at the landfill at a rate of approximately 30,000 tons per month. The municipal solid waste was compacted into 8-foot lifts; the soil-to-refuse ratio was estimated to be 1:3.5 (one ton of soil for every 3.5 tons of refuse). The landfill accepted approximately 2.5 million tons of municipal and industrial solid wastes from 1971 until 1981.

2.2 LANDFILL HISTORY

The DRL was used for sand and gravel excavation prior to the 1970s. The depths of the gravel pits were limited by the presence of groundwater to a maximum of approximately 60 feet below ground surface at the time of mining, which was an elevation of approximately 1,020 feet above mean sea level. The approximate ground surface elevation was 1,080 feet. Landfill operations began on the site in 1971. The landfill accepted municipal solid waste and industrial waste, but specific types of waste accepted were not documented.

The DRL was closed by a cease-and-desist order issued by the Arizona Department of Health Services (ADHS) in February 1979. A Consent Agreement was entered between the City and ADHS in June 1979 and amended in December 1979 to properly close the site. In 1981, an injunction was issued by the state of Arizona for failure to comply with the consent agreement. Based on the 1979 Consent Agreements and the 1981 Injunction between the City and the State of Arizona, the City was required to perform the following:

- Perform groundwater monitoring
- Characterize hydrogeological and geological conditions and environmental impacts
- Prevent washout of waste material
- Perform monitoring and control of LFG
- Cease acceptance of hazardous wastes and liquid wastes, and control the disposal of permitted liquid wastes
- Raise the existing pit bottoms to 10 feet above the highest known water level
- Permanently close the landfill by November 12, 1980.
The 1979 and 1981 Consent Agreements and Injunction were vacated by the court in November 2000. In 1985, the Arizona Department of Environmental Quality (ADEQ) was formed; ADEQ assumed regulatory responsibility for landfills from the ADHS.

A Remedial Action Plan (RAP) was finalized in 1991 (Dames and Moore, 1991). According to the RAP, the depth of the bottom of the landfill was estimated to range between 30 and 60 feet below ground surface (bgs). The RAP indicated that the south bank of the Salt River channel was armored with rip-rap to protect the landfill from erosion and inundation in the event of a 100-year flood.

After closure of the landfill in 1981, the City imported soil to cap the site. The former Rio Salado Park, a 20-acre recreational park, was located in the south-central area of the landfill and was situated over approximately 3.8 acres of refuse. The park, now closed, included two enclosed structures (a restroom and a service building) and an open-roof handball court structure, which no longer remains.

The DRL generated LFG containing methane due to organic degradation of refuse. An LFG collection and discharge system was maintained at the landfill to prevent offsite migration of methane gas.

The RAP indicated that the DRL was not adversely impacting groundwater quality and that a source other than the DRL appeared to be responsible for degradation of inorganic water quality immediately west of the landfill. ADEQ requested additional monitoring and installation of more wells, which confirmed the previous conclusions. ADEQ subsequently agreed to reduce the frequency of monitoring from quarterly to annually.

### 2.3 Previous Redevelopment Plans

In 1999, the Rio Salado Sports Group proposed development of the landfill as the Del Rio Golf Course. In June 1999, 35 test pits were surveyed to evaluate the physical characteristics of the existing landfill cover. A leachate generation assessment of the existing landfill cover and proposed golf course cover systems was performed to evaluate potential changes in leachate production due to the proposed golf course development. It was concluded that the development would not increase leachate discharge from the landfill and that the golf course would not contribute to the groundwater contamination. An additional 60 test pits were excavated in 2003 to further evaluate the cover. A Final Design and Site Characterization Report summarized these findings (SCS Engineers, 2003).

In 2010, the City investigated the feasibility of redeveloping the site as a large park facility, which generally consisted of three elements (SCS Engineers, 2010). Proposed redevelopment of the eastern portion of the site (approximately 50 acres of landfilled area) included soccer and baseball fields, shade ramadas, an operations building/restroom, and parking areas. The central portion of the site approximately 20 acres which was reportedly not landfilled) was to include a recreation center, skateboard park, lighted basketball courts, playground, splash pad, restroom, and a portion of the entrance road. The western portion of the site includes approximately 52 acres of landfilled area, and proposed improvements included an equestrian center, operations
building, BMX track and plaza, mesquite bosque, open turf area, scenic overlook, and a portion of the entrance road.

2.4 CURRENT SITE CONDITIONS

A topographic map with site conditions as of 2010 is provided as Figure 2. Based on a site visit performed on February 10, 2017, the site is currently vacant and appears essentially the same as shown on the 2010 map. A park formerly occupied the central portion of the site, but has been closed for several years. A paved entrance road and parking areas are located in the south-central portion of the site, and a few maintenance roads on the site have been surfaced with asphalt millings. Previous park structures such as restrooms and ball courts have been removed, and the only remaining structures on the site are chain link fences, a maintenance building, and the LFG flare station in the central portion of the site. LFG wells and control system piping are present on the west, south, and east edges of the site, and groundwater monitoring wells and utility boxes were observed in several locations.

Soil and asphalt millings have been stockpiled on the site. As described in a May 2010 Preliminary Grading Plan memorandum (SCS Engineers, 2010), an estimated 250,000 cubic yards of soil were present on the west and central portions of the site as shown on Figure 2. It does not appear that significant amounts of soil have been added or removed from these piles since 2010. It appears that additional asphalt millings have been added on the eastern portion of the site since 2010. The amount of asphalt millings or other materials that may have been placed since 2010 has not been quantified.

2.5 CURRENT REGULATORY STATUS

The DRL is classified as “a closed solid waste facility” per A.R.S. 49-701. Therefore, the Waste Programs Division of ADEQ will allow redevelopment so long as the DRL remains “a closed solid waste facility.” In order to maintain the existing closed status, the following conditions at a minimum must be met:

- When the project is completed, there will not be an increase in leachate that would result in a discharge.

- When the project is completed, the concentration of methane gas will not exceed 25 percent of the lower explosive limit in on-site structures, and the concentration of methane gas in soils will not exceed the lower explosive limit at the property line.

- Protection has been provided to prevent remaining waste from causing any vector, odor, litter, or other environmental nuisance (e.g., waste remains covered).

- The operator provides a notice to the Department containing the information required by Section 49-762.07, subsection A, paragraphs 1, 2, and 5, and a brief description of the project.
ADEQ approval for waste relocation within the existing landfill and cover disturbance may not be required, but SCS recommends that a courtesy notification be provided regarding any planned investigation or construction activities that will disturb significant amounts of waste.

2.6 LANDFILL COVER CONDITIONS

The Final Design and Soil Characterization Report for the previously-proposed golf course (SCS Engineers, 2003) summarized the combined test pit investigations. As shown in Figure 3, the thickness of cover soil ranged from 4 inches to over 60 inches, with the majority of locations exceeding 60 inches. Soil types identified by the cover studies varied across the site. The primary soil types consist of either sand or gravel, including the following USCS classifications:

- GP – Poorly-graded gravel
- GW – Well-graded gravel
- GP-GM – Poorly-graded gravel with silt and sand
- GM – Silty gravel with sand
- SP – Poorly-graded sand
- SM – Silty sand
- SP-SM – Poorly-graded sand with silt and gravel
- SC – Clayey sand
- SC-SM – Silty, clayey sand

2.7 ESTIMATED EXTENT AND THICKNESS OF WASTE

Elevations of the base of each disposal cell were shown in the Dames and Moore RAP; the source of the elevation data was cited as Sverdrup & Parcel and Associates, 1980. Using these elevations, the topographic map prepared by Kinney Aerial in December 2002, and the thickness of soil cover identified by SCS in 1999 and 2003, estimates of the thickness of refuse range from approximately 25 to 48 feet as shown on Figure 4. These must be considered approximations, because the specific locations of the Sverdrup survey points are not known, so it was assumed that the base elevation was consistent throughout each cell. In addition, buried waste at the site continues to settle.

As described in the Final Design and Soil Characterization Report (SCS Engineers, 2003), SCS verified the existing waste limits at the DRL using historical aerial photography and field investigation methods. Aerial photographs for 1972, 1973, 1974, 1976, 1979, and 1981 were reviewed and the visible waste limits were scaled onto a drawing of the site. Coordinates of these limits were then used to stake the limits in the field. Twelve test pits were excavated across the staked waste boundary to visually verify the limits. SCS then used an electromagnetic survey instrument (EM-31) to further evaluate the limits of waste. The boundaries determined by field methods were compared to the waste limits determined by the aerial photography. Minimal discrepancies were noted, and they were field checked with additional test pits. Using these methods, SCS estimated the waste limit boundary to contain 103.26 acres.
2.8 GROUNDWATER QUALITY

Five groundwater monitoring wells were installed at or around the facility between October and December 1979 to evaluate the potential influence of the DRL on groundwater quality. Five additional groundwater monitoring wells were installed in 1987 to assist the groundwater quality investigation. Monitoring well locations are shown on Figure 5.

Groundwater elevations across the site historically have ranged from about 25 to over 85 feet below ground surface, at which point site monitoring wells reportedly went dry in 2013 (City of Phoenix, 2017). The bottom of the landfill cells is estimated to vary between 20 and 60 feet below the ground surface. The direction of groundwater flow across the site has been generally to the west-northwest.

The DRL is not subject to the groundwater monitoring requirements of 40 CFR 258.50 through 258.59. According to ARS 49-250, closed facilities and municipal solid waste landfills that have an approved solid waste facility plan are exempt from the requirements of the Aquifer Protection Permit (APP). However, the DRL was issued a Groundwater Protection Permit in July of 1986, and the facility is subject to the groundwater and leachate monitoring requirements specified in the permit.

On September 18, 2000, the City and the State of Arizona entered into the Del Rio Landfill Administrative Agreement for continued groundwater and methane monitoring. The Administrative Agreement specified annual monitoring of wells DM16-1S, DM16-5, and DM16-6 on an annual basis for a list of analytes provided as Appendix 2 to the Agreement.

On January 23, 2009, the City submitted a Certificate of Completion for the landfill monitoring agreement, and ADEQ accepted the certificate (ADEQ, 2009). The City voluntarily continued annual groundwater monitoring until 2013, at which time the groundwater level had reportedly dropped below the bottom of the monitoring wells so that further monitoring could not be performed (City of Phoenix, 2017).

The Certificate of Completion stated that groundwater monitoring reports were submitted to ADEQ for a period of eight years, between 2001 and 2008. During that time, there were no exceedances of Aquifer Water Quality Standards (AWQS) in the monitored wells. Subsequent voluntary annual monitoring events in 2010, 2011, 2012, and 2013 also did not identify exceedances of AWQS in the monitored wells.

2.9 LANDFILL GAS

2.9.1 LFG Migration Control System

An active LFG migration control system was installed at the landfill by the City in 1982 to prevent the offsite migration of LFG at levels exceeding regulatory thresholds at the landfill boundaries. The system is operated under Maricopa County Air Quality Department Permit #990053 (Maricopa County Air Quality Department, 2016) that was revised in December 2016, and expires in May 2022. In addition to specifying the operating requirements for the LFG
control system, the permit also regulates dust generating activities and hydrogen sulfide (H2S) emissions.

The LFG migration control system includes 31 LFG extraction wells installed along the perimeter of the landfill, excluding the north side adjacent to the Salt River (see Figure 6). The system consists of two perimeter LFG header pipelines that feed the flare station located in the central portion of the site. The east LFG collection system consists of 16 LFG extraction wells and the west LFG collection system consists of 15 LFG extraction wells. LFG is extracted under vacuum provided by two 15-horsepower electric blowers, and a flare destroys the collected methane gas by combustion.

In accordance with permit requirements, a Compliance Source Test was performed for the flare station in 2010 (Bryan A. Stirrat & Associates, 2010). Measured parameters included oxygen, carbon dioxide, carbon monoxide, nitrogen oxides, moisture, flow rate, temperature, hydrogen sulfide, and total gaseous non-methane organics. The source test results showed that the flare emissions were below permit limits.

Monthly flare monitoring data required by the permit was reviewed for the last five years (January 2012 to November 2016). These data indicate that the system has operated an average of 668 hours per month (ranging from 480 to 766 hours per month) at an average flow rate of 97 standard cubic feet per minute (ranging from 56 to 233 SCFM). The average methane concentration coming into the flare ranged from 17% to 25%, and shows a slight trend upward for the last five years as shown at right. This increase may be due to a similar upward trend seen in hours of operation per month.

2.9.2 Perimeter Probe Monitoring

The LFG migration control program includes 28 LFG monitoring probes located along the west, south, and east facility boundary, as shown on Figure 6. Probes are monitored monthly on a voluntary basis by the City to ensure that the lateral migration of LFG is controlled so that subsurface methane at the property boundary does not exceed 5% methane.

Review of probe monitoring data from the last five years (January 2012 to December 2016) did not identify any measurements exceeding 5% methane that were due to LFG. As shown on Figure 6, methane was detected below 5% in five of the probes. All of these detections were one-time events, and did not reoccur in subsequent monitoring events. Since May 2014, all probes have been non-detect for methane.

In December 2014, LFG probe #1 exceeded 5%, but upon further investigation, the result was due to a leak from a nearby underground natural gas pipeline. The leak was repaired by Southwest Gas, and readings decreased to below 5% within three days, and methane has been non-detect since that time (ADEQ, 2015).
2.9.3 **Hydrogen Sulfide Compliance**

A Compliance Demonstration for hydrogen sulfide (H₂S) was performed in 2007, and included monitoring of six LFG probes along on the east side of the landfill where the closest off-site buildings were located. All measurements were below the limit of 0.03 parts per million by volume (City of Phoenix, 2007).

2.10 **Surface Water**

Based on 1997 aerial site topography, surface water is managed by three primary underground storm drains. These three storm drains serve as the main arteries for removing collected surface water from the site and into the Salt River channel. A series of catch basins and lateral storm drains collect surface water and convey it to one of the primary storm drains.

3.0 **Potential Issues**

3.1 **Development Issues**

The presence of buried waste beneath the site will affect its proposed development due to potential settlement, potential contact with trash during construction or maintenance activities, and the presence of LFG. Also, adequate cover of waste must be maintained. Any proposed future land uses should ensure that required regulatory requirements are met and that human health and the environment are protected.

Key design goals should include:

- Achieve acceptable performance as the site settles due to a combination of consolidation and decomposition of the landfill mass, as well as consolidation of any compressible soils below the landfill mass. Buildings and other structures must be designed to accommodate anticipated settlement, and building entrances, utility connections, surface grades, and utility slopes must be designed such that they provide acceptable performance over the life of the development while settlement is occurring.

- Minimize infiltration of water through the landfill cover into the underlying waste. The cover system (including any new buildings or pavements) must be able to accommodate irrigation and rainfall, and irrigation and surface water drainage systems must be properly designed and managed to handle both routine and non-routine irrigation and rainfall events.

- Minimize disturbance of buried waste materials, as these can present safety issues and may require special handling (e.g., sampling, possible offsite disposal) and regulatory involvement once excavated.
3.2 CONTACT WITH WASTE

Underground utilities or foundations may penetrate waste materials. If possible, this should be avoided. If waste is disturbed, proper handling of waste materials would be required, and overexcavation may be appropriate so that utilities or structural components are not in direct contact with trash. If landscaping with deeper root systems penetrates into waste materials, plant growth may be affected by lack of water or adequate soil nutrients. If areas covered with soil will be actively used (e.g., athletic fields), adequate cover will be required, particularly where routine activities will disturb the soil such as baseball diamond base paths.

3.3 SETTLEMENT

3.3.1 Potential Effects of Settlement

Initial settlement can occur in response to increased loading (such as that associated with additional fill or structures), and secondary settlement can occur due to ongoing decomposition and raveling of buried waste. Irrigation may also affect settlement by affecting the weight and decomposition rate of waste. Due to unknown factors including the exact composition and placement of waste, rate of waste decomposition, distribution, age, and moisture content of existing waste, accurate predictions of settlement rate and the overall magnitude of settlement are difficult to make. Site-specific estimates are discussed in Section 3.3.2.

Differential settlement resulting in irregular topography and possible drainage issues is likely to occur due to the variable thickness and distribution of waste on this site. This is especially true if fill is added to the site, which will increase the load and thus the rate of settlement, particularly in areas of thicker waste. Higher slopes (2% or more) may be desirable to maintain positive drainage on the site, but these slopes may be too large for athletic field playing surfaces. Therefore, it is likely that periodic local filling and turf replacement will be necessary to maintain a consistent playing surface.

The following sections discuss the effects of these types of settlement on each of the proposed development features.

3.3.1.1 Structures

Structures such as buildings, restrooms, armadas or other rigid features may respond to settlement by becoming unlevel or crooked when portions of the feature settle at different rates than others. This can result in improper fit of doors and windows and unacceptably tilted floors, and rigid buildings materials may crack. If a structure settles at a different rate than surrounding area, utility connections may be damaged, stormwater may not drain away from the structure, or access issues may be created by gaps or vertical grade changes between the building and surrounding grade. Settlement may be load-dependent, so structures with a heavier foundation loading may be affected more.
3.3.1.2 Utilities

Aboveground light poles may tilt or their utility connections may be damaged. Horizontal underground utilities may experience flexing, bending, or cracking due to differential settlement. Gravity-flow pipelines may experience grade changes that could affect their flow.

3.3.1.3 Surface grade

Differential settlement may result in low or high areas that could affect the usability of athletic playing fields, parking lots, roads, or walkways. Such low areas may also accumulate runoff or irrigation water that could infiltrate into the underlying waste.

3.3.2 Estimated Settlement Amounts

3.3.2.1 Assumptions for Settlement Estimates

The following assumptions were used for evaluating potential settlement at the DRL:

- Site was used for sand and gravel excavation prior to the 1970s, and the landfill was operated from 1971 until November 1980.
- Municipal solid waste was reportedly received at the landfill at a rate of approximately 30,000 tons per month.
- The municipal solid waste was compacted into 8-foot lifts; the soil-to-refuse ratio was estimated to be 1:3.5 (one ton of soil for every 3.5 tons of refuse).
- The landfill accepted approximately 2.5 million tons of municipal and industrial solid wastes from 1971 until 1981. Specific types of waste accepted were not documented.
- Waste thickness reportedly varies from approximately 25 feet to 49 feet.
- After closure of the landfill in 1981, the City imported soil to cap the site.
- Based on test pits excavated in 1999, existing cover thickness ranged from 4 inches to over 60 inches, with the majority of locations exceeding 60 inches. Soil types identified by the cover studies varied across the site. The primary soil types consist of either sand or gravel ranging from GP to SC-SM.
- The DRL generated relatively small quantities of LFG, and a gas collection and discharge system was maintained at the landfill to prevent offsite migration of methane gas.

3.3.2.2 Estimated Short Term Settlement

Settlement will result from two factors: (1) short term settlement resulting from addition of soil or other surface loadings that may be placed and (2) long term settlement due to on-going decomposition of the waste.
The method used to compute waste settlement from addition of soil or other loads is from Sowers (1970) “Settlement of Waste Disposal Fills.” This method is based on the assumption that for the short term (approximately several months) waste will compress due to imposition of new loads (pressures) in a fashion similar to that experienced by soft clays and organic deposits. Short term compression does not include the impact of decomposition of organic matter within the waste, which Sowers considers analogous to secondary consolidation. Waste decomposition-related settlement occurs over a much longer period of time (years) compared to short term load-related settlement and is related to the rate at which the organics degrade.

The method of analysis involved estimating compression properties of the waste (void ratio and compression coefficient), initial and proposed new loadings within the compressible waste layers, and waste thickness. The following relationship from Sowers was used:

\[ S = H \times \left( \frac{C_c}{1+e_0} \right) \times \log \left( \frac{P_0 + \Delta P}{P_0} \right) \]

Where,

- **S** = short term settlement due to new loading ΔP
- **H** = initial waste thickness
- **e_0** = initial void ratio
- **C_c** = compression coefficient (from Sowers)
  - 0.15*e_0 for low organic, less compressible waste
  - 0.55*e_0 for higher organic, more compressible waste
- **P_0** = initial stress within middle of underlying compressible layer
- **ΔP** = change in stress due to loading (at middle of compressible layer)

The waste compression coefficient, C_c, is a function of initial void ratio (e_0) which Sowers estimated based on empirical information. The lower range of 0.15*e_0 represents waste with low organic matter or is otherwise less compressible (due to heavy compaction equipment or methods, waste composition, etc.); the higher range of 0.55*e_0 represents waste with high organic content and/or is otherwise more highly compressible.

Due to the age of the waste, which is over 30 years, and since it was compacted into 8-foot lifts with an estimated soil-to-refuse ratio of 1:3.5 (one ton of soil for every 3.5 tons of refuse) it is assumed that the compression coefficient will be in the range of 0.20*e_0 to 0.30*e_0, which is the lower part of the range suggested by Sowers, and averaging 0.25*e_0.

### 3.3.2.2.1 Short Term Settlement from Addition of New Cover Soil

As shown in Table 1, calculations were performed to evaluate potential settlement for an example scenario where two feet of soil cover (assume a density of 125 pounds per cubic foot, or pcf) is added to the landfill areas. Assuming a void ratio of 3.0 for the waste, an average in-place density of 50 pcf and an average new loading ΔP = 2 X 125 pcf = 250 pounds per square foot (psf) over the entire area, it may be expected that the waste will exhibit a short term settlement of up to about 9 inches (0.74 feet) solely as a result of the addition of an average of two feet of additional cover soil.
Table 1. Settlement Estimates For 2 Feet Of New Cover

<table>
<thead>
<tr>
<th>Waste Depth (H in feet)</th>
<th>Stress @ Center (Po in psf)</th>
<th>New Soil Thickness (feet)</th>
<th>Induced Stress @ Center (ΔP in psf)</th>
<th>Void Ratio (e)</th>
<th>Coeff. Of Compression (Cc)</th>
<th>Estimated Settlement (S, in feet)</th>
<th>Percent Change In Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>625</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>2.7%</td>
</tr>
<tr>
<td>30</td>
<td>750</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>2.3%</td>
</tr>
<tr>
<td>35</td>
<td>875</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>2.0%</td>
</tr>
<tr>
<td>40</td>
<td>1000</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>1.8%</td>
</tr>
<tr>
<td>45</td>
<td>1125</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>1.6%</td>
</tr>
<tr>
<td>50</td>
<td>1250</td>
<td>2</td>
<td>250</td>
<td>3.0</td>
<td>0.75</td>
<td>0.7</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

A heavier load (e.g., thicker cover soil added) will increase the settlement proportionally. This indicates that the actual amount of fill placed to reach final grades will be approximately 25% to 30% greater than if no settlement were to occur. However, a significant amount of this settlement will occur as the new fill is being placed and for a short period of time after completion, in the range of several weeks to about two months.

3.3.2.2.2 Short Term Settlement from Surcharging

As shown in Table 2, if a 5-foot thick surcharge layer weighing 125 pcf (total load of 625 psf) is placed over the area, the settlement related to the surcharge is estimated to increase to about 1.4 to 1.7 feet.

Table 2. Settlement Estimates For 5 Feet Of Surcharge Fill

<table>
<thead>
<tr>
<th>Waste Depth (H In Feet)</th>
<th>Stress @ Center (Po In Psf)</th>
<th>New Soil Thickness (Feet)</th>
<th>Induced Stress @ Center (ΔP In Psf)</th>
<th>Void Ratio (E)</th>
<th>Coeff. Of Compression (Cc)</th>
<th>Estimated Settlement (S, In Feet)</th>
<th>Percent Change In Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>625</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.4</td>
<td>5.6%</td>
</tr>
<tr>
<td>30</td>
<td>750</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.5</td>
<td>4.9%</td>
</tr>
<tr>
<td>35</td>
<td>875</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.5</td>
<td>4.4%</td>
</tr>
<tr>
<td>40</td>
<td>1000</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.6</td>
<td>4.0%</td>
</tr>
<tr>
<td>45</td>
<td>1125</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.6</td>
<td>3.6%</td>
</tr>
<tr>
<td>50</td>
<td>1250</td>
<td>5</td>
<td>625</td>
<td>3.0</td>
<td>0.75</td>
<td>1.7</td>
<td>3.3%</td>
</tr>
</tbody>
</table>

Once the surcharge is removed, the waste should remain in this compressed condition (little or no rebound occurs) and should exhibit less long term compression from the remaining grading fill and from decomposition. The amount of settlement remaining after surcharging is best estimated from settlement plate monitoring data, but should be less than approximately 20% to 30% of the surcharge-related settlement.
3.3.2.3 Estimated Long Term Settlement

After the short term (related to new load) settlement has dissipated, the waste will continue to settle as a result of on-going waste decomposition. This long-term settlement will occur whether a surcharge is placed or not.

Following Sowers methodology, the method of analysis involves estimating compression properties of the waste (void ratio and compression coefficient), and considering the duration of time the waste has been in place and undergone some degree of decomposition. The following relationship from Sowers was used:

\[ L = H \times \left( \frac{C_\alpha}{1+e_0} \right) \times \log\left( \frac{T_2}{T_1} \right) \]

Where,

\[ L = \text{long term settlement over time} \]
\[ H = \text{initial waste thickness} \]
\[ e_0 = \text{initial void ratio} \]
\[ C_\alpha = \text{long term coefficient (from Sowers)} \]

\[ = 0.03 \times e_0 \text{ for low organic, less compressible waste} \]
\[ = 0.09 \times e_0 \text{ for higher organic, more compressible waste} \]

\[ T_1 = \text{time factor measured from middle of filling to time of athletic field construction} \]
\[ \text{(~1975 – 2010 = 35 years)} \]
\[ T_2 = \text{time factor measured after athletic field construction, for 5 years out, } T_2=40 \text{ years, for 20 years out } T_2=55 \text{ years.} \]

Based on this model and assuming \( C_\alpha = 0.06 \) (middle of the range value), void ratio of 3.0, \( T_1=35 \) years and \( T_2=65 \) years (30 years after completion of construction), the estimated long term settlement was approximately 4 inches (0.3 feet) where the waste is 25 feet deep, to 7 inches (0.6 feet) where the waste is 50 feet deep.

Table 3. Long Term Settlement Estimate At 30 Years

<table>
<thead>
<tr>
<th>Waste Depth (H in feet)</th>
<th>Time Period After Construction (years)</th>
<th>Time Factor T1 (years)</th>
<th>Time Factor T2 (years)</th>
<th>Void Ratio (e0)</th>
<th>Coeff. Of Compression (Cα)</th>
<th>Estimated Settlement (S, in feet)</th>
<th>Percent Change In Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>25</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.3</td>
<td>1.2%</td>
</tr>
<tr>
<td>30</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.4</td>
<td>1.2%</td>
</tr>
<tr>
<td>35</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.4</td>
<td>1.2%</td>
</tr>
<tr>
<td>40</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.5</td>
<td>1.2%</td>
</tr>
<tr>
<td>45</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.5</td>
<td>1.2%</td>
</tr>
<tr>
<td>50</td>
<td>30</td>
<td>35</td>
<td>65</td>
<td>3.0</td>
<td>0.18</td>
<td>0.6</td>
<td>1.2%</td>
</tr>
</tbody>
</table>

3.3.2.4 Differential Settlement

Taking the long term settlement into account, and allowing a margin of error of two times, the design should account for differential settlement as follows:
• Between areas with known different waste thicknesses, assume at least 8 inches to 10 inches between areas of 25 and 50 feet of waste, respectively.

• Within areas of similar waste thickness, assume about ½ the estimated total settlement, or 4 to 8 inches, due to the inherent variation in waste properties.

• These are not cumulative values, but the design should consider the more conservative value that applies.

3.3.2.5 General Comments on Settlement Estimates

As with all waste settlement estimates, the magnitudes calculated are based on empirical relationships and engineering judgment and should be taken as approximations. Although conservative assumptions were applied, the actual values in any particular location may be somewhat higher or lower depending upon historic waste compaction and composition, daily cover thickness and usage, in place waste density, waste lifts, and related operational conditions. Surcharging and monitoring of settlement can provide an early indication of whether the actual settlement will be within the ranges estimated. A geotechnical investigation should be performed in connection with design of specific structures or pavement cross-sections.

3.4 LEACHATE/GROUNDWATER QUALITY

3.4.1 Potential Impacts from Infiltration of Irrigation or Storm Water

Irrigation and stormwater must be properly managed so that water does not form ponds and/or percolate into underlying waste materials. Allowing water to penetrate the waste mass may accelerate waste decomposition, which could potentially increase subsurface temperatures, settlement, and LFG generation. In addition, maintenance of the landfill cover is important to maintain the “closed” regulatory status of the landfill, which prohibits activities resulting in an increase in leachate (Arizona Revised Statutes 49-701 29 (k)).

3.4.2 Previous Modeling Results for Irrigation Infiltration

SCS performed an infiltration assessment to demonstrate that the development of the Del Rio Golf Project would not create an increase in the production of leachate that could be discharged from the landfill. The rate of precipitation or surface water percolating through the landfill and golf course covers was evaluated using the Hydrologic Evaluation of Landfill Performance (HELP) Model. The HELP Model is a computer-based water balance model developed by the Army Corps of Engineers to assist landfill designers and regulators in predicting infiltration through covers and into the underlying waste at landfills.

Existing and proposed soil cover conditions were modeled. For each existing soil cover condition configuration, a corresponding golf course cover was established by adding a vegetative layer to support turf growth and, if necessary, an environmental grade layer (EGL) to decrease infiltration in areas of inadequate existing cover. The EGL layer considered by the golf course design consisted of soils with USCS soil classification of SM or SP-SM with permeability
less than $2.6 \times 10^{-4}$ centimeters per second (cm/s). The thickness of the EGL was varied until a reduction in percolation (compared to the existing condition) was obtained.

The model for the golf course assumed the following monthly irrigation amounts supplied by Coates Irrigation for Bermuda grass golf turf in Phoenix.

**Table 4. Assumed Irrigation Requirements**

<table>
<thead>
<tr>
<th>Month</th>
<th>Monthly Irrigation (In)</th>
<th>Increase By 15% for Golf Turf</th>
<th>Increase By 15% For Overseeding</th>
<th>Daily Amount (In)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.47</td>
<td>0.54</td>
<td>0.62</td>
<td>0.02</td>
</tr>
<tr>
<td>February</td>
<td>0.62</td>
<td>0.71</td>
<td>0.82</td>
<td>0.03</td>
</tr>
<tr>
<td>March</td>
<td>1.95</td>
<td>2.24</td>
<td>2.58</td>
<td>0.08</td>
</tr>
<tr>
<td>April</td>
<td>4.22</td>
<td>4.85</td>
<td>4.85</td>
<td>0.16</td>
</tr>
<tr>
<td>May</td>
<td>6.50</td>
<td>7.48</td>
<td>7.48</td>
<td>0.24</td>
</tr>
<tr>
<td>June</td>
<td>7.10</td>
<td>8.17</td>
<td>8.17</td>
<td>0.27</td>
</tr>
<tr>
<td>July</td>
<td>7.81</td>
<td>8.98</td>
<td>8.98</td>
<td>0.29</td>
</tr>
<tr>
<td>August</td>
<td>6.72</td>
<td>7.73</td>
<td>7.73</td>
<td>0.25</td>
</tr>
<tr>
<td>September</td>
<td>5.78</td>
<td>6.65</td>
<td>6.65</td>
<td>0.22</td>
</tr>
<tr>
<td>October</td>
<td>3.59</td>
<td>4.13</td>
<td>4.75</td>
<td>0.15</td>
</tr>
<tr>
<td>November</td>
<td>1.02</td>
<td>1.17</td>
<td>1.35</td>
<td>0.04</td>
</tr>
<tr>
<td>December</td>
<td>0.47</td>
<td>0.54</td>
<td>0.62</td>
<td>0.02</td>
</tr>
<tr>
<td>Totals</td>
<td>46.25</td>
<td>53.19</td>
<td>54.59</td>
<td></td>
</tr>
</tbody>
</table>

Using these amounts as inputs to the HELP model, it was concluded that the following general cover conditions would be adequate to prevent irrigation water from infiltrating the waste mass:

**Table 5. Modeled Cover Systems**

<table>
<thead>
<tr>
<th>Existing Cover</th>
<th>Additional Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil Type</td>
<td>Thickness</td>
</tr>
<tr>
<td>Sand</td>
<td>≥48”</td>
</tr>
<tr>
<td>Sand</td>
<td>&lt;48”</td>
</tr>
<tr>
<td>Gravel</td>
<td>&lt;24”</td>
</tr>
<tr>
<td>Gravel</td>
<td>≥24”</td>
</tr>
</tbody>
</table>

These cover scenarios are graphically illustrated below:
3.5 LANDFILL GAS

3.5.1 Potential Impacts on Development

As solid waste decomposes in a landfill under anaerobic conditions, it produces LFG made up of 
carbon dioxide and methane. Methane is colorless and odorless, but if allowed to collect at 
concentrations between about 5 and 15% in the presence of oxygen, and if a source of ignition is 
present, methane can explode. Methane generation decreases over time, but the DRL continues 
to produce LFG.

LFG can accumulate in enclosed spaces such as basements, vaults, and unvented light poles, 
resulting in possible explosion hazards. LFG can also collect in and move through preferred 
migration pathways such as utility trenches to reach enclosed areas. Finally, large amounts of 
LFG or the elevated temperatures associated with waste decomposition may affect turf or 
landscaping growth.

As discussed above, LFG generation may be increased if water is allowed to enter the waste 
through irrigation or surface water drainage.

3.5.2 Current LFG Control Measures

As discussed in Section 2.9, a LFG control system is currently operating on the site. Recovery 
wells associated with this system are generally located around the perimeter of the site (except 
for the north boundary along the Salt River), and they are intended to control the potential off-
site migration of LFG. Perimeter monitoring probes are generally located along the southern, 
western, and eastern boundary of the site, and are monitored to confirm that subsurface methane 
at the property boundary does not exceed 5% methane. LFG concentration and distribution in 
the central portions of the site, which may eventually contain improvements, are not currently 
monitored.

3.6 OTHER

3.6.1 Landscaping Over Waste Areas

Root structures may penetrate into waste depending on plant type and cover thickness. This may 
affect plant growth, as well as create a potential conduit for water infiltration through the cover.

4.0 MITIGATION ALTERNATIVES

The following discussion of mitigation alternatives and possible site-specific solutions was 
developed specifically for a conceptual master plan of a regional municipal park facility, which 
included specific site uses such as sports fields, equestrian facilities, warehouse-type operations 
buildings, etc. These examples are provided for information only, and should not be considered 
an exhaustive analysis of mitigation alternatives or solutions for all types of potential land uses at 
the site. Furthermore, the estimated costs are not site-specific and were developed in 2010; 
therefore, they should not be considered accurate for current conditions.
4.1 Settlement

4.1.1 Common Mitigation Options

4.1.1.1 No Action

This option would employ no measures to remove or pre-compress the underlying waste or improve the structural support for buildings or other features. Benefits include minimal up-front costs, but long-term costs could be significant for maintenance, repair, or replacement of features if they settle to an unacceptable degree.

4.1.1.2 Waste Removal

This option would consist of removing waste from beneath a planned structure. Depending on variables including (but not limited to) the nature and depth of waste and the type of planned structure and its associated load, the full vertical extent of waste could be removed, or only the upper portion of waste could be removed. Removed waste could be re-placed and covered elsewhere on the site, or it could be removed from the site for off-site disposal. The void left from waste removal could be replaced with engineered fill material or a subsurface structure such as an underground parking garage. This alternative may be used by itself, or in combination with one or more of the alternatives discussed below.

4.1.1.3 Surcharging

Surcharging is a proven method of improving soft ground conditions, including landfill waste. The surcharge process involves placing several feet or more of material such as soil, asphalt millings, or crushed concrete across a proposed road or building area and allowing the material to remain in place for a year or more. The weight of the material compresses the underlying soft soil or waste for a period of time and is then removed. The pre-compressed layer will have a reduced potential for settlement when the final load or structure is placed over it. This option does not eliminate future settlement. It may be used in conjunction with geogrid reinforcement (described in Section 4.1.1.6) to reduce the potential for residual differential settlement.

The height of the surcharge and lateral extent are functions of the proposed structure. Typical guidance is for a surcharge loading (pressure) to be equal to 1.5 to 2 times the planned pressure of the new structure and that the surcharge remains in place until the rate of settlement is reduced to an acceptable level. For this project, varying surcharge heights would be used since some areas will include only sports field turf, while other areas would include structures with a higher load. The lower most one to two feet of surcharge soil will likely settle into the ground and remain in place as part of the final subgrade.

An advantage of surcharging over the other methods is that monitoring of settlement rates is performed as part of the method. This is typically done by installing “settlement plates,” which consist of a plate to which a vertical pole is attached. The plate is placed beneath the stockpiled material, and the pole extends above the pile so that its elevation can be periodically surveyed. The results of this monitoring allow the engineer to track the progress of settlement and make quantitatively-based predictions as to when the surcharge may be removed and how much settlement remains.
Typically, the initial rate and magnitude of surcharge-induced settlement will be relatively large; over time, the rate and magnitude will be reduced and level off. Based on the settlement trend, which often follows a logarithmic relationship, a large portion of the surcharge-induced settlement typically occurs in the initial several months.

The disadvantage of surcharging is the time to complete the surcharge is not known until several sets of readings are available. The primary benefit of this approach is relatively low initial cost, depending on the availability of suitable surcharge material. If a significant amount of surcharge material can be cost-effectively obtained from sources such as nearby construction projects and such material is suitable for the environmental grade layer discussed in Section 3.4.2, it can first be used for the surcharge loading, and then it can be reused as additional cover soil after surcharging is complete.

Typical 2010 costs for purchase, transportation (within 20 miles), and placement of unprocessed soil were approximately $11 per cubic yard (material cost $1.50/cy, loading and unloading $2.00/cy, and transportation $7.50/cy). If surplus soils are available from nearby construction projects, this cost could be less.

**4.1.1.4 Deep Dynamic Compaction**

In cases where waste or soil ground stabilization is needed to depths of less than 25 to 30 feet, a method known deep dynamic compaction (DDC) may be employed. This is a proven method that has been used for several decades to stabilize soft or weak soil materials. The method involves repeatedly raising and dropping a heavy concrete mass on top of compressible or weak soils a sufficient number of times to compact and strengthen the soil. The number of drops, height of each drop, and weight of the rammer is a function of the depth and type of soil to be impacted. For pure refuse materials containing mostly organic matter, the maximum depth of influence is limited to less than 25 to 30 feet.

The DDC process typically occurs over the entire building pad area, along road and utility corridors, and to some nominal distance beyond. Craters are formed as the soil is compressed, which must be re-leveled with new fill. Because this method will compress material below and to the sides of the impact areas, it has the potential to disturb nearby sensitive underground structures or utilities. As such, it could disturb nearby LFG control equipment such as wells and piping.

The allowable safe distance between the DDC impact areas and underground structures will vary from site to site, depending on the material encountered and utility design, and should be discussed with the contractor. It may be prudent to conduct a field test that includes vibration monitors to detect ground motions at various distances. It should be noted that several of the LFG wells and associated piping are located within some of the areas that may be considered for DDC, and may therefore need to be moved and replaced.

DDC does not eliminate settlement, but will often reduce settlement following treatment to relatively small amounts. The time to complete the treatment process is considerably less than surcharging. This option may be used in conjunction with geogrid reinforcement to reduce the potential for residual differential settlement.
Costs to perform DDC are site-specific, but a rule of thumb is to allow for $50,000 to $100,000 for mobilization (depending on crane size) and $1 to $2 per square foot of treated area (2010 estimates).

4.1.1.5 Deep Foundation Support

For multi-story buildings or buildings that are more sensitive to differential settlement or unable to tolerate significant movement, deep foundation support may be provided by piles or piers that extend through the waste material and into underlying native soils. Such deep foundations would derive their ultimate bearing capacity through a combination of side friction and end bearing. If a deep foundation system is planned, additional investigation of the underlying native soils in combination with two or more field pile loading tests is typically recommended. Such pile loading tests would require that several piles be driven (or test piers installed) through the waste layer and embedded into underlying soils and subsequently loaded to at least twice the anticipated building design load. Information from both driving and loading of the test piles would then be used to design the foundation system. In addition, it is necessary to address transitions from structures supported by piles to surrounding areas that are subject to settlement.

While this option can virtually eliminate settlement of a building, it is relatively expensive; 2010 costs were estimated to range from $15 to $25 per square foot or more depending on a wide range of variables such as waste depth, underlying soil type, and loading. In some cases, it may be necessary to install sewers with a deep foundation support system (e.g., piles and grade beams). The additional cost for such support could be on the order of $150 per lineal foot depending on waste depth, loading, and other variables (2010 estimates).

4.1.1.6 Geogrid Reinforcement

Geogrids are manufactured thermo-plastic products that are placed within layers or lifts of compacted fill or over soft ground to add tensile reinforcement. They are typically made of polyethylene, polyester, and are deployed in rolls directly on the ground.

While geogrids are capable of improving soil bearing capacity and reducing the potential for abrupt differential settlement between adjacent areas, geogrids will not reduce total settlement for sites with significant thickness of underlying compressible materials. In other words, if there is a compressible soil layer below the geogrid, that layer will still compress over time. Therefore, it is unlikely that geogrids alone would provide sufficient ground improvement other than in localized areas such as under roadways or utilities.

Although this option does not eliminate overall settlement, it can minimize localized low spots or transitions at a moderate cost of approximately $0.75 per square foot for a single-layer system (2010 estimate).

4.1.2 Possible Site-Specific Solutions for Park Plan

4.1.2.1 Buildings

Solutions for addressing settlement issues associated with buildings are somewhat load-dependent, in that heavier structures are more likely to induce settlement in underlying
compressible waste. Placement of larger structures in the central portion of the site, where waste is apparently not present, would eliminate settlement issues associated with buried waste, but LFG issues will still apply as discussed in Section 4.3.

The previous park plan included two warehouse-type operations buildings, restrooms, and ramadas. The following options are specific to those types of structures:

**Ramadas**
Assuming these consist of a concrete slab supporting a roof structure on posts or pillars, they can probably be placed over landfilled areas on reinforced concrete slabs without additional foundation support. Ideally, they would be placed in areas that have been treated by surcharging or DDC. Design of such structures could include a method to adjust the pillars that support the roof, so that the structure can be leveled and plumbed if affected by differential settlement.

**Stand-Alone Restrooms**
Because of the higher loading of these structures and the presence of utilities, it would be preferable to locate these structures in areas that have been treated by surcharging or DDC, and geogrid reinforcement should extend beyond the perimeter of the building to reduce the effects of differential settlement between the building and surrounding area. Rather than a prefabricated block building that is placed on a concrete slab, lighter, less brittle materials should be used that will minimize loading and would not readily show cracks that may occur due to differential settlement. The slab should be reinforced to withstand cracking from potential differential settlement. Utility connections should be flexible, and if possible, designed to enter the building at the surface rather than through the slab to facilitate visual inspection and repairs, and to limit potential LFG migration into the building.

**Operations Buildings**
As discussed above, heavy brittle materials such as concrete block should be avoided in favor of lighter, less brittle materials if buildings are placed on or near landfilled areas. These structures should be placed on reinforced slabs in areas that have been treated by waste removal, surcharging, or DDC, and supplemented by geogrid reinforcement. Settlement could be limited by placing these structures on piers or pilings, which is a more costly option. Utility connections should be flexible, and if possible, designed to enter the building at the surface rather than through the slab to facilitate visual inspection and repairs, and to limit potential LFG migration into the building.

**4.1.2.2 Utilities**
Underground utilities or clusters of utilities should be designed based on the expected settlement and backfilled with non-cohesive materials to avoid stressing pipes as settlement occurs. Where underground utilities are located over waste or at transitions from waste to non-waste areas, they should be constructed of flexible materials such as high-density polyethylene (HDPE). It may be desirable to incorporate swing joints or similar features to account for potential “stretching” of pipes or conduits in response to differential settlement; this is especially important in utility connections to buildings, which may settle at different rates than the surrounding ground.

Underground utilities that rely on gravity feed (such as sewage systems) may require an exaggerated grade so that differential settlement will not result in low spots that impede flow.
Alternatively, it may be necessary to install sewers with a deep foundation support system (e.g., piles and grade beams). The additional cost for such support could be on the order of $150 per lineal foot depending on waste depth, loading, and other variables (2010 estimate).

Aboveground utilities such as large light standards used for sports fields should either be placed on piers that penetrate below the waste, with routine inspections and maintenance performed to assure that settlement does not result in creating accessible “caves” or similar enclosed spaces beneath the foundation slab. Alternatively, they should be placed in pre-compacted locations and designed so that they can be periodically adjusted to maintain their vertical orientation. Electrical connections should be flexible due to potential differential settlement.

Where utility trenches leave the site, barriers (e.g., bentonite dams) should be constructed across each trench to reduce the potential for LFG to migrate offsite along the utility trench.

4.1.2.3 Sports Fields

Sports fields or other turf areas requiring a flat surface should be improved prior to construction, or differential settlement will likely be unacceptable. At a minimum, these areas should be treated by surcharging. Depending on the amount of settlement surcharging induces, it may also be appropriate to use single-layer geogrid reinforcement beneath the playing field areas. Dynamic deep compaction may also be used in these areas, but the cost will be higher. For either option, at least two feet or more of cover soil will be required to manage infiltration and to prevent contact with waste in potential disturbance areas such as baseball diamond base paths.

Either option may not eliminate settlement, so it should be assumed that more frequent maintenance of playing fields will be required, including possible turf repair, replacement, or addition of soil to maintain a level surface. If possible, the surface should be constructed with a slightly exaggerated grade (at least 1%) so that positive drainage is maintained from the playing surface to surrounding areas, even if differential settlement occurs. Chain link fencing around may also require periodic maintenance and adjustment.

As discussed in Section 4.1.2.2, light poles and irrigation systems will require special consideration.

4.1.2.4 Equestrian Facility

It is assumed that the riding area portions of the equestrian facility can tolerate a moderate amount of settlement, since these areas will be bare soil that can be easily regraded to maintain a level surface. Therefore, it is feasible to construct this feature without pre-compaction of underlying waste, but due to the presence of surrounding features such as fences and grandstands, surcharging is recommended. At least two feet of cover soil will be required to manage infiltration and to prevent contact with waste in potential disturbance areas such as riding rings.

Fences should be constructed in modular fashion so that sections can be disassembled and adjusted if settlement causes them to become crooked.
Assuming the grandstand/shade structure will consist of a metal roof on metal posts or pillars, it can probably be placed over landfilled areas without deep foundation support depending on the load at each support structure. At a minimum, this structure should be placed in a location that has been treated by surcharging or DDC. Design of such structures could include a method to adjust the pillars that support the roof, so that the structure can be leveled and plumbed if affected by differential settlement.

**4.1.2.5 BMX Facilities**

Assuming the BMX track will be bare soil that can be easily regraded to maintain the planned topography, this area may not require improvement for settlement purposes. Once again, it is important to provide adequate soil cover (more than two feet) over any buried wastes to assure that bare soil is not eroded to the extent that waste is exposed. If the facility will include paved walkways, rigid grandstands, or other structures, these areas may need to be stabilized by surcharging or DDC. If the BMX Plaza will include paved or rigid features, this area also should be stabilized by surcharging or DDC.

**4.1.2.6 Roads and Parking Areas**

Paved and unpaved roads and parking areas should be treated by DDC or surcharging prior to construction. It should be assumed that more frequent maintenance of the roads and parking areas will be required, including possible pavement repair, replacement, regrading, or addition of decomposed granite to maintain an acceptable level surface. If feasible, it may be desirable to minimize the amount of rigid features and surface all roads and parking areas with material such as decomposed granite or asphalt millings rather than rigid pavement so that cracking of pavement is not an issue.

**4.1.2.7 Open Turf and Mesquite Bosque Areas**

It is assumed that settlement of these areas is acceptable, provided that irrigation systems are flexible to accommodate settlement. Periodic regrading and/or filling may be necessary to eliminate any low spots that could accumulate surface water.

**4.1.2.8 Facilities in Non-Landfill Areas**

For facilities in the non-landfill portions of the site, the issue of settlement associated with compression of waste should not apply, but normal geotechnical issues will still apply. If features are near the edge of waste or extend into waste areas, those transitions should be treated with alternatives such as surcharging or DDC, and possible geogrid reinforcement.

**4.2 LEACHATE/GROUNDWATER QUALITY**

**4.2.1 Common Mitigation Options**

The goal of these mitigation options is to minimize or eliminate infiltration of water into the waste mass of the landfill.
4.2.1.1 No Action

If thin areas of landfill cover allow surface water to enter the waste, settlement could increase, LFG generation could increase, and leachate could be increased. In addition to creating design, construction, and maintenance challenges, this could cause the landfill to lose its “closed” regulatory status (see Section 2.5).

4.2.1.2 Geomembrane Covers

Geomembrane cover systems tend to be expensive, but would reduce the amount of additional cover soil that would be required, except in areas where soil is needed to provide a barrier between waste and land uses that could damage a geomembrane. Care would be necessary to prevent damage to the liner during maintenance or other activities.

The additional unit cost of this alternative was estimated in 2010 to be approximately $2 per square foot. For the sports fields portion of the planned park facility, it was estimated that the cost of this alternative would be approximately $4.8 million for approximately 50 acres.

4.2.1.3 Soil Covers

Soil covers can be of two types: conventional soil covers employing a low-permeability barrier layer such as clay, and evapotranspiration (ET) covers that rely on soil thickness and evapotranspiration to prevent infiltration of surface water. ET covers tend to be less expensive than the conventional type, and are effective in the arid Southwest. As previously discussed in Section 3.4.2, existing cover soil and additional soil where necessary can be used as an effective ET cover system for this site. It is possible that the soils used for surcharging can be subsequently used for final cover, which could make this option more cost effective.

Cost for these covers varies depending on thickness, soil type, and other variables. For purposes of comparison with the geomembrane cost discussed above in Section 4.2.1.2, the cost for import and rough grading of an additional two feet of soil in the proposed sports field area was estimated in 2010 to be approximately $2 million.

4.2.1.4 Management of Irrigation and Surface Water

Measures that may be used to minimize infiltration of irrigation water include secondary containment or low-permeability layers beneath water lines to prevent leaks from impacting the fill beneath, and monitoring of infiltration in irrigated areas. Based on the conceptual park design, it was assumed that stormwater would not be retained in landfilled areas, so construction of lined retention basins or similar features would not be necessary. However, areas between soccer fields and other areas that may temporarily collect stormwater may be of concern; any such collection areas should be designed to minimize the potential for infiltration into waste materials (e.g., by lining them with a geomembrane material).
4.2.2 Possible Site-Specific Solutions for Park Plan

4.2.2.1 Irrigation Infiltration

As discussed in Section 3.4.2, infiltration modeling performed for the golf course design concluded that the following cover conditions would be adequate to prevent infiltration from turf irrigation:

Table 6. Recommended Thickness of Additional Cover

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>Existing Cover Thickness</th>
<th>Additional Cover</th>
<th>Environmental Grade Layer (EGL)</th>
<th>Vegetative Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>≥48”</td>
<td></td>
<td>Not needed</td>
<td>12</td>
</tr>
<tr>
<td>Sand</td>
<td>&lt;48”</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>&lt;24”</td>
<td></td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>Gravel</td>
<td>≥24”</td>
<td></td>
<td>15</td>
<td>12</td>
</tr>
</tbody>
</table>

Based on these recommendations, a worst-case assumption can be made that 15 inches of EGL and 12 inches of vegetative layer would be required in irrigated turf areas. For the park feasibility evaluation, it was assumed that the entire sports field area, the open turf area, and the scenic overlook area would be irrigated, which would require installation of a cover system consisting of 15 inches of EGL and 12 inches of vegetative layer, which would require a total of approximately 250,000 cubic yards of soil. Using the same cost as that of the surcharge soil, it was estimated in 2010 that this would cost approximately $2.8 million. This was considered a conservative estimate, because many areas already have adequate soil cover. With further analysis to delineate existing sand cover exceeding 48 inches in proposed irrigated areas, it should be possible to reduce the amount of EGL required.

It should be noted that the previous modeling of the proposed cover system for the golf course assumed that a membrane liner would be used under heavily-irrigated tees and greens to minimize infiltration and the potential adverse effect on turf from LFG. If such uses are anticipated, additional cover modifications may be appropriate. Similarly, it may be appropriate to install liners beneath major irrigation pipes and surface water drainage accumulation areas.

Depending on the nature and thickness of the final landfill cover system, soil moisture beneath irrigated areas should be monitored to verify that irrigation water is not penetrating the landfill cover. This can be performed manually using cores or observation wells, or using automated monitoring systems such as soil-moisture sensors commonly used in landscaping. The most common are tensiometers, solid-state tensiometers, electrical-resistance blocks and point-contact blocks. Simpler approaches (shallow observation wells that are monitored periodically) also could be considered. Irrigation pipelines should also be monitored for potential leakage.

4.2.2.2 Surface Drainage

Frequent inspections of drainage should be performed, and localized settlement areas must be addressed so that they are not allowed to retain surface water over waste areas. If possible, surface water should not be allowed to accumulate over waste areas due to increased loading.
(which could cause settlement) and the potential for infiltration into the waste. If surface water must accumulate over waste areas, it may be appropriate to install a geomembrane or low-permeability layer beneath such areas. Soil moisture beneath such areas should be monitored as described in Section 4.2.2.1 above.

4.3 LANDFILL GAS

4.3.1 Common Mitigation Options

Structures into which LFG could collect should be protected with LFG mitigation measures. Passive measures such as impermeable membrane barriers and gas venting systems with monitoring may be adequate given the relatively low concentrations of methane expected. Passive systems can be designed so that they can be easily converted to an active system by addition of a vacuum or blower system in the event that LFG accumulates beneath the structure.

Other measures which should be taken to mitigate the presence of LFG include the use of conduit seals for electric utilities and vented light poles. Underground utility trenches can be constructed with low-permeability “dams” to prevent lateral migration of LFG through trench bedding material.

4.3.2 Possible Site-Specific Solutions for Park Plan

4.3.2.1 Buildings

Accumulation of LFG in and beneath buildings can be mitigated by a venting layer beneath structures, with an appropriate membrane barrier between the vent system and the building. LFG can be vented passively or actively through vertical risers that are incorporated into the building. If passive venting is employed, ongoing monitoring should be performed to evaluate whether it is maintaining an appropriate level of protection. If not, the passive venting system can be made active by connecting a blower to the vents, providing active ventilation of the vent layer. In addition to controlling methane, such a system may also mitigate hydrogen sulfide and other toxic constituents that might be present in the gas (e.g., by allowing gas to vent above the roof level, similar to plumbing stack vents for sewer gases)

As a rough rule of thumb, 2010 costs for installing a methane mitigation system were estimated between $2 and $8 per square foot of building footprint, plus additional size-dependent costs if active ventilation is required.

For structures located in non-waste areas, the need for a barrier and venting system depends on the potential for lateral migration of LFG; this is largely a function of the distance to nearby waste. If feasible, monitoring of the proposed building location can be performed prior to design. LFG cutoff trenches can also be used if necessary to minimize lateral migration of LFG from waste areas into non-waste areas.

Open structures such as grandstands and ramadas should not have a significant potential to accumulate LFG. However, attention should be paid to confined spaces such as utility boxes associated with these structures to ensure they are either vented or protected from LFG, or both.
4.3.2.2 Utilities

Utility connections for buildings can be designed and constructed to reduce the potential for LFG to enter building structures. For example, electric conduits should be appropriately sealed. If aboveground utility connections can be used (where underground utilities emerge outside the building footprint and enter buildings above the floor), slab penetrations that could provide migration pathways for LFG to enter structures would be minimized.

Utility trench dams should be installed at intervals where utility trenches cross over waste areas, and especially where trenches pass from waste to non-waste areas, to reduce the potential for lateral migration of LFG along underground utility trenches.

Light poles or other utility poles located in waste areas should be vented. Settlement can occur around light pole foundations, potentially creating voids around the pole that could accumulate LFG and be accessible to persons at the surface. Periodic inspections and maintenance should be performed to fill and repair any such settlement voids.

4.3.2.3 Sports Fields, Turf, and Landscaped Areas

There is a low potential for accumulation of LFG beneath turf and other vegetated areas, but LFG can affect turf and plant growth if it is present in the root zone in excessive amounts. If necessary, this problem can be mitigated by installation of a sand venting layer beneath the vegetative layer.

5.0 RECOMMENDATIONS FOR PARK PLAN

As discussed in Section 4.0, the following recommendations were based on specific plans for the municipal park facility, and may not be relevant to other types of land uses on the site.

5.1 PRELIMINARY RECOMMENDATIONS FOR MITIGATION

5.1.1 Landfill Cover

An evapotranspiration-type cover system appears to be a technically feasible and cost-effective alternative to minimize infiltration of surface water into waste beneath irrigated areas. If soil can be obtained that meets the criteria necessary for the EGL (see Section 3.4.2), existing modeling indicates that no more than 15 inches of EGL and 12 inches of vegetative layer would be necessary. It is possible that the thickness of the EGL can be decreased by further analysis of existing data regarding cover thickness and soil types, and if appropriate soil from nearby construction sites can be used at a reduced cost.

5.1.2 Buildings

Based on preliminary settlement estimates, it appears that surcharging would be a technically feasible and cost-effective alternative for foundation improvement for park-related structures over waste. Settlement plate testing should be performed in at least three areas that are surcharged to simulate load conditions that would be imposed by proposed buildings.
Depending on the results of initial surcharge monitoring and the structures’ tolerance for potential settlement, surcharging may be adequate, or DDC may be necessary for larger structures such as the operations buildings. With either alternative, a minimum of two layers of geogrid reinforcement may be appropriate to reduce potential differential settlement at building margins.

Buildings located over waste should include a venting layer and membrane system beneath the structure. LFG can be vented passively above the roof through vertical risers that are incorporated into the building. Depending on the results of ongoing monitoring, it may be necessary to install blowers and connect them to the vents, providing active ventilation of the vent layer. Utility connections and slab penetrations should be sealed.

Buildings located in non-waste areas may not need an LFG mitigation system, but the proposed locations of such structures should be monitored for the presence of LFG prior to design and construction. Depending on the findings of such monitoring, an LFG cutoff trench may be an acceptable alternative to an under-building venting system.

All enclosed buildings should be routinely monitored for LFG accumulation.

### 5.1.3 Sports Fields and Open Turf

Settlement plate testing should be performed in at least three areas that are surcharged to simulate load conditions that would be imposed by irrigated turf. If initial surcharge monitoring indicates minimal settlement would occur in response to addition of irrigated turf, additional pre-compaction may not be necessary. However, a single-layer geogrid reinforcement system may be appropriate to minimize the effects of localized differential settlement. Adequate soil cover should be maintained beneath areas of potential disturbance, such as baseball diamond base paths. It may be possible to use the same soil for surcharging as for the ET cover system, but surcharging will require a thicker layer of soil. Therefore, it would be best to perform surcharging in phases so that excess soil does not remain on the site at the end of the process. If the same soil can be used for surcharging and the cover, the cost for surcharging would include only moving of soil and monitoring.

Light poles or other utility poles located in waste areas should be vented, and if settlement can occur around them, routine inspections and maintenance should be performed to assure that settlement does not result in creating accessible “caves” or similar enclosed spaces beneath the foundation slab that can accumulate LFG.

### 5.1.4 Equestrian/BMX Facilities

Adequate cover thickness should be maintained in unsurfaced high-activity areas such as riding rings and the BMX track.

### 5.1.5 Roads and Parking Areas

Roads and parking areas should be treated by surcharging or DDC depending on the results of settlement plate testing. Flexible paving and hardscape should be used to the maximum extent possible.
5.2 RECOMMENDATIONS FOR ADDITIONAL INVESTIGATION

As with previous sections of this report, this section includes recommendations that are specific to the previously-planned park facility. Different recommendations may apply depending on variables such as the location and type of buildings, the type and extent of landscaping, etc.

The services of a qualified environmental consultant and licensed professional engineer should be retained to guide additional investigation and design of mitigation measures specific to any specific land use planned for the DRL site.

5.2.1 Waste Presence and Extent

Prior to finalizing the conceptual plan, the absence of waste should be confirmed at all proposed buildings and other hardscape features, including the central portion of the site that is reportedly not landfilled. The specific location of the edge of waste near hardscape features and where roads pass from landfilled to non-landfilled areas should be confirmed.

The depth of waste beneath planned buildings such as the restrooms and operations buildings should be confirmed to refine settlement estimates. This could have an influence on the type of foundation improvement necessary for these structures.

It may also be appropriate to verify the reported presence and location of a “seam” of non-landfilled area running north-south through the eastern portion of the site. This feature could increase the potential for future differential settlement.

5.2.2 Landfill Gas

Additional investigation of LFG generation and distribution at the site should be performed to evaluate the need for LFG mitigation for structures and other potential improvements, and to provide a basis for design of mitigation alternatives. The current and past operating parameters and monitoring results of the LFG control system should be reviewed to further evaluate the amount of gas recovered and the potential for future landfill gas generation and migration relative to proposed site development.

The potential for LFG to accumulate beneath buildings and other features should be evaluated by monitoring of LFG concentrations and pressures at specific building or improvement locations. This can be accomplished by placing LFG monitoring probes within or near waste areas at proposed locations of sports fields, playgrounds, buildings, or other areas that may experience more intensive use. These probes should be sampled for LFG (methane, carbon dioxide, oxygen, and balance gases) as well as hydrogen sulfide and trace volatile organic compounds. In addition, these probes should be monitored for pressure to evaluate the migration potential of these gases. If possible, monitoring and sampling should be performed at periods of maximum potential LFG generation, barometric pressure changes, and periods when the LFG control system is not operating.

One or more LFG monitoring probes should be installed at or near the location of the proposed recreation center to evaluate the potential for migration of LFG to this area from nearby waste.
5.2.3 Surcharge Settlement Testing

Settlement plate tests should be performed in areas where buildings, irrigated turf, and other areas that could be adversely affected by settlement. This will require placement of soil at the site in thicknesses up to five feet or more, and monitoring should be performed for as long as possible, but no less than six months.

5.2.4 Soil Cover Design

The existing infiltration modeling should be revised using site-specific irrigation amounts and specific soil properties of potential borrow sources to develop a site and use-specific thickness for the EGL. The existing soil cover thicknesses mapped by previous investigations should be specifically evaluated to identify areas where existing cover is adequate, and where additional EGL is necessary. The results of these analyses can then be used to refine cost estimates for the landfill cover system.

6.0 REFERENCES

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City of Phoenix
Del Rio Landfill
Phoenix, Arizona

Figure 1
Site Location
Source: SCS Engineers, February 2010
City of Phoenix
Del Rio Landfill
Phoenix, Arizona

Figure 3
Landfill Cover Conditions
Figure 4
Extent and Thickness of Waste

Source: SCS Engineers, February 2010
Source: City of Phoenix, June 1995
Figure 6
Landfill Gas Control and Monitoring System

Source: City of Phoenix, September 2005

- LFG probe location, 0% methane since 2012
- Date of reading with methane detection
- Initial reading > 5% methane, subsequent reading 0
- Initial reading < 5%, subsequent reading 0