Final Report

Engineering Evaluation of 21-Inch Vitrified Clay Tijeras Sewer Interceptor at Kirtland Air Force Base

Submitted to

Kirtland Air Force Base,
Albuquerque, New Mexico

March 5, 2004

CH2MHILL

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Acronyms

AACE International	Association for the Advancement of Cost Engineering International
AFB	Air Force Base (Kirtland)
ASTM	American Society for Testing and Materials
CCTV	closed-circuit television inspection
cfs	cubic feet per second
CIPP	cured-in-place-pipe method
City	City of Albuquerque
CY	cubic yards
ET	evapotranspiration
ft^2	square feet
ft^3	cubic feet
HDPE	high-density polyethylene
lb/ft^3	pounds per cubic feet
lb/LF	pounds per linear foot
LF-002	Landfill-002
MH	manhole
msl	mean sea level
NCPI	National Clay Pipe Institute
NSWMA	National Solid Waste Management Association
pcf	pounds per cubic foot
PVC	polyvinyl chloride
SPT	standard penetration test
TIJ	Tijeras Sewer Interceptor
USAF	U.S. Air Force
VCP	vitrified clay pipeline

Introduction

Purpose

Kirtland Air Force Base (AFB) in Albuquerque, New Mexico, is responsible for Landfill-002 (LF-002) and the surrounding area. One of Kirtland AFB's long-term goals is to cover LF-002 using evapotranspiration (ET) technology. The ET cover will prevent rainfall from percolating through the landfill material and into the groundwater aquifer located 400 feet below the landfill.

In pursuit of this goal, Kirtland AFB needs to establish the structural integrity of the Tijeras Interceptor, an existing sewer line that runs through LF-002, but is owned and operated by the City of Albuquerque (City). Both the City and Kirtland AFB are interested in avoiding leakages and possible pipe failures that may result in leachate generation within the landfill and potentially impact groundwater.

Kirtland AFB retained the services of CH2M HILL to perform an engineering analysis of the existing 21-inch vitrified clay pipeline (VCP) that runs through LF-002. In this report, CH2M HILL evaluates the risk to groundwater and develops and evaluates several alternatives for the pipeline: leaving the existing pipe in place, rehabilitating it, or relocating it.

Background

Kirtland AFB is located in the southeast quadrant of Albuquerque, New Mexico. The base covers 51,558 acres to the east of Albuquerque International Sunport. Figure 1 depicts the location of Kirtland AFB and of LF-002 within the base.

LF-002

LF-002 is located between the Trestle Aircraft Testing Facility and the Advanced Research Electromagnetic Simulator facility (which lie to the north) and the active channel of the Tijeras Arroyo (which lies to the south) as shown in Figure 2. LF-002 operated from 1942 to 1965. During that time, the 37-acre landfill was reportedly used as trench and fill. LF-002 is no longer in operation.

Current estimates conclude that LF-002 contains approximately 1,321,700 cubic yards (CY) of waste. According to a Foster Wheeler report (2002), no written records of the quantities or nature of the materials disposed in LF-002 have been recovered. To create a best guess as to the contents of LF-002, Foster Wheeler conducted informal, undocumented interviews. The implication of the Foster Wheeler investigation is that LF-002 contained general refuse, construction and demolition debris, and potentially hazardous materials, such as 55-gallon drums containing liquid solvents and plastic wastes. The depths at which these materials are buried range from 9 to 20 feet over approximately 37 acres.

The U.S. Army Corps of Engineers contracted Foster Wheeler to design and build an ET cover for LF-002. The existing LF-002 area will be regraded prior to placing the ET cover. The ET cover will consist of local soil and natural vegetation, and be 3 feet thick. When it rains or snows, the ET cover will act like a sponge, holding in most of the moisture. The moisture will then evaporate from the soil surface layer or transpire through the roots and leaves of the plants.

Tijeras Arroyo 100-Year Floodplain

Tijeras Arroyo lies at the southern edge of LF-002 and is dry most of the year. According to a 1979 U.S. Army Corps of Engineers study (which is prior to the arroyo improvements made in 1987, 1988, and 1999), the 100-year floodplain covered 80 percent of the LF-002 area. In the event of a flood of this magnitude, portions of the site would potentially have been covered with 2 to 3 feet of water. Such an inundation would have resulted in infiltration and potential leachate production in addition to creating a potential for erosion of large sections of the landfill with possible transport of material.

In 1987 and 1988, channel improvements were made to the bank of Tijeras Arroyo along approximately 3,850 feet adjacent to LF-002 to control the erosive effects of flooding. The entire north bank and the majority of the south bank of the arroyo were regraded to a slope of 2H:1V (2 feet of horizontal distance for every drop of 1 foot). The north bank and portions of the south bank were armored with a 1-foot-thick gabion mattress covering approximately 270,000 square feet (ft^2). In addition to channel upgrades, a 1,550-foot training dike was constructed in 1999 between the Tijeras Arroyo and LF-002. The dike was an earthen berm constructed with soil compacted in 6-inch lifts with the top 6 inches completed with base course material. The purpose of the dike was to direct north overbank flow upstream of LF-002 into the main channel, thereby reducing the likelihood of the discharge inundating portions of LF-002.

Groundwater Monitoring Results

A large groundwater aquifer that serves the community of Albuquerque is in the vicinity of the project site. According to the monitoring well test data, the depth to groundwater at LF-002 ranged from approximately 383.76 feet to 413.5 feet. A groundwater elevation map is provided in Figure 3. The elevation of the water surface as measured in March 2002 ranged from 4,864.49 feet to 4,866.85 feet above mean sea level (msl). The invert elevation of manhole (MH) #15 of the existing 21-inch VCP near monitoring well 3 is 5269.66 feet above msl.

The groundwater elevation map in Figure 3 also shows that the depth to groundwater is approximately 400 feet below the ground surface in the vicinity of LF-002. The largest decrease in the water level each year was generally observed between March and December, with smaller declines or slight rebounds from December to March.

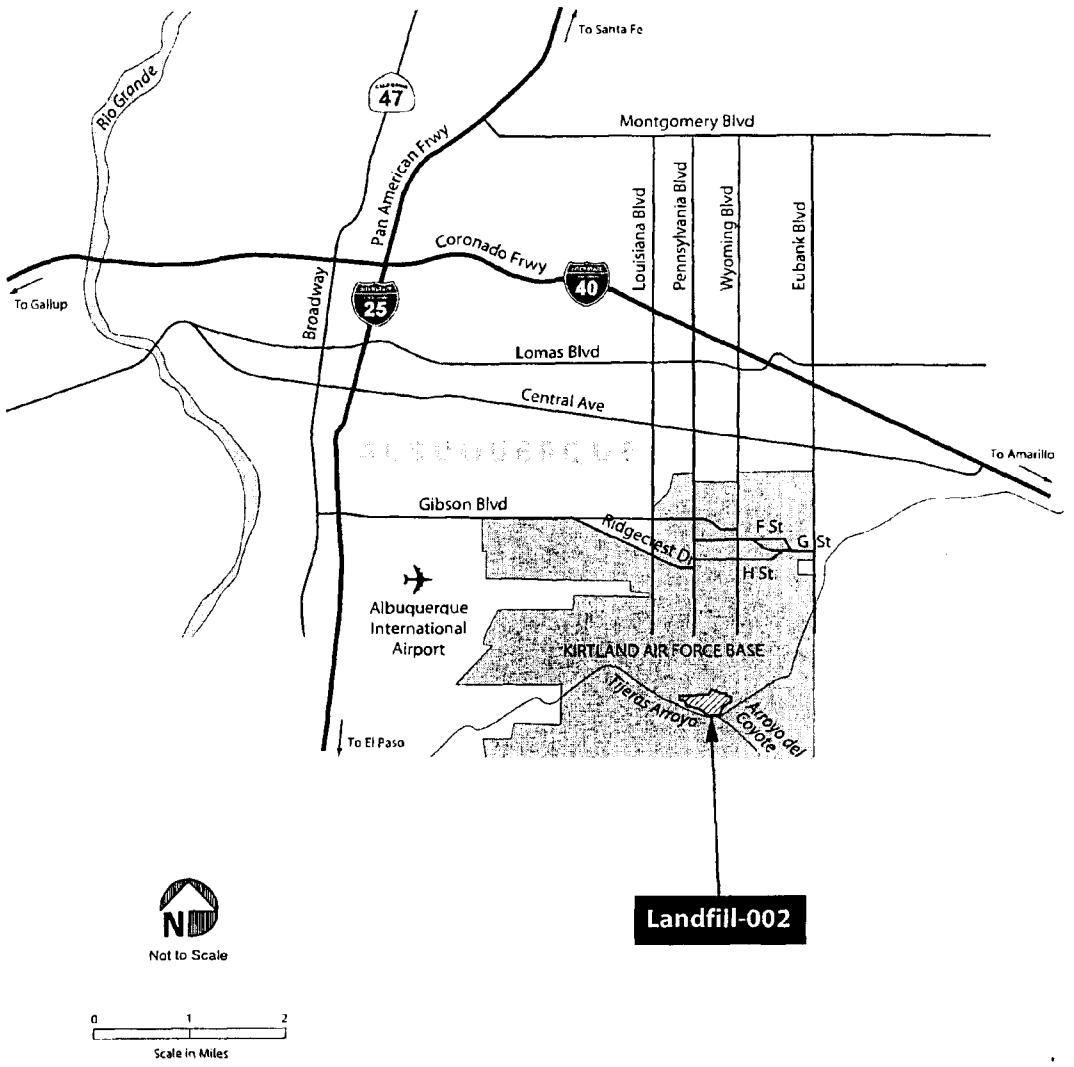

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Figure 1
Vicinity Map
Kirtland AFB, New Mexico

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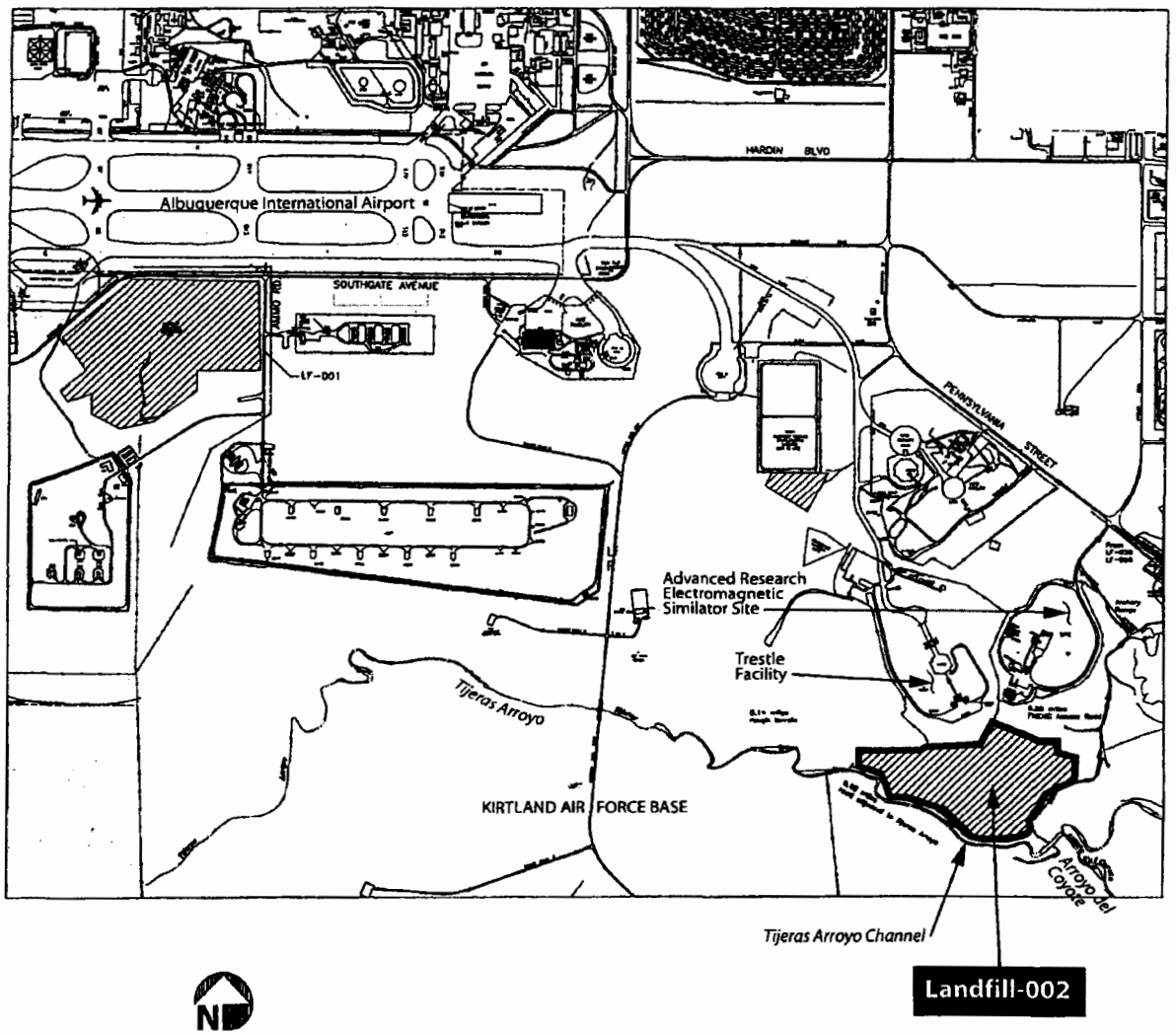

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Figure 2
Location Map
Landfill - 002
Kirtland AFB, New Mexico

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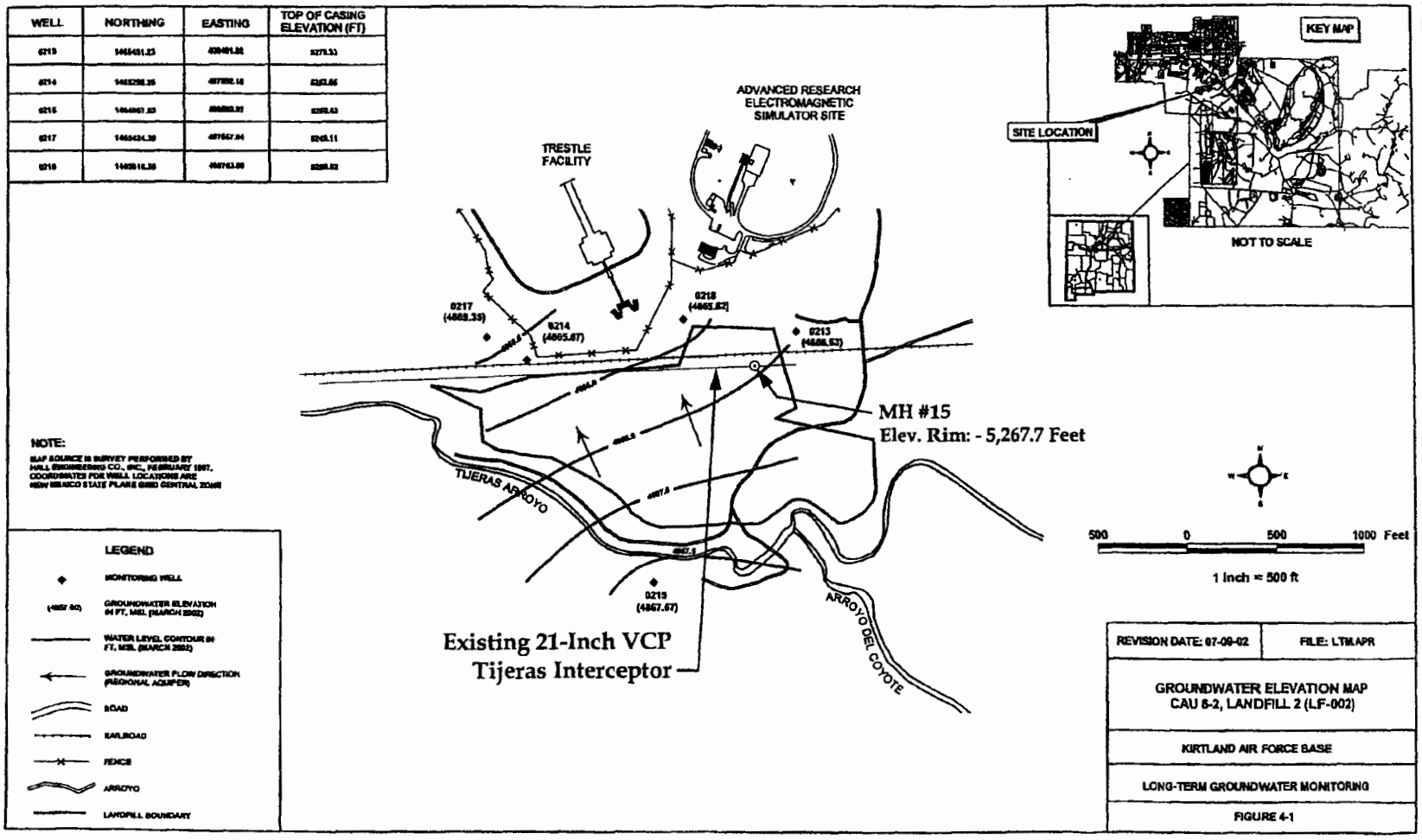
WELL	NORTHING	EASTING	TOP OF CASING ELEVATION (FT)
0213	1465451.23	489491.82	5273.33
0214	1465258.35	487892.18	5267.66
0215	1464867.33	488883.97	5268.43
0217	1465424.39	487667.84	5268.11
0218	1465816.36	488763.89	5268.52



NOTE:

MAP SOURCE IS SURVEY PERFORMED BY HALL ENGINEERING CO., INC., ALBUQUERQUE, 1997. COORDINATES FOR WELL LOCATIONS ARE NEW MEXICO STATE PLANE GRID CENTRAL ZONE

LEGEND

- MONITORING WELL
- (4857.60) GROUNDWATER ELEVATION IN FT, MSL (MARCH 2002)
- WATER LEVEL CONTOUR IN FT, MSL (MARCH 2002)
- GROUNDWATER FLOW DIRECTION (REGIONAL AQUIFER)
- ROAD
- RAILROAD
- FENCE
- ARROYO
- LANDFILL BOUNDARY

REVISION DATE: 07-09-02	FILE: LTMAPR
GROUNDWATER ELEVATION MAP CAU 6-2, LANDFILL 2 (LF-002)	
KIRTLAND AIR FORCE BASE	
LONG-TERM GROUNDWATER MONITORING	
FIGURE 4-1	

Figure 3
Groundwater Elevation Map
In The Vicinity Of LF-002
Kirtland AFB, New Mexico

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21-Inch VCP Tijeras Sewer Interceptor (TIJ)

According to as-built information, the 21-inch VCP was installed in 1977 approximately 10 feet below the existing grade of the landfill at the time. Kirtland AFB had landfill material removed from the trench section and imported a bedding material as shown in Figure 4. The total length of the 21-inch VCP running under LF-002 is approximately 2,535 feet. The length of each pipe segment between the six manholes within LF-002 is approximately 333 feet (Figure 5).

During the design process, Kirtland AFB decided to seek a third-party evaluation of the Tijeras Sewer Interceptor (TIJ). The contractor inspected the 21-inch VCP using closed-circuit television (CCTV) and presented a report and tape of the inspection. The pipeline is in good condition and does not have any noticeable defects. The CCTV inspection report is provided in Appendix A of this report. Figures A-1 through A-5 in Appendix A illustrate the condition of the existing 21-inch VCP. Based on the apparent good condition of the VCP, the parties involved made the decision that the alternatives to be evaluated should include leaving this existing pipe in place beneath LF-002 after placement of the ET cover.

Roles of Kirtland AFB and City of Albuquerque

Kirtland AFB owns the property where the landfill is located and is responsible for operations of the landfill; whereas, the 21-inch VCP is owned and operated by the City of Albuquerque. The City constructed the sewer line and operates within a 10-foot easement through the Kirtland AFB property.

Currently, Kirtland AFB is in the process of approving the final design of the ET cover, which was submitted by Foster Wheeler (final design submittal, 2002). According to the design documents, Foster Wheeler recommends raising the height of two manholes so that all existing manholes are above the proposed grade before the ET cover is placed, as shown in Figure 6.

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MANHOLE RIM/COVER ELEVATIONS

Manhole Rim/Cover Elevation Code	Manhole Cover To Be ___ Ft. Above Natural Ground Surface
A	0
B	0.5
C	1.5
D	4

MANHOLE TYPES

Unless otherwise shown on the plans, all manholes shall be Type "S" as shown in the Owner's Standard Details and shall be precast concrete or cast in place concrete with steel reinforcing as for precast manholes (see detail). See this sheet for arrangement for manholes with ring above grade.

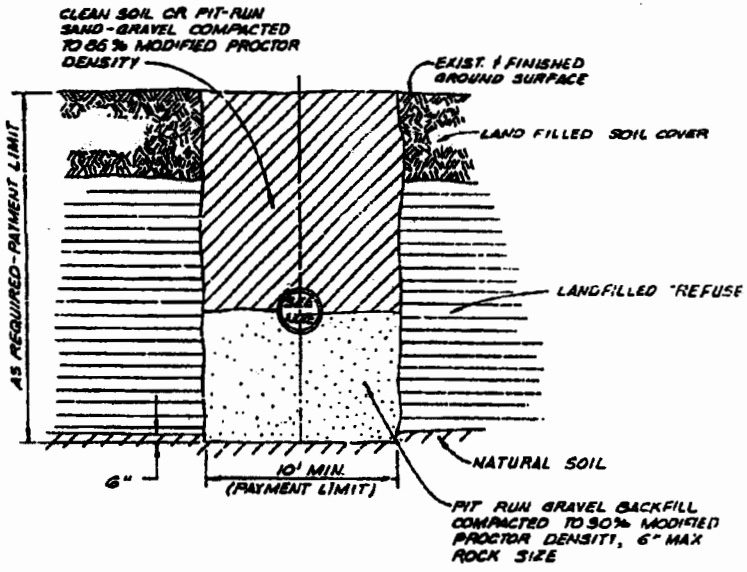
MANHOLE RING AND COVER

All manhole rings and covers shall be aluminum as shown in the Owner's Standard Details.

PIPE BEDDING CONDITIONS

Pipe Dia.	Max. Trench Width	Minimum Allowable ASTM C-12 Bedding Class					
		Class "D" for Trench Depths UP TO	Class "C" for Trench Depths OVER	UP TO	Class "B" for Trench Depths OVER	UP TO	Class "A" for Trench Depths OVER
8"	2'-6"	10'	10'	14'	14'	18'	18'
15"	3'-0"	10'	10'	22'	22'	-	-
18"	4'-6"	8'	8'	12'	12'	14'	14'
21"	4'-6"	8'	8'	12'	12'	16'	16'

NOTE: Trench depth is to pipe invert. If trench width at the top of the pipe exceeds that shown above, the Contractor may be required to furnish a higher class of bedding at no additional expense to the Owner.



DESCRIPTION:
REMOVE AND DISPOSE OF ALL SOIL COVER AND LANDFILLED REFUSE TO THE NATURAL SOIL LEVEL. PLACE AND MANNER OF DISPOSAL MUST BE APPROVED BY THE OWNER. THE CONTRACTOR SHALL FURNISH ALL BACKFILL MATERIAL AS SHOWN

NOTE:
PIPE TO HAVE CLASS A BEDDING (NOT SHOWN IN DETAIL) IN ACCORDANCE WITH ASTM C-12

SANITARY LANDFILL CROSSING DETAIL

NO SCALE

SEWER PIPE MATERIALS

Unless otherwise shown on the plans, all sewer pipe for this project shall be extra strength vitrified clay pipe. "DIP" indicates ductile iron pipe.

Figure 4
As Built Drawings for
Existing 21-Inch VCP Tijeras Interceptor
Kirtland AFB, New Mexico

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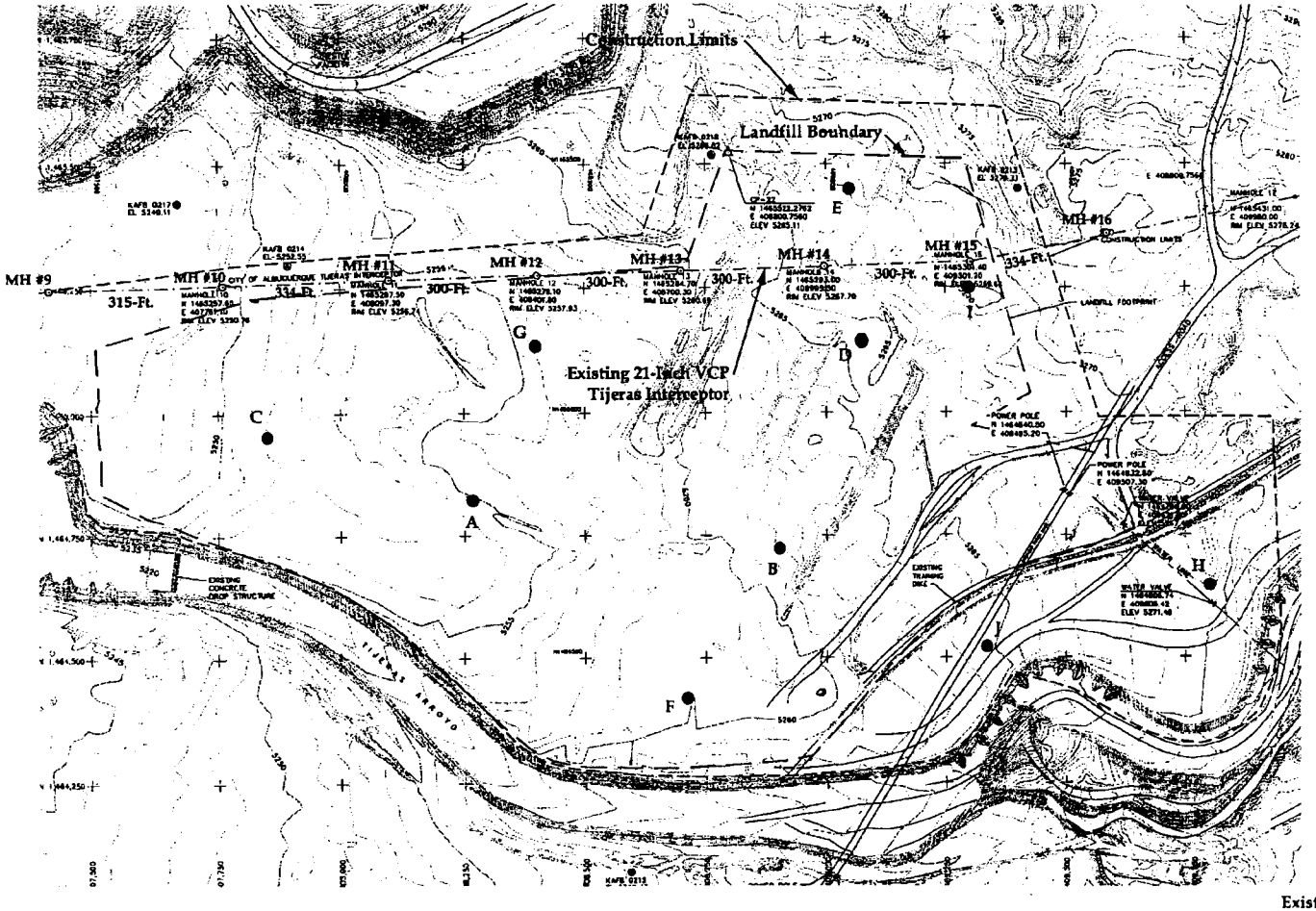

Figure 5
Existing Sewer Line and Borings
KAFB Site Map of Landfill-002
Kirtland AFB, New Mexico

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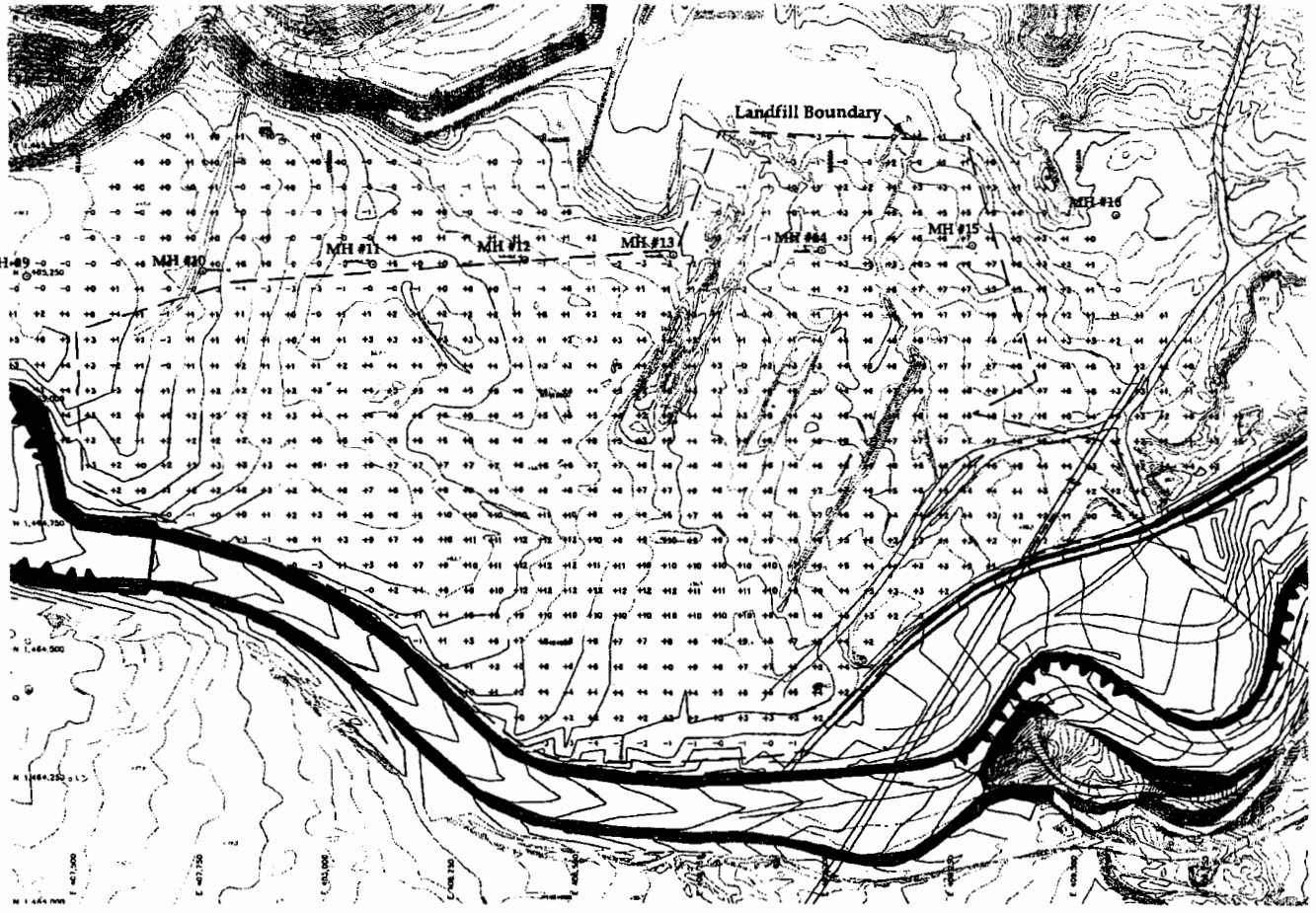

Figure 6
Cut and Fill Plan of Landfill-002
Kirtland AFB, New Mexico

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Project Process

CH2M HILL was retained to perform a third-party engineering analysis and evaluate the structural integrity of the 21-inch VCP beneath LF-002 and to evaluate options for rehabilitation, renovation, or relocation of the existing VCP. CH2M HILL identified project issues, developed evaluation criteria, and identified alternatives for the potential rehabilitation or replacement of the VCP beneath LF-002. CH2M HILL used this information to develop alternatives and recommendations for the existing sewer line. To accomplish this, CH2M HILL developed the criteria used to evaluate the alternatives, weighed the criteria to determine their relative level of importance to the stakeholders, performed an initial screening analysis to reduce the number of alternatives that needed detailed engineering analysis, and provided an objective means of evaluating the final alternatives.

Project Issues

CH2M HILL identified project issues based on information from stakeholders at the kickoff meeting as well as through phone conversations, site visits, and review of available maps, drawings, reports, and other data. A list of the issues related to LF-002 and the 21-inch VCP are documented below:

1. Structural integrity of the 21-inch VCP beneath LF-002 is of concern. According to the City of Albuquerque staff and Kirtland AFB staff, two pipe failures have occurred on the Kirtland AFB property over the past 10 years as listed below:
    - On September 14, 1994, a pipe failure occurred on a 30-inch-diameter concrete sewer pipeline about 1 mile west of the existing sewer under LF-002. The pipeline ruptured and spilled an estimated 110 million gallons of raw sewage about 1,500 feet west of the sewage lagoons.
    - In 2002, another failure occurred in the same concrete pipeline that failed in 1994 downstream of a manhole near the end of the area that had been rehabilitated.
2. A leaking line or failure of the existing 21-inch VCP in the future may compromise the integrity of the landfill cover or generate leachate that may impact groundwater.
3. Refuse contents are not known. LF-002 may contain construction demolition debris, general refuse, and potentially hazardous materials such as 55-gallon drums containing liquid solvents and plastic wastes. Also the depths of the refuse may vary between 9 and 20 feet. This landfill was in operation between 1940 and 1965, and it has not been used since. Kirtland AFB plans to construct a 47-acre ET cover over the 37-acre LF-002 site. Work is expected to begin in spring 2004.
4. The long-term goal of Kirtland AFB is to close the landfill with an appropriate cover and fence the landfill boundary. Kirtland AFB is responsible for the maintenance and operation of the landfill cover over the next 30 years. The City is responsible for the

maintenance and operation of the 21-inch VCP. If the existing pipe is to remain in place, the City requests a gate be installed to allow future access to the pipe for maintenance and inspection.

5. Kirtland AFB has raised concerns that the City may damage the landfill cover while accessing the 21-inch VCP in the future if repairs or replacement are required. If repairs or replacement of the sewer line beneath the landfill are required in the future, the landfill cover will have to be removed and replaced to a condition that maintains the integrity of the cap in the vicinity of the existing pipeline.
6. Leakages and possible pipe failures may result in leachate generation from waste and potentially impact groundwater, which according to monitoring well data are approximately 400 feet below the surface grade.
7. The ET cover will cover the entire landfill footprint including the area above the existing sewer pipeline area. Six manholes lie within the landfill area and two of them may have to be raised to elevate them above the proposed new grade.
8. Currently, the City doesn't have a regular maintenance program on the 21-inch sewer pipe. Although the City has not had any problems with this pipe since it has been installed, they anticipate that they may have to access the site once every 5 to 10 years (or when blockages occur). The City will most likely use a truck-mounted sewer vacuum cleaning unit (approximately 20 tons) for maintenance or blockages.
9. If the pipeline remains in place, maintenance costs for the pipeline and the ET cover will be the responsibility of both Kirtland AFB and the City. Kirtland AFB will be responsible for maintenance of the landfill and any monitoring of the existing line. The City will be responsible for maintaining the operations of the 21-inch VCP.
10. The City prefers any construction after the landfill cover is placed be minimized in order to minimize impacts to the pipeline.

Project Criteria

A list of decision criteria was developed to address concerns and issues related to the project. Each of the criteria was measurable so that an evaluation could be made regarding the differences between alternatives. The criteria were reviewed with and validated by the stakeholders on November 18, 2003, via a conference call. The following criteria were used for the evaluation:

1. Life-cycle cost
2. Future access to 21-inch VCP for regular maintenance and structural repairs
3. Loading on the pipeline
4. Impact to operations at Kirtland AFB
5. Existing capacity needs
6. Future capacity needs
7. Construction costs
8. Maintenance costs of pipeline
9. Maintenance costs of landfill cover

10. Risk of contamination of groundwater
11. Potential damage to the sewer pipe from differential settlement
12. Loss of use of adjacent property

Table 1 presents the most important (highest weighted) criteria as chosen by Kirtland AFB staff and the City of Albuquerque staff from the above 12 criteria.

TABLE 1
Criteria Chosen by Kirtland AFB and City of Albuquerque Personnel

Kirtland AFB	City of Albuquerque
Construction costs	Potential damage to the sewer pipe from differential settlement
Maintenance costs of landfill cover	
Future access to interceptor for regular maintenance and structural repairs	Future access to interceptor for regular maintenance and structural repairs
Risk of contamination of groundwater	Risk of contamination of groundwater

The final list of criteria chosen for evaluating the proposed alternatives are given in Table 2.

TABLE 2
Final List of Criteria Chosen for Evaluating Proposed Alternatives

No.	Decision Criteria	Decision Criteria Description
1	Risk of contamination of groundwater	According to monitoring well data, the depth to groundwater is approximately 400 feet below the ground surface. This criterion evaluated the possibility of leachate contaminating the groundwater resulting from failure or leaking of the existing pipe. This is measured in terms of low, medium, and high risk level.
2	Potential damage to the sewer pipe from differential settlement	Kirtland AFB plans to regrade the site and install an ET cover on LF-002. This additional overburden may cause stress on the pipeline at joints resulting in the potential settlement along the pipeline alignment. An estimate of likely settlement was calculated based on soil information in the vicinity of the existing 21-inch VCP.
3	Future access to interceptor for regular maintenance and structural repairs	The access to the existing 21-inch VCP will be limited after the landfill area is fenced. The City anticipates that they may have to access the site no more than once every 5 or 10 years in the future unless a blockage occurs. This ease of accessibility is measured in terms of low, medium, and high.
4	Impacts to property adjacent to LF-002	Relocation of the pipe will result in reduced usage of adjacent land. In the future, no buildings or structures could be constructed over the pipe. If manholes are abovegrade, then traffic patterns through the site may be altered. These impacts are measured as low, medium, and high.

TABLE 2
Final List of Criteria Chosen for Evaluating Proposed Alternatives

No.	Decision Criteria	Decision Criteria Description
5	Impacts to operations at Kirtland AFB	Reconstruction or rehabilitation of the pipeline will require additional construction vehicles accessing the site. The activities expected for the maintenance of the existing pipeline or relocation of the pipeline include constructing access roads, excavating material, pipe bedding, constructing or elevating manholes. Potential impacts of these activities to Kirtland AFB property around the landfill area will be measured as none, low, medium, or high.
6	Loading on the pipeline (safety factor)	The LF-002 area will be regraded before the 3-foot ET cover is placed. This may result in overburden pressure at certain points along the existing 21-inch VCP. The pipe is checked for its load-bearing capacity and the result is expressed in terms of safety factor. A safety factor of greater than or equal to 1.0 is recommended. A safety factor less than 1.0 is unacceptable.
7	Existing capacity requirements	Currently, the 21-inch VCP carries a flow of 3 cubic feet per second (cfs). The pipe has a total flow-carrying capacity of 36 cfs. The flow-carrying capacity for each alternative was calculated (for estimated roughness factors) to determine if existing capacity requirements are met. This value is expressed in cfs.
8	Future capacity requirements	If development is anticipated in the future, then an increase in flow in the next 25 years may require either an increased pipe diameter or alternatives that do not reduce capacity. This value is expressed in cfs.
9	Construction costs	The construction costs are calculated by identifying construction activities that would be required to construct the alternatives. Unit costs were developed based on engineering judgment for the quantity of material, location of the project, and the cost of labor and materials. These costs are expressed in terms of dollars.
10	Life-cycle costs (annual costs) for the maintenance of pipeline	The life-cycle costs were calculated for maintenance of the pipeline, cleaning, CCTV inspections, and potential repairs. These costs are expressed in terms of dollars.
11	Life-cycle costs (annual costs) for the maintenance of landfill	The life-cycle costs (annual costs) were calculated for the maintenance of the landfill and to restore the ET cover each time the area was disturbed to complete maintenance activities on the pipeline. These costs are expressed in terms of dollars.
12	Life-cycle costs (total annual costs)	The total life-cycle costs (annual costs) were calculated for each alternative to compare their construction and maintenance costs over their estimated design life. These costs are expressed in terms of dollars.

Alternatives

Initially 23 alternatives were developed for evaluation concerning the rehabilitation or replacement of the 21-inch VCP. Table 3 provides the initial list of 23 alternatives.

TABLE 3
Initial List of 23 Alternatives Developed for the 21-Inch VCP Evaluation

No.	Initial List of Alternatives Developed for the 21-Inch VCP
1.	Existing Pipeline Remains in Place
a)	Regular CCTV inspection every 3 years
b)	Regular flow monitoring every year
c)	Do both
d)	Install concrete cap on existing pipe
2.	Sewer Pipeline Rehabilitation
a)	At the time landfill cap is placed 1. Cured in place pipe 2. Sliplining 3. Fold and Form
b)	Defer rehabilitation until recommended by inspections/monitoring 1. Cured in place pipe 2. Sliplining 3. Fold and Form
3.	Reconstruct Sewer Pipe in the Same Location
a)	At the time landfill cap is placed 1. Open cut 2. Pipe bursting 3. Microtunneling
b)	Defer rehabilitation until recommended by inspections/monitoring 1. Open cut 2. Pipe bursting 3. Microtunneling
4.	Reconstruct Sewer Pipe in a New Location
a)	At the time landfill cap is placed 1. Open cut 2. Microtunneling 3. Directional Drilling
b)	Defer reconstruction until recommended by inspections/monitoring 1. Open cut 2. Microtunneling 3. Directional Drilling
c)	Revise sewer pipe size for future needs

After reviewing the initial list with the City of Albuquerque and Kirtland AFB, the list of 23 alternatives was screened down to four feasible alternatives for analysis.

Proposed Alternatives

After the preliminary screening evaluation, the following four alternatives were proposed for further evaluation:

- **Alternative 1.** Existing 21-inch VCP remains in place with regular CCTV inspection every 3 years. Defer rehabilitation or replacement until needed.
- **Alternative 2.** After the ET cover is placed, rehabilitate the 21-inch VCP using the cured-in-place-pipe (CIPP) method. The CIPP is a trenchless technology method used that inserts a thermosetting resin-saturated material into the existing pipeline to restore its full service conditions from manhole to manhole.
- **Alternative 3.** After the landfill cap is placed, rehabilitate the 21-inch VCP using the fold-and-form method. The fold-and-form method is a trenchless technology method that makes use of a thermoplastic (high-density polyethylene [HDPE] or polyvinyl chloride [PVC]) pipe that is folded and deformed to reduce the cross-sectional area. The folded pipe is rolled onto a spool for transport to the job site. It is then pulled into place and expanded and rounded to conform to the internal shape and size of the existing pipe by heat and pressure.
- **Alternative 4.** Reconstruct the 21-inch VCP in a new location while the ET cover is placed (see Figure 7).

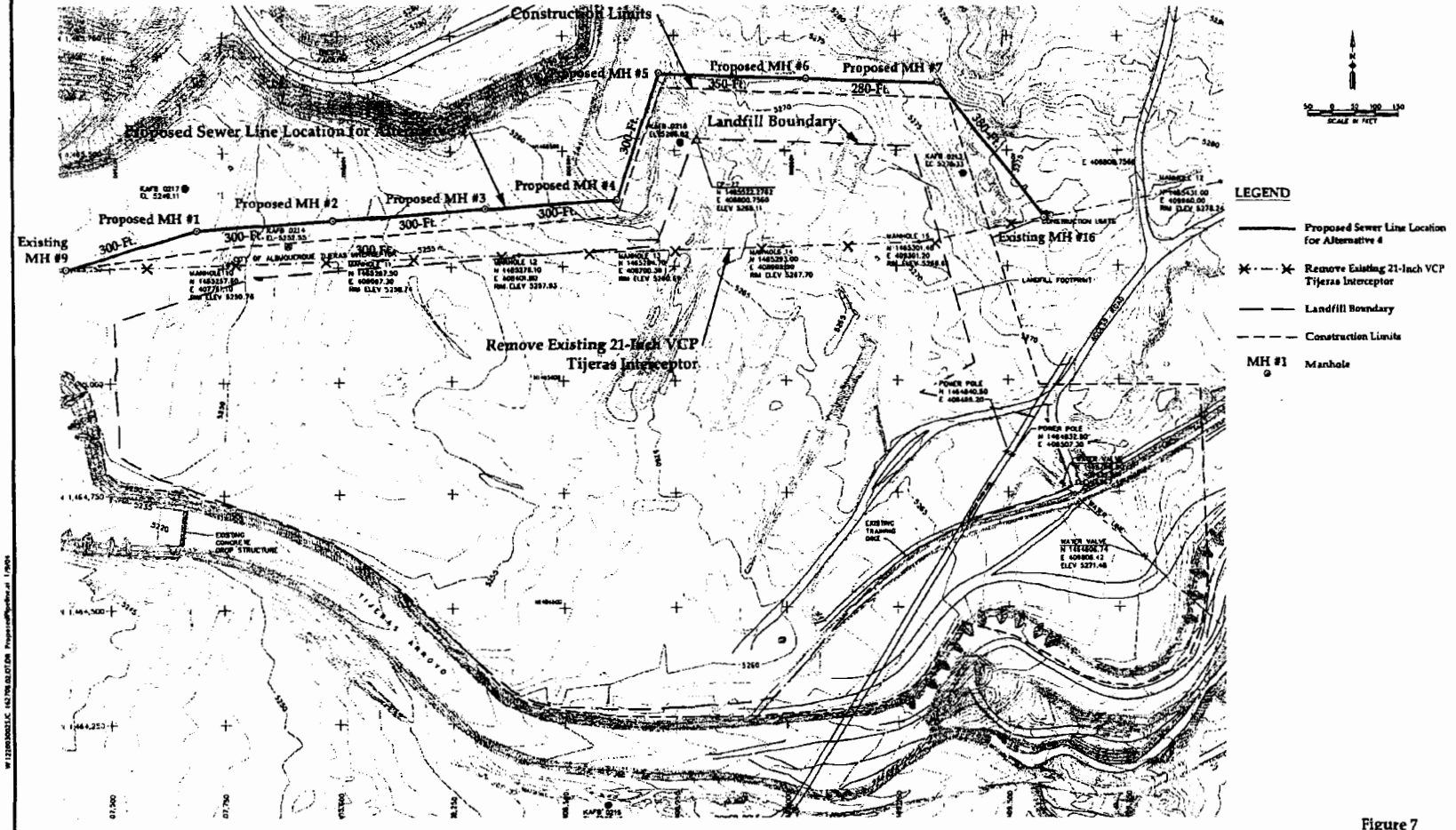

Figure 7
Alternative 4 Proposed Alignment
Kirtland AFB, New Mexico

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Engineering Analysis of Four Alternatives

The following section discusses the engineering analysis of the proposed four alternatives against each of the criteria given in Table 2. The information for the analysis was taken from the LF-002 as-built record drawings produced by Molzen-Corbin and Associates (as-built record drawings, 1977) (see Figure 4); the Landfill Grading and Drainage Plans and Cut and Fill Plan produced by Foster Wheeler (final design submittal, 2002) (see Figure 6); HTRW drilling logs for boring LF-002-A through LF-002-J (HTRW drilling log, 1996); and information obtained from the City of Albuquerque and Kirtland AFB personnel. In addition to the information collected through the above-mentioned sources, various specified assumptions were made to perform the calculations for evaluating each criteria.

Risk of Groundwater Contamination

The groundwater elevation map in Figure 3 shows that groundwater is approximately 400 feet below the ground surface in the vicinity of LF-002. The 21-inch VCP is located at 10 feet below the ground surface. Since the groundwater is at 400 feet below the existing ground surface, the risk of contamination is considered to be insignificant, even if the pipe breaks and all the sewage seeps into the landfill. Assuming prompt identification and repair of a massive line failure, the leaking sewage will most likely not reach the groundwater. A smaller, ongoing leak that is not detected could potentially impact groundwater after several years. Therefore, the risk of groundwater contamination is insignificant and relatively equal in the case of all four alternatives, and this criterion, although extremely important, is not a differentiator between alternatives.

Potential Damage to Sewer Pipe from Differential Settlement

The information used to calculate the settlement of the 21-inch VCP came from the boring logs and laboratory testing data of LF-002 provided by HTRW drilling logs (1996). The location of the boring logs on LF-002 are shown in Figure 5. Soil samples were taken at various locations in the vicinity of the existing 21-inch VCP. However, the boring logs are only 25 feet deep. The information from the borings was used to estimate the net change in overburden resulting from grading and installation of the ET cover.

Calculations of potential differential settlement are provided in Appendix B of this report. The evaluation showed that zero additional settlement is expected in the vicinity of sewer MHs #6 through #14. Zero to 5 inches of settlement may occur in the vicinity of MH #15, where an additional 10 feet of overburden will occur (7 feet of grading, 3 feet of cover). This additional estimated settlement applies to Alternatives 1, 2, and 3. The settlement calculation is not applicable for Alternative 4 because this alternative calls for the VCP to be installed outside the LF-002 footprint and to be constructed with 10 feet of cover similar to the existing pipeline. Note, however, that some settlement may occur because of construction factors (such as, settlement of bedding material) that will not occur for

Alternatives 1, 2, and 3. This potential construction settlement was not included as a part of the analysis.

Future Access to Interceptor for Regular Maintenance and Structural Repairs

Access to the existing 21-inch VCP will be limited after the LF-002 area is covered with the ET cover. After the ET cover is placed, Kirtland AFB plans to limit the access to the existing LF-002 by constructing a fence around the perimeter of the site. The City requests that Kirtland AFB install a double-swing gate to provide access to their sewer pipeline within the 10-foot easement for future maintenance. An access road adjacent to the pipeline also will facilitate maintenance activities.

The anticipated maintenance activities for the 21-inch VCP include regular CCTV inspection and cleaning of the pipeline. During maintenance, the ET cover surrounding the manholes may be impacted. For Alternatives 1, 2, and 3, future access to the interceptor for regular maintenance and structural repairs will be more restricted than if the sewer line is relocated. For Alternative 4, the 21-inch VCP will be relocated and City will have better access for regular maintenance.

Impacts on Property Adjacent to LF-002

The 21-inch VCP will remain in its existing location for Alternatives 1, 2, and 3 and, thus none of these alternatives will affect any property adjacent to LF-002. In Alternative 4, the pipe would be relocated as shown in Figure 7.

The installation of the relocated sewer line may impact some of the surrounding property adjacent to LF-002, as well as future planned uses in the area. For instance, no structures could be constructed over the top of the pipeline. If the manhole covers are abovegrade, existing vehicle access may be impacted.

LF-002 is open land and no major commercial buildings are around it (see Figure 2). According to Kirtland AFB staff, no future development is planned in the vicinity of the proposed site for the relocated pipeline.

Impacts on Operations at Kirtland AFB

In Alternative 1, no impact to operations at Kirtland AFB is expected because the existing pipe will remain in place. In Alternatives 2 and 3, the impact to operations at Kirtland AFB is minimal because of the unintrusiveness of the trenchless methods proposed. In Alternative 4, slightly more disruption will occur during construction because of an increase in construction vehicles hauling pipe material and earthwork through the Kirtland AFB facility during construction of the new pipeline. The activities expected during pipeline construction include excavating material, installing pipe and bedding, construction of manholes, and construction of an access road. During construction, vehicle access through this area would be limited.

Loading on the Pipeline (Safety Factor)

The design load for the pipeline must be less than the limit load or the pipe-bearing strength. Many uncertainties exist in service conditions, loads, uniformity in materials, and assumptions made in design. Thus, a reduction factor is used and is usually referred to as a safety factor or factor of safety. The safety factor for the 21-inch VCP is defined as the ratio of the pipe strength over the design load. The calculation of the safety factor for the existing 21-inch VCP is provided in the Appendix C of this report.

According to the Molzen-Corbin as-built record drawings (see Figure 4), the invert of the 21-inch VCP is located 10 feet below the ground surface from MH #6 through MH #17. This results in approximately 8.25 feet of cover over the existing pipe. The cover over the 21-inch VCP after placing the 3-foot ET cover will be about 11.25 feet. LF-002 will be regraded before the ET cover is placed. According to the Cut and Fill Plan and manhole modification requirements (Figure 6) produced by Foster Wheeler (2002), MH #14 will be raised by 2 feet and MH #15 will be raised by 7.2 feet. Therefore, the cover over the 21-inch VCP for MH #10 through MH #13 and MH #16 will be approximately 11.25 feet, MH #14 will be 13.25 feet, and MH #15 will be 18.25 feet. This increase in cover results in a significant increase in load at MHs #14 and #15. Therefore, the load calculations were performed for each loading condition. In Alternative 4, the sewer line is relocated and the invert depth will be assumed to be 10 feet below the ground surface, similar to the existing pipe.

The City is likely to use a truck-mounted sewer vacuum cleaning unit (approximately 20 tons) during their maintenance activities. If the pipeline is constructed after construction of the ET cover is complete, the largest live load the pipeline will experience is the load from the maintenance vehicle or H-20 loading. The following are the four loading conditions that have been considered:

Case 1. Sewer located 8.25 feet below finished grade.

Case 2. Sewer is located at 11.25 feet below finished grade at MHs #10 through #13 and MH #16 after the ET cover is placed.

Case 3. Sewer is located at 13.25 feet below finished grade at MH #14 after the ET cover is placed.

Case 4. Sewer is located at 18.25 feet below finished grade at MH #15 after the ET cover is placed.

Calculation Process

The National Clay Pipe Institute (NCPI) has developed TRENCH LOAD, a computer program that can be used to determine backfill loads, safety factors, and bedding classes. The safety factors are calculated using this program to check if the existing 21-inch VCP is able to sustain the loads as defined above for the four load cases.

If the depth of the cover is greater than 8 feet, then the concentrated and superimposed loads from truck or vehicular traffic have an insignificant impact on the pipe (Moser, A.P., 2001). Therefore, CH2M HILL did not consider the vehicle loading in the safety factor calculation.

CH2M HILL has considered only the actual weight of the backfill material around the pipe as the total trench load. The total trench load is calculated by using the Marston equation.

Based on data from Figure 4, Class B bedding is assumed. It also is assumed that the existing VCP is extra strength not standard, since standard pipe is rarely installed. With these assumptions, the field supporting strength is calculated to be approximately 7,315 pound per linear foot (lb/LF) based on the Field Supporting Strength Table (NCPI, 2002, page 49).

The safety factor is the result of dividing the field-supporting strength of the installed pipe by the calculated trench load on the pipe. A safety factor greater than 1.0 and less than or equal to 1.5 is desirable. These safety factors are calculated for Cases 1, 2, 3, and 4.

In any pipe trench, there is a minimum distance beyond which the trench width may be increased without adding to the weight on the pipe; this is called the transition width of the trench. In the existing 21-inch VCP, the trench width is about 10 feet. Typically, a 10-foot transition width would be used in this analysis for a recently installed trench. However, since settlement and compaction have occurred over the last 27 years, use of a 10-foot width in the analysis may be overly conservative in this case. Because of this, the analysis was performed using widths of 3, 5, and 10 feet. The resulting safety factors will vary depending on the width used in the calculation.

For instance, in Case 4 the depth of cover is 18.25 feet. The transition width and safety factors are as follows:

- With a transition width of 3 feet, the safety factor is 2.33.
- With a transition width of 5 feet, the safety factor is 1.04.
- With a transition width of 10 feet, the safety factor is 0.91.

The following Marston equation was used to calculate the trench loads on the pipe. The factors that are taken into consideration in the Marston equation are depth of backfill cover over the top of the pipe, effective width of trench measured at the level of the top of the pipe, unit weight of backfill, and values for frictionless characteristics of the backfill material. The Marston equation for pipe in narrow trench is given by

$$W_c = C_d w B_d^2$$

where:

W_c is the total trench load on the 21-inch VCP from fill materials in lb/ft of length,

C_d is the load calculation coefficient for the pipeline and is calculated from computation diagrams for trench conduits (NCPI, 2002) based on the depth of the cover, effective transition width, and the soil type.

w is the unit weight of fill materials in pounds per cubic feet (lb/ft^3). The soil is assumed to be silty-gravel and the unit weight of soil is taken as 133 lb/ft^3.

B_d is the effective transition width in feet.

The safety factor is determined by dividing the field supporting strength of the pipe (for this 21-inch VCP, 7,315 lb/LF) by the total trench load (as calculated by W_c). The results of the calculation of the safety factor are provided in Figures C-1 through C-4, Appendix C.

As stated above, the transition width for the calculations would be 10 feet if this were a new trench. For an effective transition width of 10 feet, the safety factor for Case 4 is approximately 0.91 (see Figure C-4 in Appendix C), which would indicate pipe failure under the design load. Although the safety factor is less than 1.0 for Case 4, we estimate the existing pipe will be able to withstand the loading without damage because the pipe was installed 27 years ago and the soil has compacted around the pipe's diameter. Such compaction can be expected to distribute the load over more than the pipe itself, resulting in a lower pressure on the pipe and a higher factor of safety. A more reasonable assumption would be to use an effective transition width of 5 feet.

The safety factors for the effective transition width of 5 feet for each of the four cases follow:

- For Case 1 (at cover depth 8.25 feet), the safety factor is 2.02.
- For Case 2 (at cover depth 11.25 feet), the safety factor is 1.48.
- For Case 3 (at cover depth 13.25 feet), the safety factor is 1.25.
- For Case 4 (at cover depth 18.25 feet), the safety factor is 1.04.

Based on the analysis for an effective width of 5 feet, the existing pipe will be adequate to handle the additional loads caused by regrading the site in the vicinity of MH #15. However, precautions should be taken while doing the regrading and loading process and during the installation of the ET cover, especially around MH #15. CH2M HILL recommends that the 21-inch VCP be videotaped after the grading is done to observe if any damage occurred to the pipeline during the regrading and loading process.

An alternate recommendation is to revise the grading plan to reduce the depth of cover in the vicinity of MH #15. For a transition width of 10 feet, the safety factor for Alternatives 1, 2, and 3 can be increased from 0.91 to 1.49 if the grading plan is revised in the vicinity of MH #15 and is reduced from 7.2 feet to 3 feet before the ET cover is placed.

Existing and Future Capacity

The Manning equation was used to calculate the flow capacity in the pipeline. Details regarding calculations for existing and future flow capacity of the 21-inch VCP before and after rehabilitation are provided in Appendix D. The coefficient of roughness "n" varied according to age and type of interior surface and lining assumed. Although the roughness factor is better for rehabilitated pipes (Alternatives 2 and 3), the diameter of the pipeline is reduced as compared to a new 21-inch VCP for Alternative 4. Parameters considered for the calculation of the quantity of sewer flow are shown in Table D-1 of Appendix D. The existing capacity of the pipeline for Alternative 1 is approximately 34 cfs; for Alternatives 2 and 3, it is approximately 46 cfs; and for Alternative 4, the capacity would be approximately 38 cfs. All four alternatives have significantly more capacity than the City's present requirement of 3 cfs.

This report assumes that if no major development occurs in the area served by the sewer line then the calculated future capacity requirement will remain unchanged. Although the

capacity is reduced over time with the age of the pipe, the City does not anticipate that the need will increase above the current capacity requirement flow of approximately 3 cfs. Therefore, since all alternatives provide the necessary capacity requirement, this criterion is not a differentiator among the alternatives.

Construction Costs

Construction costs are associated with activities required for construction or implementation of each alternative. Estimates of construction costs are provided for the four alternatives in Appendix E, Tables E-1 through E-4, along with a list of anticipated construction activities and quantities.

For Alternatives 1, 2, 3, and 4, the mobilization is considered as 10 percent of the total construction cost. Typically, mobilization includes setting up the onsite project office; developing schedules and submittals; obtaining permits, and meeting local jurisdiction requirements, project signage; and setting up other administrative capabilities for the contractor.

Miscellaneous bid items are very small and not itemized individually. Industry standards typically set the total construction costs for a planning-level estimate at 10 percent.

In Alternative 1, the existing 21-inch VCP remains in place and regular maintenance and cleaning activities are performed. Kirtland AFB will construct a fence around the landfill area. Therefore, an access road and installation of a double-swing gate will be required to maintain access to the 21-inch VCP. The calculation of the construction cost is provided in Table E-1.

In Alternative 2, the existing 21-inch VCP sewer line is rehabilitated using the CIPP trenchless method. In this method, the liner is inserted into the existing pipeline between the two manholes. This alternative also requires construction of an access road and installation of a gate to access the site in the future. The construction cost is provided in Table E-2.

For Alternative 3, the existing 21-inch VCP is rehabilitated using the fold-and-form trenchless technology. This alternative also requires construction of an access road and installation of a gate to access the site in the future. The construction cost is provided in Table E-3.

In Alternative 4, the existing 21-inch VCP is abandoned and a new 21-inch VCP will be constructed as shown in Figure 7. The existing 21-inch VCP will be left in its original location and plugs will be inserted at MHs #9 and #16. The length of the new proposed line is approximately 2,510 feet. The construction cost is provided in Table E-4.

The construction costs for listed bid items were developed based on the estimate provided by the construction contractors, CCTV vendors, and based on CH2M HILL's experience with similar projects in the southwest region of the United States. The costs were reviewed by an estimator-consultant specialist. The estimator uses costs for unit items of work adjusted for work location and economic conditions adjusted for inflation based on available data. The cost estimates for the four alternatives were prepared in accordance with the guidelines of the AACE International, (the Association for the Advancement of

Cost Engineering International). These are preliminary order-of-magnitude estimates, as there is less than 5 percent preliminary engineering complete for Alternatives 2, 3, and 4. The typical expected accuracy ranges for this class of estimate are -30/+50 percent.

A contingency of 30 percent is used for unspecified elements of the project:

- Items of work that are unidentified at the time of estimate
- Changes in cost of material
- Unforeseen site conditions
- Delays
- Changes in the bidding climate between the estimate time and actual work and other changes that may occur
- Other apparent items that haven't been designed to a detail level

The cost estimates for construction of components for each alternative are listed in Tables E-1, E-2, E-3, and E-4 and are as follows:

- Alternative 1 – $ 40,000
- Alternative 2 – $ 354,000
- Alternative 3 – $ 412,000
- Alternative 4 – $ 837,000

Life-Cycle Costs

The term *life-cycle costs* refers to a summation of all the costs, recurring and nonrecurring, related to a pipeline during its life span or design period. The life-cycle costs were calculated for each of the four alternatives to compare their construction and maintenance costs over their estimated remaining design life.

The parameters, assumptions, and calculations are shown in Appendix F, Table F-1. The calculations shown in Table F-2 are based on the values calculated in Table F-3. An interest rate of 4 percent per year is considered while calculating the life-cycle costs. For converting the future values to present worth, a uniform capital recovery factor is applied. Using a 4 percent rate, the uniform capital recovery factor is calculated for the design life of the pipe material for the four alternatives.

The annual life-cycle costs are calculated for the maintenance of the pipeline, maintenance of the landfill, and for total life-cycle costs. The total life-cycle costs are determined by using the annualized maintenance cost and the initial construction costs annualized over an estimated remaining life. These values are used to compare each of the four alternatives.

Life-Cycle Costs (Annual Costs) for the Maintenance of the 21-Inch VCP

Maintenance costs for the 21-inch VCP involve the regular CCTV inspection of the line, cleaning of the sewer line, and repairs.

From Table F-2, the life-cycle costs (annual costs) for maintenance of the 21-inch VCP are as follows:

- Alternative 1—$3,108
- Alternative 2—$2,459
- Alternative 3—$2,459
- Alternative 4—$1,805

Life-Cycle Costs (Annual Costs) for the Maintenance of the ET Cover

Maintenance costs for the ET cover include the revegetation of the 10-foot-wide easement area every time the sewer line on LF-002 is accessed for maintenance. Maintenance activities (like CCTV inspection and cleaning) for the 21-inch VCP may disturb portions of the ET cover and could require revegetation. Maintenance costs for the landfill for Alternative 4 is zero since the new location of the pipeline is outside the LF-002 area. This cost is based on the number of times the pipe may require maintenance.

From Table F-2, the life-cycle costs (annual costs) for maintenance of LF-002 follow:

- Alternative 1—$ 940
- Alternative 2—$ 654
- Alternative 3—$ 654
- Alternative 4—$ 0

Total Life-Cycle Costs (Total Annual Costs)

The total annual life-cycle costs include the total maintenance costs of the 21-inch VCP, maintenance of the ET cover, and the initial construction costs spread out over the estimated remaining design life of the pipe.

From Table F-2, the total life-cycle costs (total annual costs) follow:

- Alternative 1—$ 4,876
- Alternative 2—$ 17,150
- Alternative 3—$ 19,619
- Alternative 4—$ 36,541

Summary

The summary of the results is shown in the Table 4.

TABLE 4
Comparison of Four Alternatives Against Each Decision Criteria

Decision Criteria	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Risk of contamination of groundwater	Negligible	Negligible	Negligible	Negligible
Potential damage to the sewer pipe from differential settlement	0–5 inches	0–5 inches	0–5 inches	0 inch
Future access to interceptor for regular maintenance and structural repairs	Low	Low	Low	High
Impacts to property adjacent LF-002	None	None	None	Low
Impacts to operations at Kirtland AFB	Low	Low	Low	Low
Loading on the pipeline				
Safety Factor at trench width 5 feet	1.04	1.04	1.04	2.02
Safety Factor at trench width 10 feet	0.91[a]	0.91[a]	0.91[a]	2.02
Existing capacity	34 cfs	46 cfs	46 cfs	38 cfs
Future capacity	34 cfs	34 cfs	34 cfs	34 cfs
Construction costs	$40,000	$354,000	$412,000	$837,000
Life-cycle costs (annual costs) for the maintenance of pipeline	$3,108	$2,459	$2,459	$1,805
Life-cycle costs (annual costs) for the maintenance of landfill	$940	$654	$654	N/A
Total life-cycle costs (total annual costs)	$4,876	$17,150	$19,619	$36,541

[a] The safety factor of 0.91 could be increased to 1.49 for Alternatives 1, 2, and 3 if the fill height is reduced from 7.2 feet to 3 feet at the MH #15.

Recommendations

Preferred Alternative

The results shown in Table 4 were presented to Kirtland AFB and City of Albuquerque staff at a meeting on December 17, 2003. Table 4 results indicate that those criteria that were most highly weighted were not really differentiators between alternatives and, therefore, cost became the most important criterion for identifying a preferred alternative.

From Table 4, Alternative 1 has the lowest construction cost. The annual life-cycle cost for Alternative 1 is significantly lower than Alternatives 2, 3, and 4. The CCTV tapes indicate that the pipe is in good condition and does not have any major structural or maintenance defects.

Alternative 1 does indicate a safety factor of less than 1.0 in the vicinity of MH #15. However, the assumptions used for this calculation were based on the installation of a new pipeline and do not reflect the actual current site conditions. Less conservative assumptions indicate the existing pipeline is adequate to handle the additional loading at MH #15. However, the pipeline should be evaluated after the loading is complete in the vicinity of MH #15. Lining portions of the existing pipe may become necessary if any cracks or defects are observed near MH #15. An alternate solution is to revise the grading plan and reduce the cover in the vicinity of MH #15. With this caution noted, CH2M HILL recommends Alternative 1—leaving the existing 21-inch VCP in place and continuing to monitor for future signs of distress.

CH2M HILL recommends that the regular maintenance activities of CCTV inspections and cleaning of the pipeline be carried out every 3 years and 10 years, respectively, until the end of the VCP's design life. (CCTV inspection should be done as per the standard guidelines recommended in Appendix G.) If the existing pipe requires rehabilitation in the future, Alternative 2—Rehabilitation of the 21-inch VCP using CIPP— is preferred by the City staff.

CH2M HILL also recommends that an access gate and aggregate road be constructed to provide the City access to the existing 21-inch VCP to perform maintenance activities.

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