ALTERNATE SITE SELECTION PROCESS FOR THE FALLS CITY, TEXAS, UMTRA PROJECT

Jonathan G. Blount and Charles W. Kreitler

Final Report prepared for

U.S. Department of Energy
under Contract No. DE-FC04-87AL20532

Bureau of Economic Geology
W. L. Fisher, Director
The University of Texas at Austin
Austin, Texas 78713

July 1990

CONTENTS

Illustrations

Figures

Tables

INTRODUCTION

This evaluation of possible alternate disposal sites for the Falls City Uranium Mill Tailings Remediation Act (UMTRA) site in southeastern Texas (fig. 1) was undertaken in response to the requirements promulgated by the U.S. Department of Energy (DOE) for the remediation of UMTRA sites in accordance with the Uranium Mill Tailings Radiation Control Act of 1978. Primary objectives of this report are to (1) describe the general geology and hydrology of the areas that have been identified as containing potential alternate tailings sites and (2) describe the systematic process utilized to identify those areas that may contain potential alternate tailings disposal sites.

The alternate site selection process employed for the Falls City site generally follows the format established in the 1988 UMTRA-DOE/AL Document 200129.0007 R-4 titled "Alternate Site Selection Process for UMTRA Project Sites." Implementation of the final step of the alternate site selection process as described in the 1988 UMTRA-DOE document would, however, require the collection of detailed, site-specific lithologic and hydrologic data, and this is beyond the scope of the present study.

The site selection process used in the current study comprises three distinct phases: (1) designation of the search region and identification of the geologic formations exposed within this region; (2) screening of geologic units within the search region based upon broad geologic characteristics; and (3) application of geologic, hydrologic, environmental, and engineering criteria to the formation(s) not excluded by phase two of the process in order to identify the less favorable outcrop areas within these formations.

Implementation of this three-phase process reduced the original 7,850 mi^2 alternate site search region to a final region of interest of less than 30 mi^2. The geologic and hydrologic characteristics of the final region of interest suggest that it may contain one or more alternate tailings storage sites.

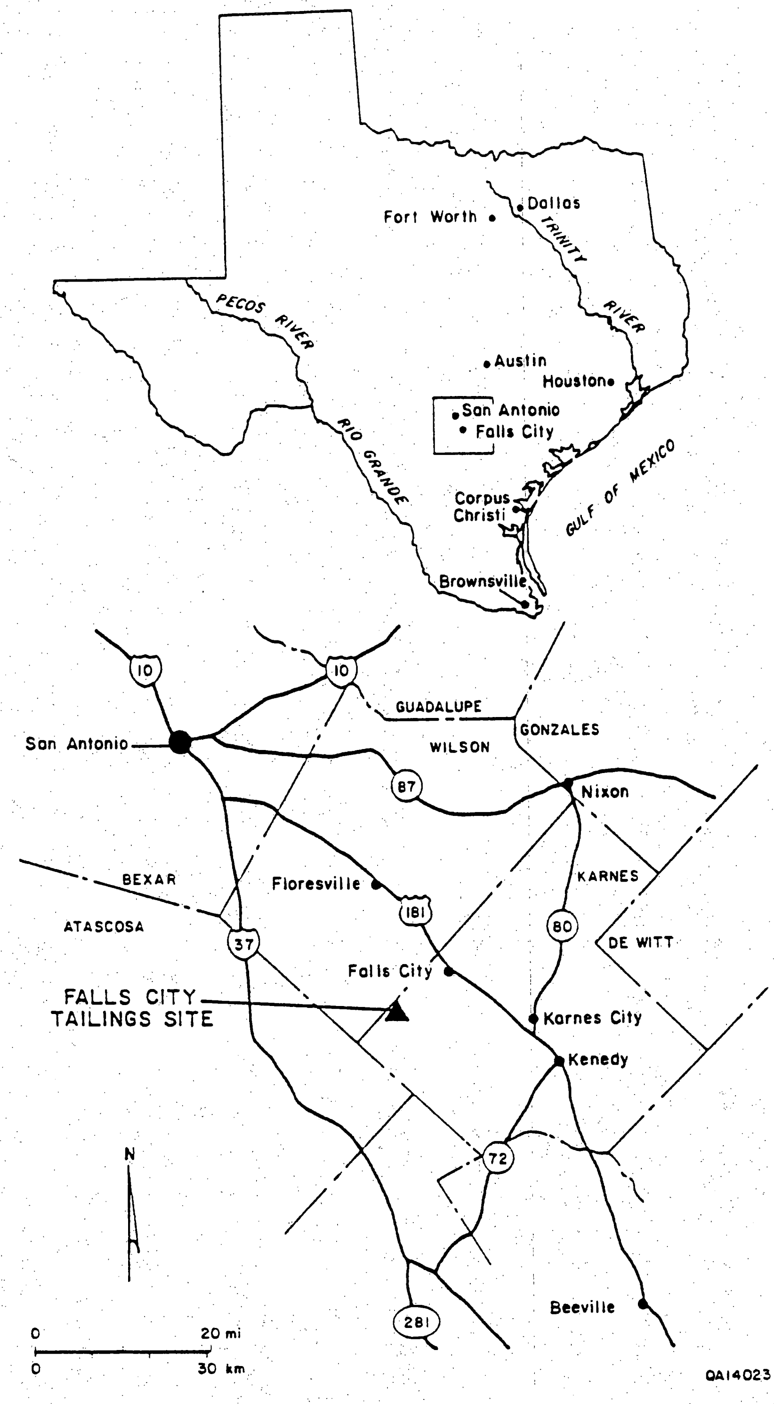

Figure 1. Location map showing the Falls City UMTRA site.

PHASE ONE

After consultation with Jacobs Engineering Group, Inc., we defined the alternate site search region as the area within a 50-mi radius of the Falls City uranium mill tailings site. This region of approximately 7,850 mi^2 was plotted on geologic maps of southeast Texas, and the geologic formations that are exposed within this search area were identified. Part of this search area is shown in figure 2.

PHASE TWO

Relevant geologic literature was reviewed, and lithologic and hydrologic descriptions of the formations that crop out within the search area were compiled (appendix). These data were used to compare the relative merits of these geologic units as potential substrates for an alternate tailings site. Units that are considered less favorable for isolating uranium mill tailings from the environment include highly to moderately permeable units such as the Yegua Formation and those that immediately overlie major fresh-water aquifers such as the Carrizo Sand.

The following six low-permeability units, listed in descending stratigraphic order, were selected for continued investigation: (1) the Frio Clay; (2) the Fashing Clay member of the Whitsett Formation; (3) the Dubose Clay member of the Whitsett Formation; (4) the Conquista Clay Member of the Whitsett Formation; (5) the Manning Formation; and (6) the Cook Mountain Formation. General lithologic and hydrologic descriptions of these formations are given in the appendix.

Using the general geologic literature and especially Brown and others (1974, 1975, 1976), Proctor and others (1975), and Wermund and Gustavson (1975, 1985a, 1985b), we compared these six low-permeability units for the following criteria: thickness, erosional characteristics,

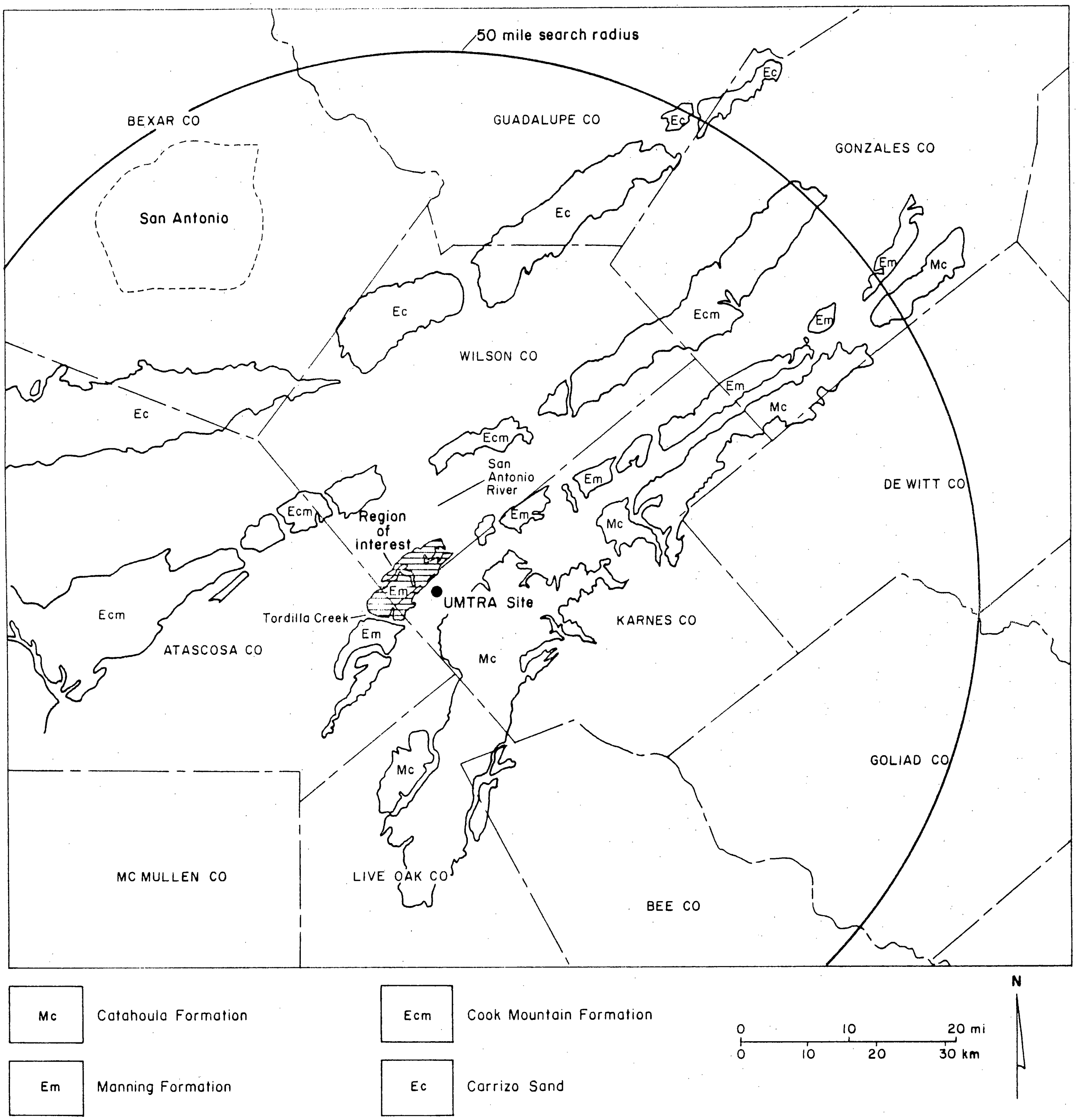

Figure 2. Outcrop map of key units in the search region.

lithologic homogeneity, and chemistry (table 1). As can be seen from the general descriptions in the appendix and the criteria summarized in table 1, the Manning Formation and the Cook Mountain Formation have characteristics that are probably more favorable than those of the other four units. In particular, the greater thickness and lithologic homogeneity of the Cook Mountain Formation and, to a lesser extent, the Manning Formation, distinguish these two formations from the other units except the Frio Clay. The Frio Clay is also a thick, relatively homogeneous, low-permeability unit. The outcrop of this unit is, however, subject to severe erosion, and it has a rugged topography that is inappropriate for an alternate site. On the basis of this analysis the Cook Mountain and Manning Formations were selected as the units with the greatest potential to serve as alternate tailings sites. Our subsequent efforts focused upon further evaluation of these units.

The Cook Mountain Formation and the Manning Formation have many characteristics in common that are favorable for an alternate tailings disposal site. However, several factors reduce the attractiveness of the Cook Mountain Formation as the host unit of an alternate site relative to the Manning Formation. (1) At its closest point the outcrop of the Cook Mountain Formation is more than 10 mi away from the Falls City site, whereas the Manning Formation crops out less than 1.5 mi away. (2) The outcrop belt of the Cook Mountain Formation is extensively farmed; the Manning Formation outcrop has large areas that are undeveloped and that are used primarily for cattle grazing. (3) The Cook Mountain Formation is composed of a thick, relatively homogeneous, sequence of montmorillonitic marine clay (fig. 3). A substrate composed of a thick, relatively impermeable, clay-rich sequence is a very favorable characteristic for an alternative tailings disposal site. Montmorillonite, however, is subject to moisture-related shrink/swell processes and when exposed to water it can more than double its volume (Mielenz and King, 1955). Depending upon seasonal variations in its water content, small ridges (gilgai) with relief of as much as 8 inches can form in the surface layers of the Cook Mountain Formation, producing severe damage to roads, buildings, and other manmade structures (Gustavson, 1975). In addition, relatively deep cracks (up to 60 inches in Cook

Table 1. Relevant characteristics of low-permeability units.

Unit	Dominant lithology	Lithologic homogeneity	Erosional character	Chemical character
Frio Clay	Up to 200 ft bentonitic clay and silty clay, some sand	Fair to good	Steep slopes, local badlands topography	High cation exchange capacity, gypsiferous, calcareous
Fashing Clay	Up to 120 ft silty clay; upper sand unit ~ 20 ft thick	Fair, unit contains channel deposits of mud and sand	Low rolling hills with many small ephemeral streams	High cation exchange capacity, gypsiferous
Dubose Member	~ 120 ft silty clay and sand, carbonaceous, bentonitic	Fair to poor, locally contains sand-filled channels	Low rolling hills with many small ephemeral streams	High cation exchange capacity
Conquista Clay	50 to 90 ft of shale, silt and sandstone; clay has bentonite and lignite	Fair. This unit has localized sandy units.	Low rolling hills with many small ephemeral streams	High cation exchange capacity
Manning Formation	>250 ft tuffaceous, lignitic shale, with interbedded sandstone	Generally fair to good, but some variability in sand content	Low rolling hills with many small ephemeral streams	High cation exchange capacity, high reducing capacity
Cook Mountain Formation	350 ft marine clay with a few lenses of sandstone and limestone	Excellent	Relatively flat slopes, abundant small drainages	High cation exchange capacity, gypsiferous, calcareous

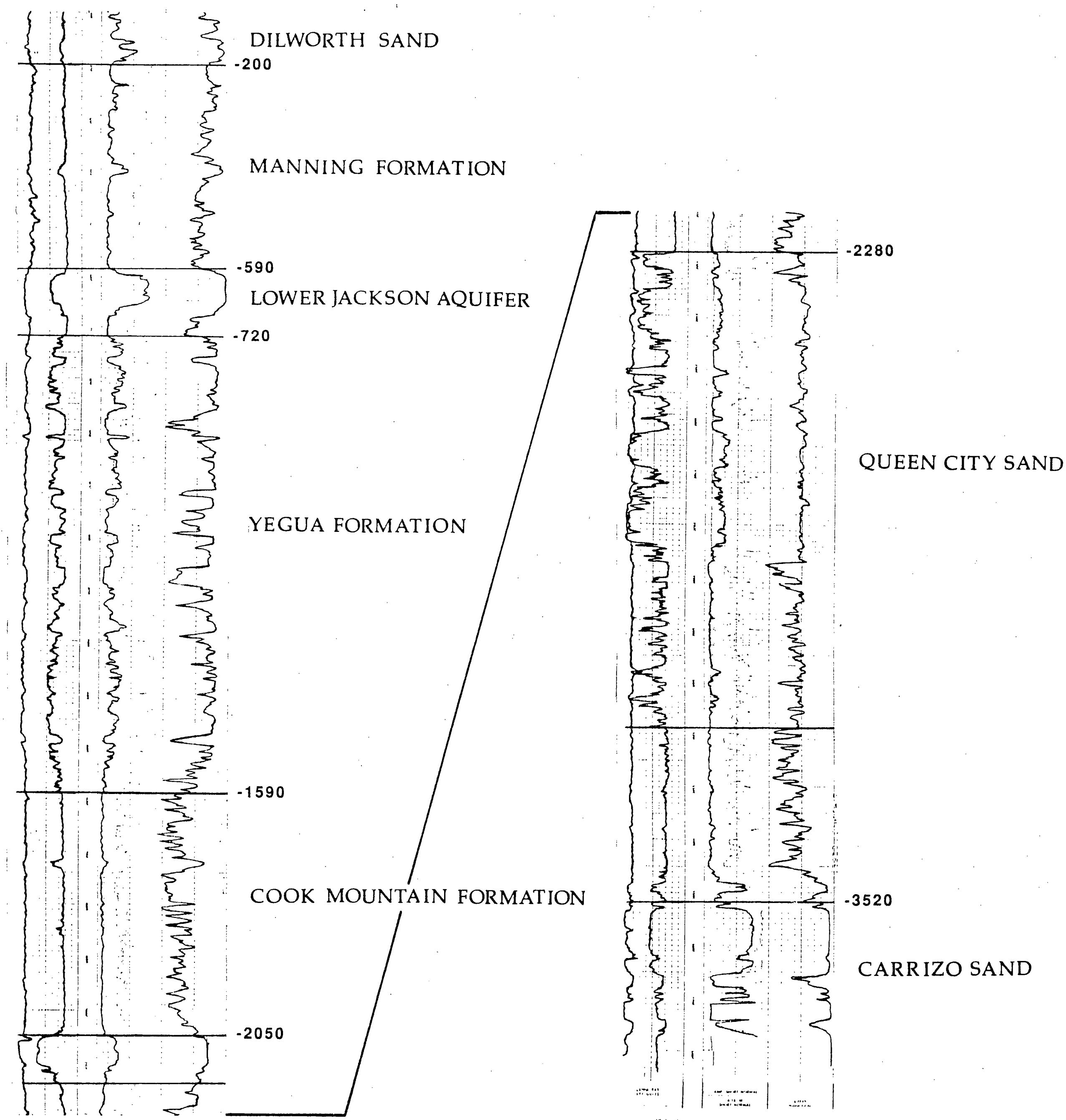

Figure 3. Type log.

Mountain soils) can form in these same layers during dry periods. Both of these phenomena are much less pronounced in montmorillonite-bearing units that also contain interbedded sand and silt (Gustavson, 1975), such as the Manning Formation.

Long-term structural integrity is a fundamental requirement for any tailings repository. On the basis of the study by Gustavson (1975), discussions with representatives of Jacobs Engineering Group, Inc., and DOE it was determined that a unit subject to severe shrink/swell processes is incompatible with the structural stability required in the host unit of a tailings facility. The Cook Mountain Formation was, therefore, dropped from further consideration. Of the six formations that were considered initially, the outcrop of the Manning Formation represents the most acceptable alternative to the current UMTRA site.

PHASE THREE

Delineation of the Initial Region of Interest

The outcrop belt of the Manning Formation was carefully studied, and large areas of this belt within the 50 mi search radius were excluded from further consideration on the basis of (1) high regional stream density; (2) proximity to individual major streams or rivers; (3) proximity to major population centers; and (4) distance from the Falls City site and borrow materials. An approximately 30 mi^2 region of interest, bounded by Tordilla Creek to the southwest and the San Antonio River to the northeast, was identified as the section of this unit that is best suited to contain alternate sites (plate [in pocket]).

Hydrological Evaluation

In order to determine the possible hydrological impact of an alternate tailings site located within the region of interest, it is necessary to (1) adequately constrain the hydrologic characteristics of the Manning Formation; (2) identify and describe the aquifers that underlie this unit, their relative importance, and their relative risk of contamination; and (3) assess any other factors that may affect the hydrological containment of the tailings if they are relocated to a site on this part of the Manning Formation outcrop.

Manning Formation Hydrology

Although the Manning Formation is composed predominantly of clay, it is laterally and vertically heterogeneous and contains some sandy and lignitic units, as evidenced on the type log (fig. 3). Quantitative hydrologic data for this unit are scarce, although some water quality, water-level, and hydraulic conductivity data are available for the upper Manning Formation at the Falls City UMTRA site. According to Bryson (1987), the monitor wells at the UMTRA site that penetrated the upper part of the Manning Formation (to a maximum extent of approximately 50 ft) encountered carbonaceous clay, clay with interlaminated very fine sand, and some lignite stringers. The average hydraulic conductivity value of the Manning Formation (0.43 ft/day) is lower than the average values obtained for the members of the Whitsett Formation (Bryson, 1987).

A potentiometric surface map of the upper Manning Formation constructed with limited data by Jacobs Engineering Group, Inc. (fig. 4A), shows the surface dipping to the southeast, similar to the potentiometric surfaces of the overlying Dilworth and Deweesville sand. Redox values in Manning Formation ground waters decrease downdip from a high of +121 mv to a low of –216 mv (fig. 4B). These data, recently obtained from Jacobs Engineering Group, Inc., suggest that there is fluid flow through permeable zones in the Manning Formation and that these zones are being progressively oxidized by the influx of surface waters. The rate and volume of fluid flow through these zones are unknown. Similar zones probably exist elsewhere in the Manning Formation, and their potential to channel oxidizing and acidic fluids from an overlying tailings pile (resulting in rapid, localized exhaustion of reducing and cation exchange

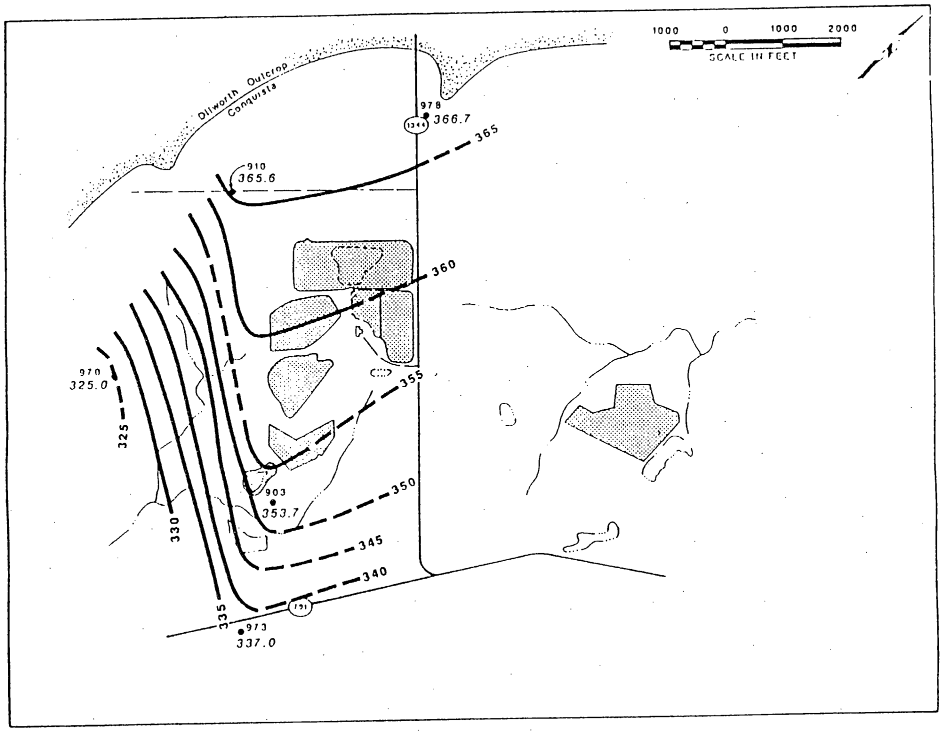

Figure 4A. Potentiometric surface map, upper Manning Formation (Jacobs Engineering Group, Inc., personal communication, 1990).

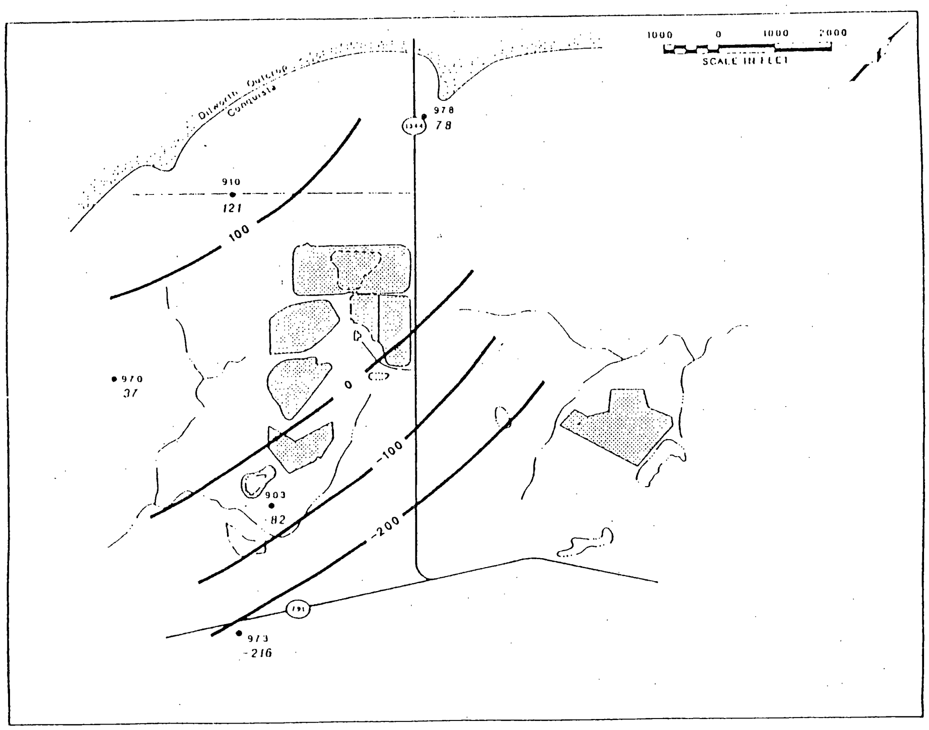

Figure 4B. Redox potential (mV) map, upper Manning Formation (Jacobs Engineering Group, Inc., personal communication, 1990).

capacity) into the subsurface must be evaluated prior to the selection of an alternate site location on this unit.

Aquifer Characterization

The relative risk of contaminating a potable ground-water supply is determined, in part, by the direction of potential vertical flow between the formation that is host to a disposal site and the underlying potable water-bearing strata. Ground water flows from areas of higher hydraulic head to areas of lower hydraulic head. The direction (but not the rate) of potential flow between two formations can be predicted by determining the relative water levels in wells that tap each of the relevant formations in a given area. If, for example, the water level in a well drilled to a given formation is higher than the water level in a nearby well drilled to a shallower formation, the potential for vertical flow is upward, and contaminated solutions from the shallower formation could not flow downward to the lower unit.

Water well data for Wilson, Karnes, and Atascosa Counties were evaluated for the region roughly bounded by the San Antonio River and Tordilla Creek. Locations of water wells that have chemical or water-level data available are plotted on the plate (in pocket). Compilations of the water-chemistry and water-level data are given in tables 2 and 3, respectively. Using these data and the reports of Anders (1957, 1960) we identified the potable-water-bearing units utilized within the region of interest, and we evaluated the head relationships between these units and the Manning Formation. The units in this area that are utilized as aquifers will be discussed in order of decreasing potential for contamination by a tailings site located on the Manning Formation.

Table 2. Available water chemistry data for wells in the area of interest.

County	Well number	Well depth	Aquifer	Sampling date	pH	SiO_2 (mg/L)	Ca (mg/L)	Mg (mg/L)	Na (mg/L)	Na+K (mg/L)	CO_3 (mg/L)	HCO_3 (mg/L)	SO_4 (mg/L)	Cl (mg/L)	F (mg/L)	NO_3 (mg/L)	TDS	Spec.Cond. (Micromhos)	Hardness as $CaCO_3$ (mg/L)
Wilson	78-07-501	3400	Carrizo	7/24/86	8.4	25	4	2	189	NA	2	444	20	35	0.4	1.3	497	864	19
Wilson	78-07-605	300	Lower Jackson	11/21/72	6.8	14	253	25	1390	NA	0	189	1380	1540	0.7	0.4	4736	6370	740
Wilson	78-07-602	650	Yegua	11/22/72	7.2	15	278	37	640	NA	0	260	1200	560	0.6	0.4	2858	5364	850
Wilson	78-07-606	290	Lower Jackson	11/21/72	7.5	34	200	25	630	NA	0	337	1170	341	0.6	0.4	2568	3360	600
Wison	K-5	165	Yegua	6/8/36	NA	NA	242	42	NA	347	NA	73	654	560	NA	NA	NA	NA	776
Wilson	K-6	235	Lower Jackson	6/8/36	NA	NA	NA	NA	NA	NA	NA	232	1232	550	NA	NA	2795	NA	NA
Wilson	K-8	147	Lower Jackson?	11/28/55	8.1	40	157	5.8	NA	679	NA	399	677	610	NA	NA	2370	4360	416
Wilson	J-11	135	Yegua ?	6/6/36	NA	NA	261	34	NA	447	NA	256	1036	340	NA	NA	NA	NA	796
Karnes	C-46	280	Lower Jackson	7/12/56	7.9	NA	NA	NA	NA	NA	NA	266	NA	910	NA	NA	NA	6190	740
Karnes	C-48	305	Lower Jackson	11/29/55	7.7	16	145	15	NA	1010	NA	204	914	1060	NA	1.2	3260	5170	424
Karnes	78-07-901	3766	Carrizo	7/17/79	8.3	30	4	1	237	240	0	522	44	46	0.6	0.1	622	1064	13

NA = not available

Table 3. Available water-level data for wells in the area of interest.

County	Well number	Well depth (ft)	Aquifer	Depth to water	Date measured
Wilson	K-5	165	Yegua	112.1	4/55
Wilson	K-6	235	Lower Jackson	120	4/55
Wilson	K-8	147	Lower Jackson?	83.9	11/55
Wilson	J-11	135	Yegua?	94.5	3/55
Karnes	C-46	280	Lower Jackson	137.4	10/55
Karnes	C-48	305	Lower Jackson	107.8	10/55

Lower Jackson Group

This aquifer consists of the Caddell and Wellborn Formations and is immediately overlain by the Manning Formation. Several wells (ranging in depth from 235 to 305 ft) located on the outcrop of the Manning Formation between the San Antonio River and Tordilla Creek are known to obtain water from this aquifer. Waters from these wells have TDS concentrations that range between 2,500 and 4,736 mg/L. Lower Jackson Group waters are of poor quality (table 2) and are used primarily for livestock. Water levels in wells that were drilled to the lower Jackson aquifer range from 83.9 to 137.4 ft below land surface (table 3). This suggests that within this region there is a potential for downward flow between the outcrop of the Manning Formation and the lower Jackson aquifer. A water well discussed by Anders (1957) is worthy of special mention. This well (K-8 by Anders' nomenclature) is located just inside the Wilson County line approximately 3 mi northeast of the Falls City tailings site near the Falls City fault trace and the downdip edge of the Manning Formation outcrop (plate [in pocket]). It was drilled to a depth of only 147 ft, which suggests either that it was producing water from a permeable layer in the Manning Formation or that part of the section above the lower Jackson aquifers has been faulted out. No other wells have been identified that potentially produce water from the Manning Formation.

Yegua Formation

The Yegua Formation is a minor aquifer in the region. Three wells have been identified in the area of interest that produced small amounts of poor-quality water from this unit (table 2). Limited water-level data (two wells measured in 1955 with water levels of 94.5 and 112.1 ft) suggest a possible downward head between the Yegua Formation and the Manning Formation. The Yegua Formation, however, would be separated from a potential tailings site located on outcrop of the Manning Formation by the subcrop of the Manning Formation and by the Caddell and Wellborn Formations. There is a relatively low probability for contamination of the Yegua by tailings effluents.

Carrizo Sand

The majority of the wells in Wilson, Karnes, and Atascosa Counties were drilled to the Carrizo Sand (the deepest source of fresh to slightly saline water in Texas), but no water-level data are available for this unit within the area of interest. Water-chemistry data are available on two relevant Carrizo wells, including one located at the Falls City UMTRA site (plate [in pocket]). Because of heavy use of the Carrizo Sand for water over the last 20 to 30 years, the potentiometric surface of this aquifer has declined significantly in southeastern Texas. Given the generally poor water quality of the other aquifers in this region, continued growth in water consumption from the Carrizo Sand is very likely. If this trend does continue, the potentiometric surface of the Carrizo will be lowered even further. Although the potential may exist for flow to occur from the overlying Manning Formation into the Carrizo Sand, there is more than 2,500 ft of relatively low permeability strata (including the Cook Mountain Formation) separating these two units (fig. 3). Contamination of the Carrizo Sand with tailings effluent by normal interformational flow is considered a remote possibility.

Miscellaneous Problems

The Falls City fault is located approximately 1 mi northwest of the UMTRA site. Although no evidence has been found that this fault remains active, there is evidence that it is affecting the local drainage pattern.

Maps reviewed at the Railroad Commission indicate that there are numerous abandoned oil exploration wells in the region. Any abandoned wells located on, or adjacent to, an area that is selected for an alternate site location should be inspected and evaluated as potential pathways for contamination to reach the underlying aquifers.

Delineation of the Final Region of Interest

Aerial photographs, 1:24,000-scale topographic sheets, soil maps, and field inspections were used to exclude inappropriate areas from within the approximately 30 mi^2 region of interest (plate [in pocket]). The areas were excluded on the basis of the following factors:

(1) Thickness of the Manning Formation subcrop: To ensure the presence of an adequate barrier to vertical seepage of tailings solutions, areas of the Manning outcrop with an estimated subcrop thickness of 100 ft or less were eliminated from consideration (plate [in pocket]).

(2) Topography and drainage characteristics: Areas that are cut by, or that are immediately adjacent to, major drainages were avoided.

(3) Distance from the Falls City fault: A 0.5-mi-wide buffer zone was established north of the Falls City fault. The area that fell within this zone was dropped from consideration. This exclusionary criterion will minimize the potential of the fault to increase the rate of erosion at a prospective site, or to act as a conduit for contaminated solutions into the subsurface.

(4) Distance from the UMTRA site and accessibility: Areas that exceeded a distance of 5 mi from the current tailings site or that were not accessible by the existing road system were eliminated from consideration.

The final region of interest produced by this exclusionary process should contain one or more adequate potential alternate tailings sites.

Because of the lithologic heterogeneity of the Manning Formation, however, a final site (or sites) cannot be selected without detailed, site-specific lithologic and hydrologic investigations.

CONCLUSIONS AND RECOMMENDATIONS

(1) The Cook Mountain Formation and the Manning Formation are the most suitable units for an alternate tailings site located within a 50-mi radius of the Falls City UMTRA site, according to general geologic and hydrologic criteria.

(2) Because of the severe shrink/swell processes active in the Cook Mountain Formation, outcrop areas of this unit are probably not sufficiently stable to serve as the substrate for an alternate site. An engineering study of this problem may be justified, however, if the tailings have to be moved and if the Manning Formation proves unsatisfactory.

(3) Based primarily upon its generally low permeability, adequate thickness, high cation exchange capacity, and significant reducing potential, the Manning Formation (table 2) probably contains several potential alternate sites within the final restricted area of interest (plate [in pocket]). Selection of an area from near the hydrologic divide within the final region of interest would minimize the possible effects of upstream drainage as well as the chances of flood waters from either river reaching a potential alternate site. However, because the lithology of the Manning Formation is expected to be laterally and vertically heterogeneous, detailed site-specific subsurface information on this unit is required to better constrain its lithologic and hydrologic characteristics prior to the final selection of an alternate site location.

(4) Maps reviewed at the Railroad Commission indicate that there are numerous abandoned oil exploration wells in the region. Any abandoned wells located on an area that is selected for an alternate site location should be inspected and evaluated as potential pathways for contaminated water to reach underlying aquifers.

ACKNOWLEDGMENTS

Research for this report was funded by the U.S. Department of Energy under Contract Number DE-FC04-87AL20532.

We thank Jay Raney and Patricia Dickerson of the Bureau of Economic Geology for their reviews of the manuscript. Tucker F. Hentz was the technical editor and Amanda R. Masterson was the production editor. Word processing was by Melissa Snell. Jamie H. Coggin assembled the report.

REFERENCES

Anders, R. B., 1957, Ground-water geology of Wilson County, Texas: Texas Board of Water Engineers, Bulletin 5710, 63 p.

———— 1960, Ground-water geology of Karnes County, Texas: Texas Board of Water Engineers, Bulletin 6007, 111 p.

Anders, R. B., and Baker, E. T., Jr., 1961, Ground-water geology of Live Oak County, Texas: Texas Board of Water Engineers, Bulletin 6105, 124 p.

Brown, T. E., Brewton, J. L., McGowen, J. H., Proctor, C. V., Aronow, S., and Barnes, V. E., 1975, Beeville-Bay City Sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

Brown, T. E., Waechter, N. B., Owens, F., Howeth, I., and Barnes, V. E., 1976, Crystal City-Eagle Pass Sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

Brown, T. E., Waechter, N. B., Rose, P. R., and Barnes, V. E., 1974, San Antonio Sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

Bryson, H. C., 1987, Ground-water contamination at the Falls City, Texas, Uranium Mill Tailings site: University of Virginia, Master's thesis, 131 p.

Camp, Dresser and McKee, Inc., 1981, Environmental report, Texaco, Inc., and Sunoco Energy Development Co. Hobson Tex-1 In-Situ Uranium Project, 209 p.

Folk, R. F., Hayes, M. O., Brown, T. E., Eargle, D. H., Weeks, A. D., Barnes, V. E., and Clabaugh, S. E., 1961, Field excursion, Central Texas, bentonites, uranium-bearing rocks, vermiculites: University of Texas, Austin, Bureau of Economic Geology Guidebook 3, 53 p.

Gustavson, T. C., 1975, Microrelief (gilgai) structures on expansive clays of the Texas Coastal Plain—their recognition and significance in engineering construction: The University of Texas at Austin, Bureau of Economic Geology Geological Circular 75-7, 18 p.

Mielenz, R. C., and King, M. E., 1955, Physical-chemical properties and engineering performance of clays, *in* Pask, J. A., and Turner, M. D., eds., Clays and clay technology: California Division of Mines Bulletin 169, p. 196–254.

Proctor, C. V., Jr., Brown, T. E., Waechter, N. B., Aronow, S., Pieper, M. K., and Barnes, V. E., 1975, Seguin Sheet: The University of Texas at Austin, Bureau of Economic Geology Geologic Atlas of Texas, scale 1:250,000.

Wermund, E. G., and Gustavson, T. C., 1975, The Guadalupe-Lavaca-San Antonio-Nueces River Basins Regional Study, Crystal City East Sheet, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file maps.

———— 1975, The Guadalupe-Lavaca-San Antonio-Nueces River Basins Regional Study, Beeville West Sheets, Texas: The University of Texas at Austin, Bureau of Economic Geology, open-file maps.

———— 1985a, The Guadalupe-Lavaca-San Antonio-Nueces River Basins Regional Study—San Antonio East Sheets: The University of Texas at Austin, Bureau of Economic Geology, 5 plates, scale 1:250,000.

———— 1985b, The Guadalupe-Lavaca-San Antonio-Nueces River Basins Regional Study—Seguin West Sheets: The University of Texas at Austin, Bureau of Economic Geology, 5 plates, scale 1:250,000.

APPENDIX: FORMATION DESCRIPTIONS

INTRODUCTION

General stratigraphic and hydrologic information on the Tertiary units within the 50-mi search radius is taken primarily from Anders (1957, 1960) and from Anders and Baker (1961). Stratigraphic descriptions of the Jackson Group and the Whitsett Formation in particular were compiled, in large part, from Camp, Dresser and McKee (1981) and from Brown and others (1976).

PALEOCENE SERIES

MIDWAY GROUP: The units of the Midway Group are the oldest Tertiary rocks in south-central Texas. This group is not exposed in Wilson or Karnes Counties but does crop out farther west in Bexar County near the edge of the 50-mi search radius. The Midway Group lies unconformably upon rocks of Late Cretaceous age and it consists primarily of clay and silt in the subsurface of both Wilson and Karnes Counties. This formation does not contain fresh water in either Wilson or Karnes Counties (Anders, 1957, 1960).

EOCENE SERIES

WILCOX GROUP: The Wilcox Group unconformably overlies the Midway Group and crops out in Bexar County and the northwestern edge of Wilson County. The sandy nature of this group, its potential (although limited) as a water source in the outcrop area, and the distance of the outcrop from the current tailings site significantly reduce its favorability as an alternate tailings disposal site.

In Wilson County the Wilcox Group is composed primarily of medium- to fine-grained sand and clay. At or near its outcrop area in Wilson County, this unit yields variable amounts of water of poor to good quality. Downdip from the outcrop area the water quality is probably sufficient only for agricultural purposes.

In Karnes County the top of the Wilcox can be found at a depth of 3,300 ft or greater and it is approximately 2,200 ft thick. Anders (1960) gives a relatively detailed description of this formation in Karnes County; he states that it consists of thinly bedded silt, clay, fine- to medium-grained sandstone, sandy shale and clay with thin beds of lignite. Water analyses from one well and electric log interpretations from other wells suggest that the water in the Wilcox of Karnes County is moderately to very saline (Anders, 1960).

CLAIBORNE GROUP: This group is composed of an alternating series of marine and non-marine sediments that range in composition from relatively clean sands to a thick, nearly homogeneous clay unit. The individual formations in this group are described below.

(1) Carrizo Sand: The Carrizo Sand unconformably overlies the Wilcox Group and crops out in a 2.0–2.5 mi wide northeast-trending belt in the northern and northwestern parts of Wilson County. The Carrizo is approximately 1,000 ft thick at the Wilson/Karnes county line. It is composed primarily of medium- to fine-grained sand, silt and clay. The clay content of this unit increases downdip. It is the deepest fresh-water aquifer in Texas and is a major source of water in this region. It is, therefore, a very poor candidate for containing an alternate tailings containment site.

(2) Mount Selman Formation: This formation is subdivided into three members. Each member is described below in ascending stratigraphic order.

(A) The Reklaw Member conformably overlies the Carrizo Sand and crops out within the 50-mi search radius in Wilson, Bexar, and Atascosa Counties. According to Anders (1960), this unit consists largely of up to 400 ft of marine clay and shale in the subsurface of Karnes County. Anders (1957) notes, however, that the unit is thinner and locally much sandier in outcrop and in the shallow subsurface. This unit is not an aquifer in Karnes County, but it yields small amounts of poor-quality, highly mineralized water near the outcrop in Wilson County. Because of the stratigraphic proximity of this unit (immediately over the Carrizo Sand, a major fresh-water aquifer) and its locally sandy nature at the outcrop, this unit is considered to be less attractive as an alternate tailings site than several other units within the search region.

(B) The Queen City Sand Member conformably overlies the Reklaw Member and crops out (west of Karnes County) in Wilson, Bexar, and Atascosa Counties. In Wilson County this unit consists of medium- to fine-grained sand interbedded with shale. The Queen City yields moderate amounts of water that varies in quality from good to poor in Wilson County; it does not contain potable water in Karnes County.

(C) The Weches Greensand is the youngest member of the Mount Selman Formation. It is in conformable contact with the Queen City Member and it crops out in central Wilson County where it is composed of approximately 100 ft of fossiliferous, glauconitic sand and shale. According to Anders (1957, 1960) this unit increases in thickness and clay content downdip and is of no importance as an aquifer in either Wilson or Karnes County. Because of its sandy nature and proximity to freshwater-bearing strata this member is a marginal candidate for an alternative tailings site.

(3) Sparta Sand: This unit conformably overlies the Mount Selman Formation. It consists primarily of fine sand and clay. Near the outcrop area this unit produces moderate amounts of water of fair to good quality. The water becomes highly mineralized downdip, and according to Anders (1960) this unit contains no fresh or slightly saline water in Karnes County.

(4) Cook Mountain Formation: This formation is in unconformable contact with the Sparta Sand. It is found at a depth of approximately 400 ft in the subsurface along the Wilson/Karnes county line. It is about 400 to 450 ft thick and consists mainly of fossiliferous marine clay and shale with a few lenses of sandstone and limestone. It also contains small amounts of glauconite and gypsum. Small amounts of highly mineralized water are produced from this formation near the outcrop in Wilson County.

This unit is not an aquifer in Karnes County. Because of its thickness and low permeability, the outcrop of this unit may contain suitable alternate sites for disposal of the uranium mill tailings.

(5) Yegua Formation: The youngest member of the Claiborne Group, the Yegua unconformably overlies the Cook Mountain Formation. This unit crops out just north of the Wilson/Karnes county line. It comprises mostly medium- to fine-grained sand, silt and clay with lesser gypsum and lignite. This unit yields small to moderate amounts of fresh to moderately saline water near the oucrop area and is a locally important (although poor-quality) aquifer. This highly permeable freshwater-bearing unit is unsuitable for tailings containment.

JACKSON GROUP: The Jackson Group is of particular interest because the Falls City tailings are underlain by the Whitsett Formation, the youngest of the four formations in this group. Anders (1957, 1960) did not supply hydrologic information on the individual Jackson formations, but he noted that the lower part of the Jackson Group produces small quantities of slightly to moderately saline water from depths of less than 1,000 ft and that the upper part of the Jackson produces small to moderate quantities of fresh to slightly saline water. According to Anders (1960), wells to the upper Jackson Group may include one Karnes City municipal well. As noted in the introduction, the following descriptions of the members of the Jackson Group and of the Whitsett Formation were compiled primarily from Camp, Dresser and McKee (1981) and from Brown and others (1976).

(1) Caddell Formation: The Caddell Formation conformably overlies the Yegua Formation and it outcrops subparallel to the northern border of Karnes County. The exposed area ranges from 0.2 to 1.6 mi wide and is approximately 19 mi long. This unit ranges from 50 to 100 ft thick at the outcrop and is composed mainly of clay with a few poorly sorted, glauconitic sandstone and siltstone stringers. The clay is typically bentonitic and fossiliferous, and in some locations it contains lignite.

(2) Wellborn Formation: A 20-mi-long strip of this unit with a maximum width of about 1.1 mi crops out in northern Karnes County. It has an average thickness of approximately

150 ft, and it conformably overlies the Caddell Formation. The unit consists primarily of fine- to medium-grained sandstones and interstratified clay units. This unit is probably too sandy and too thin to be a primary candidate for a tailings disposal site.

(3) Manning Formation: This formation is in conformable contact with the Wellborn Formation. It varies between 250 and 350 ft in thickness, and the outcrop is as much as 3.5 mi wide. The Manning Formation is composed primarily of tuffaceous, carbonaceous to lignitic shale and lesser interbedded sandstone (Brown and others, 1976). The thickness of this predominantly shale sequence, its high cation exchange capacity, its strongly reducing nature (evidenced by its abundant organic carbon content), and its proximity to the Falls City site make this unit a potential candidate for an alternative site location.

(4) Whitsett Formation: The Whitsett Formation crops out as a 37-mi-long and approximately 2-mi-wide belt in northern Karnes County. There are six members of this formation, as will be described.

(A) The Dilworth Sandstone Member is an aquifer in Karnes County. It is composed primarily of barrier bar and strandplain sediments.

(B) The Conquista Clay Member is an aquitard that separates the Dilworth from the overlying Deweesville Sandstone members. This unit was deposited in a lagoonal environment and consists of about 50 to 90 ft of interstratified clay and sand. The sandy horizon in this unit at the Falls City site pinches out rapidly downdip. The clay units typically contain bentonite and lignite. The upper few feet of this member are oxidized at the Falls City tailings site and contain uranium mineralization.

(C) The Deweesville Sandstone Member (locally known as the Stones Switch sand) overlies the Conquista Clay unit and is the primary ore-bearing unit at the Falls City tailings site. At the tailings site this unit consists of two sandy layers that are separated by approximately 5 ft of highly carbonaceous laminated siltstone (Folk and others, 1961). The sandstones are silty, medium- to fine-grained, friable, tuffaceous and interstratified with bentonitic clay stringers.

(D) The Dubose Member was formed in a delta-plain environment and is composed of clay siltstone and sandstone. The clays are bentonitic and the sandstones and siltstones are tuffaceous and locally carbonaceous. This member is approximately 120 ft thick at the Falls City site.

(E) The Tordilla Sandstone Member is a barrier-bar sequence and consists of about 30 ft of medium- to fine-grained sand with interstratified clay.

(F) The Fashing Clay Member is the youngest strata of Eocene age in Karnes County. It was deposited as lagoonal muds behind the prograding barrier bars of the Whitsett Formation. Locally the Fashing Clay may consist of up to 120 ft of silty clay.

OLIGOCENE SERIES

Frio Clay Formation: This unit is in unconformable contact with the underlying Jackson Group and it is composed largely of clay, sand, and sandy silt. The clay is bentonitic and slightly calcareous and contains small amounts of gypsum. This unit does not crop out in Karnes County as it wedges out beneath the overlying Catahoula Tuff. In the subsurface the Frio Clay ranges up to 200 ft in thickness and thickens to the southeast. In adjacent Live Oak County, the Frio occurs as a unit that is distinct from the Catahoula. It crops out about 8 mi southwest of the Karnes County line. The Frio Clay is not a source of potable water in either Karnes or Live Oak Counties. In Live Oak County where this unit crops out the Frio Clay may be a suitable host for an alternate tailings disposal site.

MIOCENE SERIES

Catahoula Tuff: The Catahoula crops out as a linear belt up to 10 mi wide that strikes northeast across Karnes County. The northwest edge of this unit is exposed approximately 3 to 5 mi southeast of the Falls City tailings site. The Catahoula consists primarily of tuff, tuffaceous clay, sandy clay, bentonitic clay and discontinuous lenses of sandstone. This unit is a poor-quality aquifer and is typically used for watering stock in Live Oak County. It is, however, the only shallow source of water in its area of outcrop in Karnes County (Anders, 1960). The areas that depend on the Catahoula for water include Karnes City and parts of Kenedy. This unit may contain possible tailings storage sites but its importance as an aquifer in some areas of Karnes County is problematic.

Oakville Sandstone: This nearly uniform sand unit contains a few clay lenses and is extensively exposed in Karnes County. This formation ranges up to 800 ft in thickness and is a major fresh-water aquifer in this region. A highly permeable, potable-water-bearing unit such as the Oakville Sandstone is an unsuitable host for an alternate tailings disposal site.

Fleming Formation: This unit is largely composed of calcareous clay and interbedded medium- to fine-grained sandstone. The lithologic heterogeneity of this unit and its stratigraphic proximity to the Oakville Formation significantly lower the potential of this unit to serve as a host for an alternate tailings disposal site.