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REPORT OF INVESTIGATION

NO. 187

GEOLOGIC EVALUATION OF FIVE CULINARY WATER FACILITIES AND SETTLEMENT CANYON DAM FOR TOOELE CITY, TOOELE COUNTY, UTAH

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INTRODUCTION

This report presents the results of an investigation of geologic conditions at five culinary water facilities maintained by Tooele City Corporation and at Settlement Canyon Dam and reservoir. The facilities include four concrete water tanks and a well field. The purpose of the investigation was to determine if geologic conditions exist which may adversely effect the city's culinary water system or the dam and reservoir. The investigation included a review of available geologic literature, air photo analysis, a helicopter reconnaissance of Middle and Settlement Canyons, and 5 days of field inspection and geologic mapping. Coordination with Tooele City was through Mr. Joe D. England, Tooele City Engineer. The Utah Division of Water Rights Office of Dam Safety reviewed the sections of the report dealing with Settlement Canyon Dam.

SETTING AND PHYSIOGRAPHY

Tooele City is located in Tooele Valley on the west side of the Oquirrh Mountains (fig. 1). The Oquirrhs are a north-south trending mountain range typical of the northern Basin and Range physiographic province. Elevations in the range near Tooele reach 9000 feet above sea level, and two major drainages, Middle and Settlement Canyons, meet the valley less than a mile from the city limits. Middle Canyon has a drainage area of about 11 square miles and is characterized by steep slopes and exposed bedrock. Slopes in Settlement Canyon are slightly less steep and are covered by colluvium of varying thickness. The Settlement Canyon drainage basin is approximately 18 square miles.

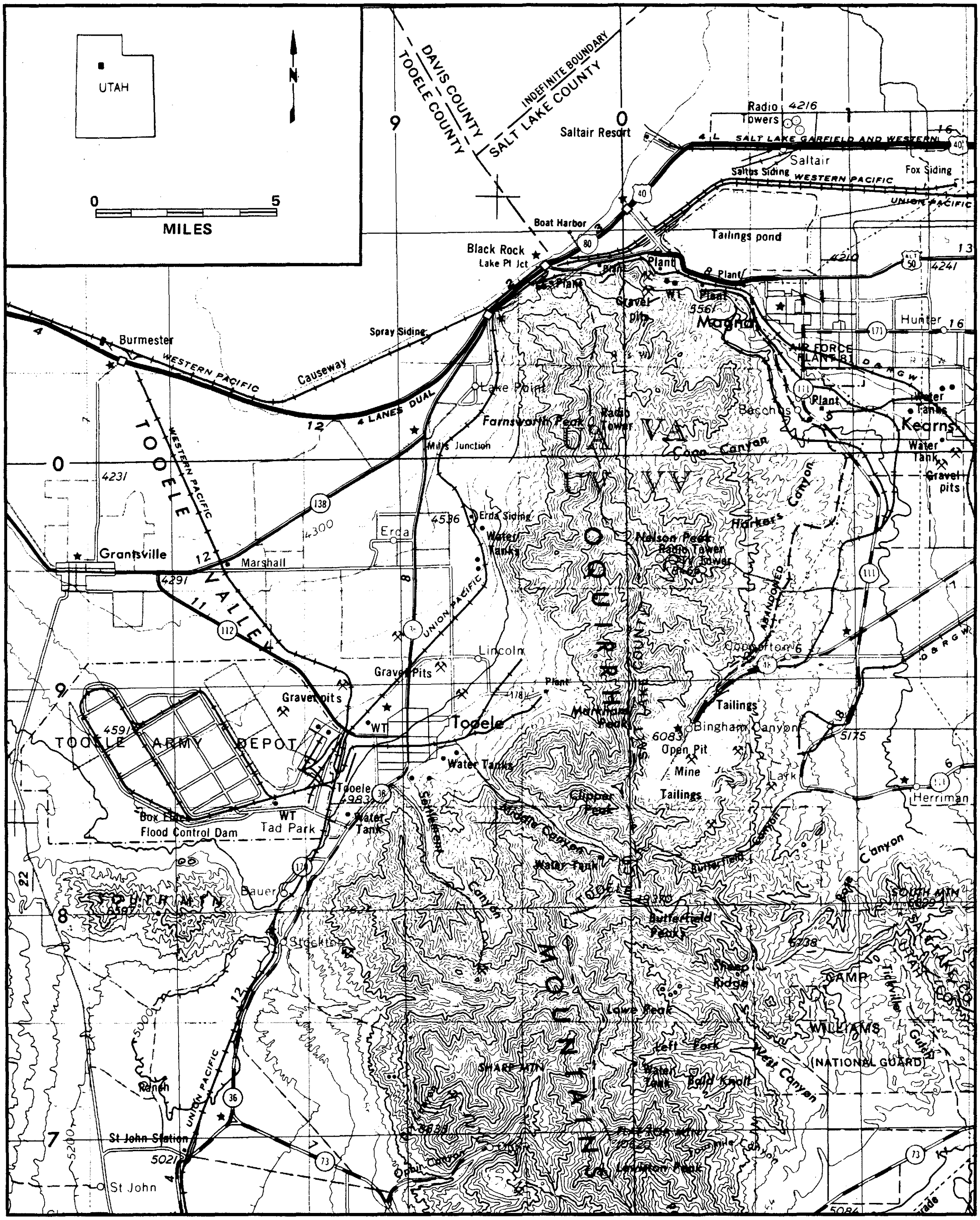


Figure 1. Location map.

Tooele City lies on a gently sloping alluvial surface at the base of the Oquirrh Mountains (fig. 2). Originally created by coalescing alluvial fans, the surface has been modified below an elevation of about 5200 feet by Lake Bonneville deposition and erosion. The Bonneville shoreline forms a clearly defined break-in-slope along the south side of town. Above the shoreline to the northeast is a remnant of the pre-lake alluvial surface (hereafter referred to in this report as the Tooele surface). Foothills of the Oquirrh Mountains lie above the shoreline to the southwest. The channel of Middle Canyon Creek is incised into the Tooele surface from the canyon mouth to the Bonneville shoreline. Settlement Canyon Creek remains in the foothills until it reaches Tooele Valley and then flows through the southeast corner of Tooele City.

The five culinary water facilities and Settlement Canyon Dam are south of Tooele City, either at or above the Bonneville shoreline (fig. 2). Water tank 1 (number designations established by Tooele City) is located at the Bonneville shoreline just south of its intersection with Middle Canyon Creek. Water tank 3 is above the shoreline on an alluvial terrace at the mouth of Settlement Canyon, and water tanks 4 and 5 are in the Oquirrh foothills. The well field is in the flood plain of Middle Canyon Creek at Angels Grove about 1/4 mile below the canyon mouth. Settlement Canyon Dam is approximately 1/2 mile above the mouth of Settlement Canyon.

GEOLOGY

The geology of the Oquirrh Mountains is lithologically and structurally complex. The range consists of a thick sequence of Paleozoic (see appendix for geologic-time scale) sedimentary strata that have been intruded by Tertiary igneous rocks. The Pennsylvanian- and Permian-age Oquirrh Group is

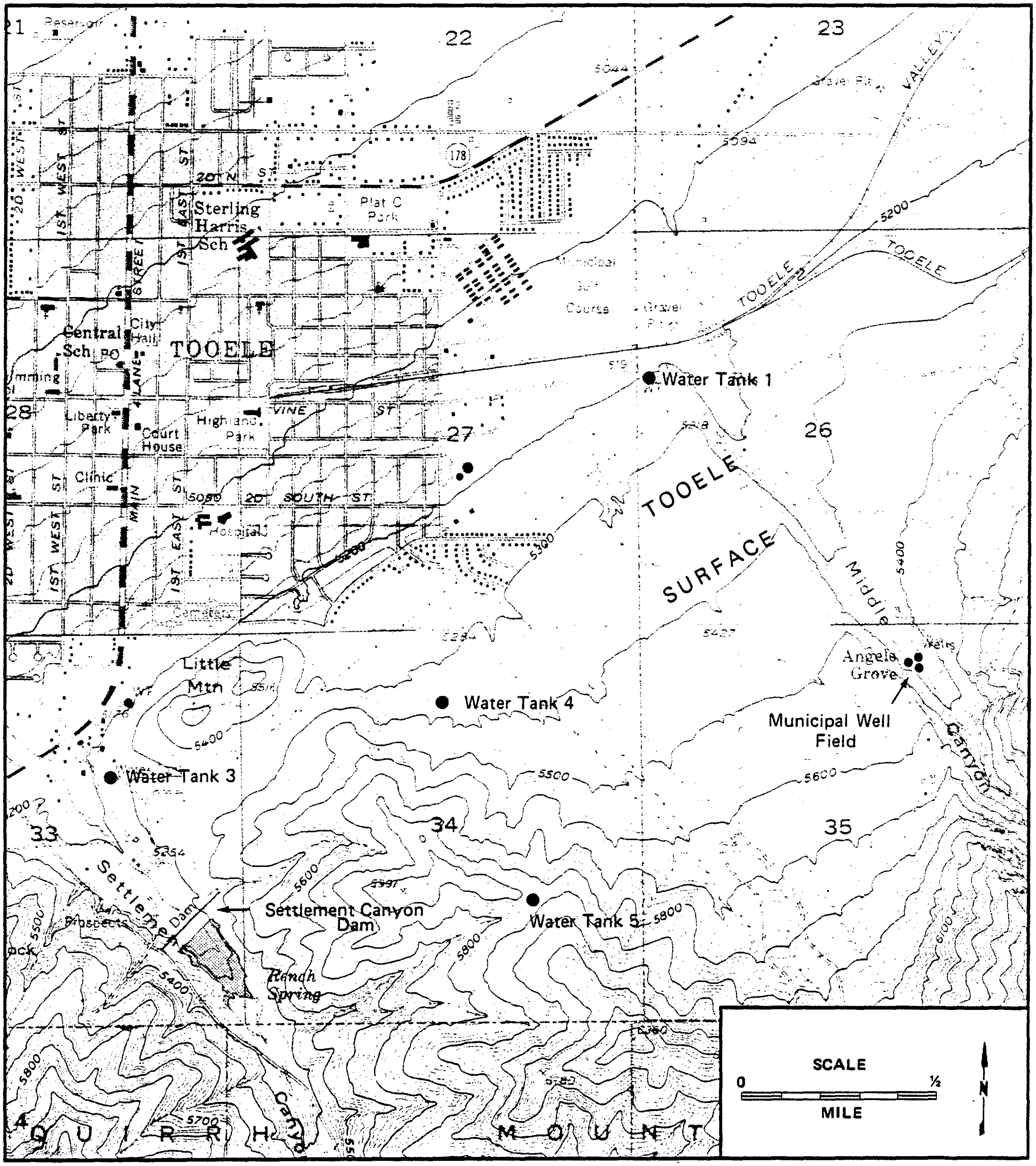


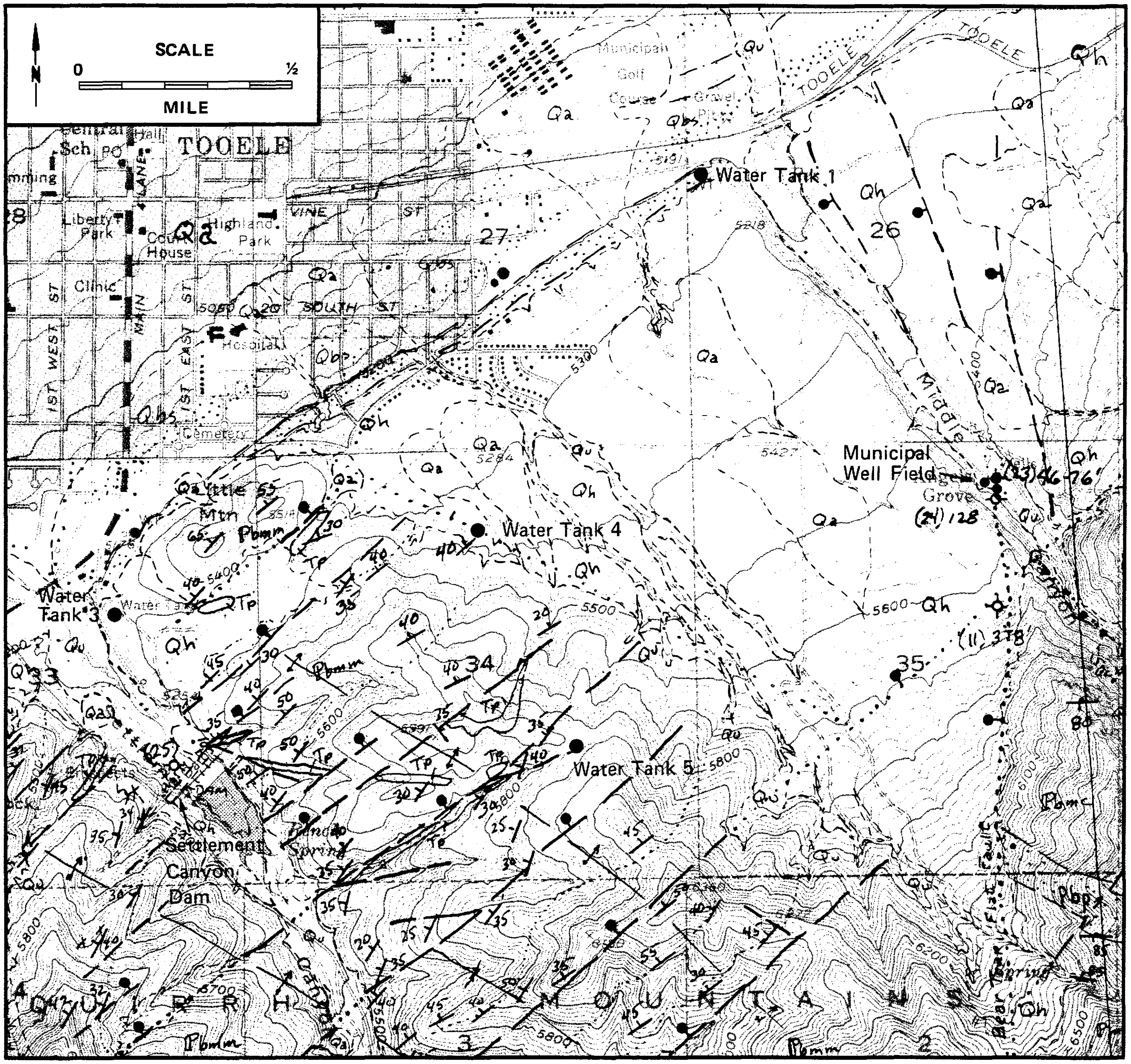
Figure 2. Vicinity map showing location of culinary water facilities and Settlement Canyon Dam.

more than 16,000 feet thick and comprises the greater part of the rocks in the northern Oquirrh Mountains (Gates, 1963). Structurally the Oquirrh Mountains near Tooele have been faulted and folded into a series of anticlines that plunge to the northwest. The folds are probably of Late Cretaceous and early Tertiary age, and are truncated by late Tertiary normal faults (Gates, 1963).

Tooker (1980) subdivided the Oquirrh Group in the Tooele 7-1/2 minute quadrangle into formations and members. Bedrock in the vicinity of the culinary water facilities and the dam (fig. 3) is assigned chiefly to the Markham Peak Member of the Bingham Mine Formation and consists of interbedded orthoquartzite, calcareous quartzite, sandstone, siltstone, and limestone. Orthoquartzite, calcareous quartzite, and quartzose sandstone of the Clipper Ridge Member of the Bingham Canyon Formation and calcareous quartzite, sandstone, and limestone of the Butterfield Peaks Formation crop out south of Middle Canyon. Numerous small Tertiary (Oligocene) igneous dikes and sills occur within the Markham Peak Member of the Bingham Canyon Formation. They are mainly gray quartz monzonite to quartz latite porphyries, and are generally highly weathered and poorly exposed (Tooker, 1980).

The Harkers Alluvium of Pleistocene age (Tooker and Roberts, 1971) underlies the Tooele surface and is exposed in a limited area south and west of Little Mountain (fig. 3). A narrow band also extends along the south side of Settlement Canyon from its mouth to a point opposite Rench Spring. The formation consists of unconsolidated, poorly sorted, fanglomerate deposits ranging in size from boulders to silt and clay. Total thickness of the formation is unknown, but at least 250 feet are exposed in the bluffs at the mouth of Middle Canyon (Tooker, 1980).

A thin layer of unconsolidated silt, sand, and gravel deposited in Pleistocene Lake Bonneville mantles Tooele Valley below the Bonneville



EXPLANATION

Qa Alluvium (Holocene) - post Lake Bonneville

Qu Alluvium (Holocene) - undifferentiated

Qc Colluvium (Holocene) - talus, gravel & boulder deposits

Qbs Lake Bonneville Deposits (Pleistocene) — stipple pattern indicates coarse beach gravel

Qh Harkers Alluvium (Pleistocene)

Tp Igneous intrusive dikes and sills (Tertiary)

Pbmm Bingham Mine Formation, Markham Peak Member (upper Pennsylvanian)

Pbmc Bingham Mine Formation, Clipper Ridge Member (upper Pennsylvanian)

Pbp Butterfield Peaks Formation (middle Pennsylvanian)

40 Strike and Dip of Beds

Contact
Dashed where approximately located

Fault
Dashed where approximately located, dotted where concealed. Bar and ball on down thrown block.

Anticline

Syncline

Figure 3. Geologic map (after Tooker, 1980).

shoreline. Coarser deposits are found along former shorelines, and fine material in lake bottom areas. Holocene alluvium and colluvium are found throughout the study area. Most occurs as talus on mountain slopes; clay, silt, sand, and gravel in stream channels; and post-lake alluvial fans. These deposits are unconsolidated, poorly to well sorted, and generally thin.

Faults in the study area can be classified into two general groups based on relative age. The first group includes high-angle normal faults in bedrock that strike northeast and have small displacements down to the west. They are probably pre-basin-and-range in age and are not active (see glossary). Faults of this type mapped by Tooker (1980) (fig. 3) were difficult to identify in the field. The second group of faults are generally north-trending, high-angle, normal faults down-dropped to the west. Longer, younger, and of greater displacement than those in the first group, they are range-bounding faults associated with basin-and-range block faulting. Appearing as strongly expressed lineaments on air photos, these faults are late Tertiary to Quaternary in age and offset unconsolidated basin-fill deposits at the mountain front (Bucknam, 1977; Anderson and Miller, 1979; Everitt and Kaliser, 1979). The most prominent of these in the study area parallels the Oquirrh Mountains from Pine Canyon to about a mile south of Middle Canyon (fig. 4). Everitt and Kaliser (1979) designated this fault the Oquirrh marginal fault, and Anderson and Miller (1979) classify it as probable late Pleistocene age, showing evidence of movement during the last 10,000 to 500,000 years. Fault scarp morphology observed in the field is consistent with pre-Holocene movement, and on that basis the Oquirrh marginal fault is considered to be potentially active (see glossary). Three other lineaments mapped as possible Quaternary faults by Tooker (1980) trend across the Tooele surface north of and roughly parallel to Middle Canyon Creek. Other workers (Bucknam, 1977;

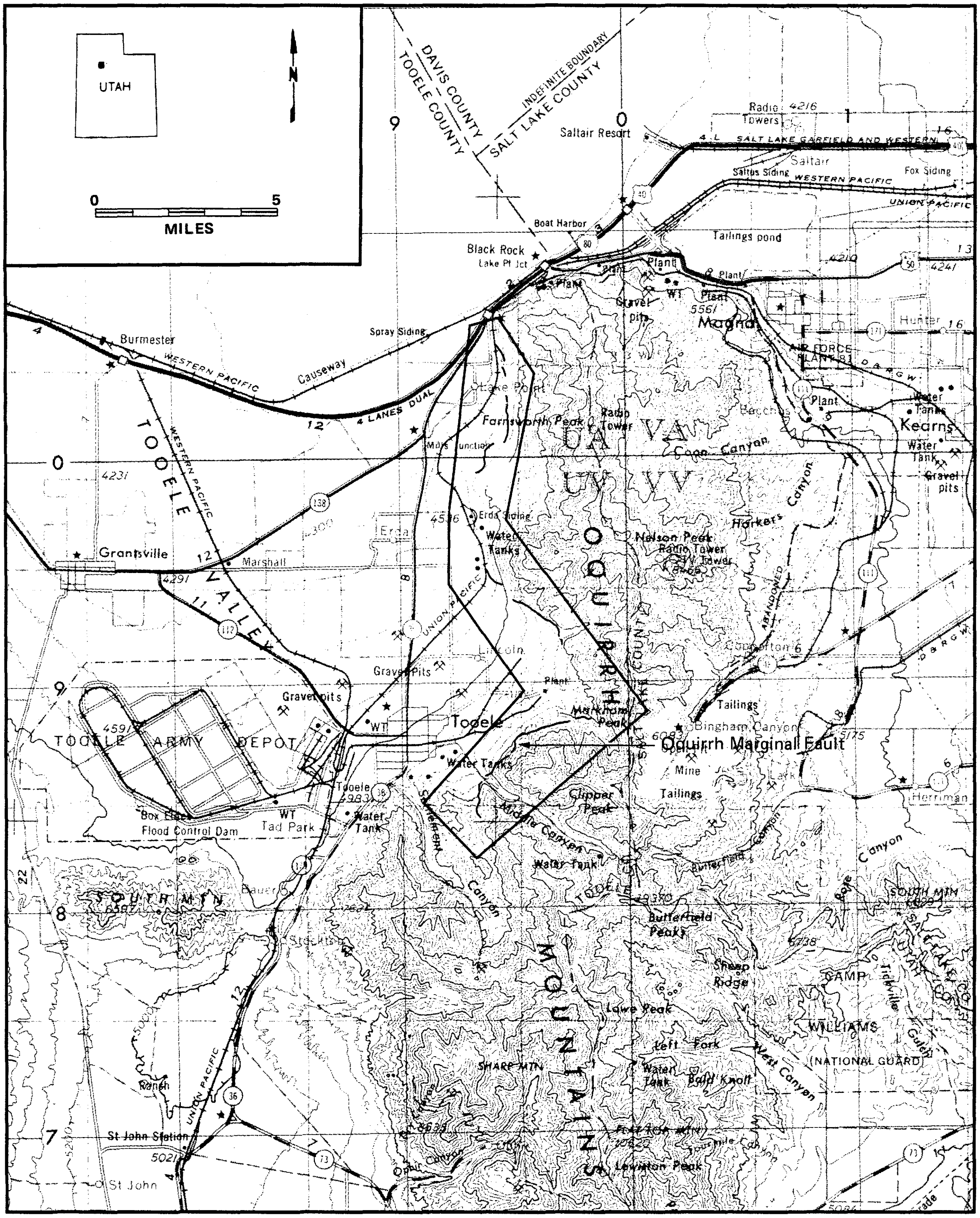


Figure 4. Map of suspected fault scarps in unconsolidated deposits near Tooele, Utah (after Bucknam, 1977).

Davis, 1978; Anderson and Miller, 1979; Everitt and Kaliser, 1979) either did not consider these lineaments to be faults and did not map them as such, or noted their presence and indicated an erosional or otherwise undetermined origin. It was concluded during this study that they are most likely stream terraces cut by ancestral Middle Canyon Creek.

Two small anticlines have been mapped in the Paleozoic rocks of the study area (Tooker, 1980). One lies just north and the other just south of Settlement Canyon (fig. 3). Both are subtly expressed and difficult to recognize in the field.

SITE EVALUATIONS

Water Tank 1

Facility: Concrete water tank, 500,000 gallon capacity, constructed 1930's or early 1940's, numerous cracks in the tank walls (none leaking).

Location: NW1/4 SW1/4 NW1/4 sec. 26, T. 3 S., R. 4 W., SLB&M.

Site Description: Water tank 1 is at the base of the break-in-slope that forms the Bonneville shoreline (fig. 2). The slope east of the water tank is short and steep, and leads up to the nearly flat Tooele surface. Slopes west of the tank grade gently toward the valley floor. The incised channel of Middle Canyon Creek is about 200 feet northeast and 50 to 75 feet lower than the water tank.

Geology: Water tank 1 is at the contact between coarse-grained Lake Bonneville shoreline deposits and the Harkers Alluvium (fig. 3). The lake deposits are thin and not well exposed at the site. They consist of fine- to medium-grained silty sand over sandy gravel. Locally the gravel exhibits early stage I caliche development. Harkers Alluvium is exposed in the slope east of the water tank. It is chiefly a poorly sorted sandy gravel to sandy clayey gravel containing numerous cobbles and boulders. The formation is unconsolidated, but generally dense and locally cemented by stage II caliche.

The nearest known fault of Quaternary age is approximately 6000 feet east at the mouth of Middle Canyon (fig. 4). The closest of the three lineaments north of Middle Canyon Creek (probable stream terraces) mapped as faults by Tooker (1980) is 1200 feet from the site.

Soil: USDA Soil Conservation Service mapping (unpublished) places the water tank on the contact between the Bingham gravelly sandy loam (Lake Bonneville deposit corollary) and the Yeates Hollow gravelly loam (Harkers Alluvium corollary). The Bingham gravelly sandy loam is chiefly clean gravel, silty sand and gravel, and clayey sand and gravel. It exhibits low plasticity, moderately rapid to rapid permeability, and low to moderate erodibility. The Yeates Hollow gravelly loam consists of gravelly clay and silt, and clayey gravel with cobbles and boulders. Plasticity is low to moderate; permeability is slow to moderate; and erodibility is low. Depth to bedrock is greater than 50 feet and may be several hundred feet.

Ground Water: The permanent water table in the vicinity of water tank 1 is controlled by the water level in Middle Canyon Creek. Depth to water is 50 feet or more. Perched water-table conditions may develop locally in the Harkers Alluvium when fields on the Tooele surface are irrigated. Examination of the slopes east of the water tank showed no evidence of ground-water seeps or seasonal springs.

Hazards: Minor rill erosion related to local runoff is occurring on the slope east of the water tank. Minor sloughing of the Harkers Alluvium was observed in cuts for a water tank service road. A potentially active fault lies approximately 6000 feet east of the site.

Summary: Water tank 1 has functioned satisfactorily at this site for more than 40 years and serious site-related problems are not anticipated in the future. It is recommended that the dirt road at the top of the slope east of the water tank be regraded to divert runoff and prevent further erosion of the slope. Maintenance of the water tank service road should avoid additional steepening of road cuts. If sloughing continues or becomes worse, a retaining wall (railroad tie or rock gabion construction) may be required to control the problem.

In the event of a major earthquake with its epicenter in Tooele Valley or in adjacent areas such as Salt Lake Valley, water tank 1 will experience ground shaking. The intensity and duration of shaking will depend on the magnitude and location of the earthquake. The potential for ground rupture (surface faulting) or ground failure (landslides, liquefaction) is low, but the age of the structure and the lack of earthquake resistant design indicate that damage from ground shaking may occur.

Water Tank 3

Facility: Concrete water tank, 2 million gallon capacity, approximately 40 years old.

Location: NE1/4 SW1/4 NE1/4 sec. 33, T. 3 S., R. 4 W., SLB&M.

Site Description: Water tank 3 is on a gently northwest sloping alluvial terrace at the mouth (north side) of Settlement Canyon (fig. 2).

Settlement Canyon Creek and its tributaries have incised their channels more than 60 feet below the terrace surface, producing steep slopes that border the site to the north, south, and west. In places, the water tank is only 25 feet from the edge of the slope.

Geology: The terrace is cut in the Harkers Alluvium, and consists of unconsolidated, medium dense, poorly sorted, sandy gravel and gravelly sand with numerous cobbles and boulders. Stage I to II caliche cementation occurs locally. The Bonneville shoreline truncates the terrace on the northwest, bringing coarse-grained lake deposits in contact with the Harkers Alluvium (fig. 3). The Markham Peak Member of the Bingham Mine Formation crops out in Little Mountain northeast of the site and in the Oquirrh foothills to the southeast. Tooker (1980) mapped northeast striking pre-basin-and-range faults on both sides of the small valley that separates Little Mountain from the remainder of the foothills. Igneous dikes and sills have been intruded along the fault bordering Little Mountain. The closest known Quaternary fault is 2-1/4 miles east of the water tank along the main mountain front (fig. 4).

Soil: USDA Soil Conservation Service mapping (unpublished) identifies site soils as the Yeates Hollow gravelly loam, consisting of gravelly clay and silt and clayey gravel with cobbles and boulders. Plasticity is low to moderate; permeability is medium to high; and erodibility is moderate to high. Depth to bedrock is greater than 60 feet.

Ground Water: Ground water in the vicinity of water tank 3 is controlled by the level of water in Settlement Canyon Creek. Depth to water is 60 feet or more. No evidence of springs or seeps was found in the site vicinity.

Hazards: Gully erosion has started at several points on the sides of the terrace. Source of the water is reported to be leaks from waterlines serving water tank 3 (J. England, oral commun., 1984). The Harkers Alluvium at this location is loose to medium dense and easily eroded. Once initiated, gullying may proceed rapidly and be difficult to control. Because of the water tank's proximity to the edge of the terrace, gully erosion left unchecked for even a few hours could endanger the structure's foundation. A potentially active fault lies 2-1/4 miles to the east.

Summary: Gully erosion resulting from leaks in the water tank or associated waterlines is the most serious site-specific geologic hazard at water tank 3. Construction of a berm between the water tank and the top of the terrace slope is recommended to prevent future leaks from running over the edge and causing additional erosion. The severity of the erosion hazard at the site warrants an increased maintenance schedule for both the water tank and waterlines to detect and prevent leaks.

In the event of a major earthquake with its epicenter in Tooele Valley or in adjacent areas such as Salt Lake Valley, water tank 3 will experience ground shaking. Ground rupture is unlikely, but failure of the steep terrace slopes is possible, particularly if saturated by water leaking from the water tank or waterlines. The age of the structure and lack of seismic resistant design indicate that damage to the facility from ground shaking is possible.

Water Tank 4

Facility: Concrete water tank, 2 million gallon capacity, approximately 25 years old.

Location: SW1/4 NW1/4 NE1/4 sec. 34, T. 3 S., R. 4 W., SLB&M.

Site Description: Water tank 4 is at the base of the Oquirrh foothills (fig. 2). Slopes at the site are moderate, but steepen abruptly to the south. The water tank occupies a low promontory between two small drainages containing ephemeral streams. Vegetation on the mountain slopes above the tank is sparse, consisting primarily of grass and low shrubs.

Geology: The promontory is underlain by the Markham Peak Member of the Bingham Mine Formation (fig. 3). Depth to bedrock is shallow and quartzite crops out near the water tank and on the hillsides to the south. The bedrock strikes northeast and dips 30 to 40 degrees to the northwest. Thin limestone interbeds were observed at several locations on the hillsides above the water tank. Tooker (1980) mapped northeast striking pre-basin-and-range faults 1000 feet northwest and 1500 feet southeast of the site. Both were difficult to identify in the field, and showed no evidence of geologically recent movement. He also mapped a northwest trending concealed fault of undetermined age (likely pre-basin-and-range) along the northwest side of the Oquirrh foothills. Although the mapped location of this inferred fault is within a few hundred feet of the water tank, no surface evidence of faulting other than a topographic break between the foothills and the Tooele surface could be found. The nearest known Quaternary fault is 1-1/2 miles east at the main mountain front (fig. 4).

Soil: USDA Soil Conservation Service mapping (unpublished) identifies site soils as the Yeates Hollow gravelly loam. Soil cover is thin (10 inches or less) and consists of silty and/or clayey sandy gravel with abundant cobbles. Plasticity is low to moderate; permeability is moderate; and erodibility is low.

Ground Water: Depth to ground water in the Bingham Mine Formation beneath the site is unknown, but is thought to be greater than 50 feet. No evidence of springs or seeps was found in the site vicinity.

Hazards: The danger to water tank 4 from site-specific geologic hazards is low. A potential for cloudburst or snowmelt flooding exists in the two drainages bordering the site. A potentially active fault is located approximately 1-1/2 miles to the east.

Summary: It is recommended that the stream channels adjacent to the site be periodically inspected and kept free of debris to prevent overbank flooding.

In the event of a major earthquake with its epicenter in Tooele Valley or in adjacent areas such as Salt Lake Valley, water tank 4 will experience ground shaking. The potential for ground rupture and/or ground failure is low. The extent of damage to the facility will depend on the intensity of the shaking and the degree to which earthquake resistant design features were incorporated during construction.

Water Tank 5

Facility: Concrete water tank, 2-1/2 million gallon capacity, constructed mid to late 1970's.

Location: SE1/4 NW1/4 SE1/4 sec. 34, T. 3 S., R. 4 W., SLB&M.

Site Description: Water tank 5 is in a saddle on top of a ridge in the Oquirrh foothills (fig. 2). Slopes increase to the northwest and southeast along the ridge, and drop off abruptly into drainages to the north and southwest.

Geology: The Markham Peak Member of the Bingham Mine Formation underlies water tank 5 (fig. 3). Quartzite and siliceous sandstone bedrock crops out over much of the site striking northeast and diping 35 to 40 degrees to the northwest. Tooker (1980) mapped a northeast striking pre-basin-and-range fault in the drainage southwest of the water tank. The fault bifurcates about 1000 feet east of the site, with one branch passing north and the other south of the water tank. Both branches are well expressed topographically, but show no evidence of geologically recent movement. Igneous sills and dikes have been intruded along the fault. The nearest known Quaternary fault is about 1-1/2 miles east at the main mountain front.

Soil: USDA Soil Conservation Service mapping (unpublished) identifies site soils as the Reywat-Brood rock outcrop association. Soil cover is very thin and consists of coarse sand and gravel with some silt and clay. Water tank 5 can be considered to be a bedrock site.

Ground Water: Depth to ground water in the Bingham Mine Formation beneath the site is unknown, but is thought to be greater than 250 feet. No springs or seeps were found in the site vicinity.

Hazards: Material excavated for the water tank foundation has been placed adjacent to the tank to create a construction laydown area and maintenance vehicle parking lot. Gully erosion has started where the pad intersects the top of the drainage on the north side of the saddle. A potentailly active fault is located approximately 1-1/2 miles to the east (fig. 4).

Summary: It is recommended that the gullies in the edge of the fill pad be backfilled and the pad be regraded to control runoff.

In the event of a major earthquake with its epicenter in Tooele

Valley or in adjacent areas such as Salt Lake Valley, water tank 5 will experience ground shaking. The potential for ground rupture and/or ground failure is low. The extent of damage to the facility will depend on the intensity of the shaking and the degree to which earthquake resistant design features were incorporated during construction.

Municipal Well Field

Facility: Four culinary water wells; associated pumps, transformer, chlorinator, and waterlines.

Location: NE1/4 NW1/4 NE1/4 sec. 35, T. 3 S., R. 4 W., SLB&M.

Site Description: The well field is located along Middle Canyon Creek approximately 1000 feet downstream from the canyon mouth (fig. 2). The creek has incised its channel 180 feet into the Tooele surface creating a narrow (400 foot wide) flood plain bordered by steep bluffs. The main channel of Middle Canyon Creek passes north of the well field and has been diked to protect the wells and the road to Middle Canyon from flooding.

Geology: The alluvial deposits comprising the flood plain are chiefly unconsolidated coarse sand, gravel, cobbles, and boulders. Well logs indicate that the thickness of the flood-plain deposits range from about 60 to 75 feet. Harkers Alluvium crops out in the bluffs on both sides of the flood plain (fig. 3). Although poorly exposed due to heavy vegetation, road cuts show that the Harkers Alluvium in the site vicinity consists of unconsolidated, poorly sorted, silty and clayey sandy gravel with abundant cobbles and boulders. Quartzite and sandstone bedrock of the Bingham Mine Formation crops out at the mouth of Middle Canyon.

Tooker (1980) has mapped two concealed faults between the well field and the canyon mouth. One is a Pleistocene-age range-bounding fault which he extends to the southeast across the Tooele surface, eventually connecting it with a bedrock fault in the Oquirrh foothills (fig. 3). Other workers (Bucknam, 1977; Anderson and Miller, 1979; Everitt and Kaliser, 1979) show a change in strike at the mouth of Middle Canyon and continue the fault (the Oquirrh marginal fault) along the mountain front (fig. 4). A strong lineament showing a deflection to the south is evident on air photos of the area. Tooker (1980) shows the southern portion of the lineament as a separate fault (Bear Trap Flat fault) and extends it northward along strike to the well field (fig. 3). Little evidence was found to support the presence of two faults, and the single range-bounding fault interpretation is preferred for this investigation. The three Quaternary faults mapped by Tooker (1980) north of Middle Canyon Creek all strike toward the well field. However, as previously discussed, they are believed to be old stream terraces and not associated with faulting.

Soil: USDA Soil Conservation Service mapping (unpublished) identifies the flood-plain soil as the Birdow loam which consists chiefly of silt and clay. Field observations showed the soil at the well field to be coarse grained and comprised of sand, gravel, and cobbles. The soil is expected to be nonplastic, highly permeable, and moderately erodible.

Ground Water: Depth to ground water is shallow and directly related to flow in Middle Canyon Creek. During the field investigation (late May and early June), it is estimated that depth to ground water was less than 10 feet.

Hazards: Overbank flooding along Middle Canyon Creek is the principal site-specific hazard to the well field. Snowmelt flooding prior to and during the field investigation necessitated additional diking of stream banks and resulted in damage to the chlorinator facility and Middle Canyon road. Soil creep is active on the bluffs above the well field and small reentrants along the crest of the bluff may indicate old slope failures or gully erosion. The reentrants are all heavily vegetated, and no evidence of recent slope failures or erosion was observed. The well field is approximately 1200 feet from a potentially active fault (fig. 4).

Summary: Flooding will continue to be a serious hazard for the well field. Considering the effect of even a temporary loss of the wells on Tooele City's culinary water system, a permanent bank stabilization project for adjacent and upstream reaches of Middle Canyon Creek is recommended.

The bluff slopes are experiencing active soil creep but do not appear to be in danger of larger slope failures under existing conditions. To insure continued stability, it is recommended that all road building, other grading, and vegetation removal be prohibited on the sides of the bluffs.

In the event of a major earthquake in Tooele Valley or in adjacent areas such as Salt Lake Valley, the well field will experience ground shaking. Ground rupture and ground failure are unlikely, but earthquake related flooding (landslide blocking Middle Canyon Creek followed by break out of the impounded water) is possible. Earthquakes commonly produce temporary and sometimes permanent changes in ground-water levels, but the serviceability of water wells following earthquakes is generally good.

Settlement Canyon Dam

Facility: Zoned earthfill dam; height 105 feet, length 1100 feet (D. Lawrence, oral commun., 1984), reservoir area (spillway crest) 31.5 acres, completed 1966.

Location: E1/2 SE1/4 sec. 33, T. 3 S., R. 4 W., SLB&M.

Site Description: Settlement Canyon Dam is 1/2 mile above the mouth of Settlement Canyon (fig. 2). The canyon bottom is approximately 350 feet wide at the dam and abutment slopes are steep. The size of the reservoir impounded by the dam is small (length 2400 feet) reflecting the moderately steep gradient of the canyon bottom.

Geology: The Markham Peak Member of the Bingham Mine Formation crops out at the right abutment and along the right side of the reservoir (fig. 3). The quartzite and limestone bedrock strikes northeast and dips 40 to 50 degrees to the northwest. Tooker (1980) mapped several northeast striking normal faults in the site vicinity along which numerous igneous dikes and sills have been intruded. Two of the faults and an associated dike are shown converging at the right dam abutment. Field inspection confirmed the presence of the dike, but evidence of faulting was difficult to verify. The left abutment and left side of the reservoir is formed by a stream terrace comprised of Harkers Alluvium (Tooker, 1980). Test pit and bore hole information obtained during site exploration for the dam indicate the terrace consists of 10 feet of dense, poorly graded clayey gravel over a less dense sand and gravel horizon (Lawrence and Sons, 1964). The canyon floor is covered by a layer of silty clay which overlies a sand and gravel horizon. Depth to bedrock beneath the canyon bottom ranges from 10 to greater than 65 feet (D. Lawrence, oral commun., 1984). Bedrock crops out on mountain slopes, and many of the pre-basin-and-range faults mapped by Tooker (1980) north of the dam and reservoir are extended directly to the south (fig. 3). The nearest known fault of Quaternary age is located about 1-3/4 miles northeast of the dam (fig. 4).

Soil: USDA Soil Conservation Service mapping (unpublished) identifies the soil in the canyon bottom as the Birdow loam. Test pits excavated during site exploration for the dam confirm the presence of a low plasticity, low permeability, moderately erodible, clay and silt soil in the flood plain along Settlement Canyon Creek. The right dam abutment and reservoir side are mapped as Reywat-Brood rock outcrop association. Soil cover is very thin and bedrock crops out in many places. The left abutment and reservoir side are shown as Yeates Hollow gravelly loam. Soils there are deep clayey gravels over clean coarse sand and gravel (Lawrence and Sons, 1964).

Ground Water: Ground-water conditions in the vicinity of Settlement Canyon Dam and reservoir are influenced by dam construction and operation. Rench Spring is situated near the center of the reservoir basin and is inundated when the water surface in the reservoir reaches an elevation of 5,310 feet. Prior to the dam, ground water moved freely through the valley-fill alluvium toward Tooele Valley. The DeLamare Tunnel, constructed in the early 1900s to collect water from the alluvium, formerly had its outlet to the creek at the point where the downstream toe of the dam is now located. Construction of an impermeable clay fill in the cutoff trench for the dam interrupted the flow of ground water and redirected that flow around and under the left abutment. The left abutment consists of clayey gravel and is underlain by a deep channel apparently having a V-shape. As the water level in the reservoir increases, there is an increase in head and a resultant greater underflow around the left abutment (D. Lawrence, oral commun., 1984). These increased flows cause a rise in ground-water levels in the valley-fill alluvium downstream from the dam. Conversely, as the level of the reservoir is lowered, a corresponding lowering of the water table is noted in observation wells in the abutment and downstream areas. Spilling from the dam to the stream has generally only minor effect on the ground water. Spilling to the channel from the concrete spillway has only occurred four times in 20 years, i.e., 1969, 1973, 1983, 1984. The duration of spilling in 1969 and 1973 was approximately two weeks. Only in 1983 and 1984 were the spills of sufficient duration (several weeks) to affect ground water through seepage from the stream channel.

Hazards: Flooding represents a major hazard to the dam. Revised calculations of the probable maximum flood possible from Settlement Canyon (determined using U.S. Army Corps of Engineers criteria ER-1110-2-106) indicate a peak discharge of 33,012 cfs and a total runoff volume of 8,265 acre-feet (Utah Division of Water Rights, 1979). The spillway will pass 30 percent of the probable maximum flood without overtopping the dam if the flood occurs when the initial reservoir level is at the spillway crest. Submaximum flooding in May, 1984, caused serious problems with reservoir sedimentation, spillway tailrace erosion, and flooding in portions of Tooele City below the dam.

No evidence of slope stability problems at the dam abutments or around the reservoir was observed during the field reconnaissance. One small slump failure in colluvium over shallow bedrock has occurred on a hillside southeast of the dam. It appears to be due to oversteepening of the slope in a road cut. Numerous slope failures occurred during the spring of 1984 in Settlement Canyon and its tributaries. Many of the failures generated debris flows, and one, originating from Bear Trap Fork, created a debris flood that reached the reservoir. The sediment-laden flood waters of the event achieved a peak flow of approximately 150 cfs, bringing the water level in the reservoir to the spillway elevation of 5,360 feet in a short period of time. The larger rocks and gravel dropped out of the stream at the head of the reservoir and the fine sediment (minus 100 mesh) filled the bottom of the reservoir to a depth of approximately 12 feet, plugging the outlet works for the irrigation system served by the dam. Stream flow continued at record rates for a period of several weeks. The flow over the spillway ranged from approximately 120 cfs at its peak with a gradual decrease to 80 cfs in a few days and then a more gradual decrease down to 60 cfs which continued for about two weeks (D. Lawrence, oral commun., 1984). The spillway discharges continued all summer. The capacity of the Tooele City floodway, approximately 80 cfs, was exceeded shortly after the initial spill and the surplus flow was routed down city streets with sandbags.

A helicopter reconnaissance of Settlement Canyon indicated that numerous detached slide masses remain on the canyon slopes and that additional debris flows/floods are possible in the future.

The nearest known potentially active fault is located approximately

1-3/4 miles northeast of the dam. In the event of an earthquake with its epicenter in Tooele Valley or in adjacent areas such as Salt Lake Valley, Settlement Canyon Dam will experience ground shaking. The potential for ground rupture and ground failure is considered low. The effect of the ground shaking on the dam will depend on the magnitude and location of the earthquake, the intensity and duration of shaking, and details of dam construction and maintenance.

Summary: A design review of Settlement Canyon Dam both with regard to its ability to safely control the probable maximum flood from Settlement Canyon and to withstand earthquake induced stresses is strongly recommended. The dam's location, a short distance upstream from Tooele City, dictates that any inadequacies discovered in these two critical areas should be quickly remedied. Erosion in the spillway tailrace was extensive during 1984. The banks should be stabilized to prevent further erosion, particularly near the dam. Future debris flows/floods and greater erosive power of Settlement Canyon Creek due to loss of vegetation during this year's floods may increase the sediment load delivered to the reservoir. Consideration should be given to a sediment-retention basin upstream from the reservoir. A basin may provide a cost-effective means of dealing with sediment accumulation in the reservoir and prevent plugging of the irrigation system outlet during periods of high flow.

CONCLUSIONS

This investigation found site-specific geologic hazards at each of the five Tooele City culinary water facilities and at Settlement Canyon Dam. In most instances the hazards were either minor or easily remedied. However, two hazards were identified that could cause serious disruption of the city's culinary water system or adversely effect the safety of Settlement Canyon Dam. They are hazards associated with earthquakes and floods. Although no facilities were found to be closer than 1200 feet to a potentially active fault, the entire area is seismically active (Everitt and Kaliser, 1979) and may be subject to severe ground shaking during an earthquake. Tooele Valley is in Uniform Building Code seismic zone 3, which may experience shaking to modified Mercalli intensity VIII or greater (see appendix). Only one of Tooele City's four water tanks (water tank 5) is new enough to have incorporated earthquake resistant design features in its construction. The other tanks are older and more vulnerable to earthquake induced stress. The city's municipal well field is far enough from potentially active faults that direct earthquake damage is unlikely. Settlement Canyon Dam also predates the general incorporation of seismic design considerations in dam construction. The effect of an earthquake on the dam is presently unknown and needs to be determined. Making that determination is a complex process requiring input from a variety of disciplines (geology, earthquake engineering, foundation engineering, and structural engineering). Likewise, a similar study is needed by Tooele City to evaluate and prepare for the effect of an earthquake on its older water tanks. Because certain aspects of the study would be common to all the facilities, the city may wish to consider entering into a cooperative agreement with the Settlement Canyon Irrigation Company to pursue such an investigation.

Flooding presents a direct threat to Tooele City's municipal well field and to Settlement Canyon Dam. Measures need to be taken to protect both facilities. Stabilization of Middle Canyon Creek adjacent to and upstream from the well field to accomodate cloudburst and snowmelt flooding can be accomplished in a variety of ways. The method selected will depend on economic and land-use decisions made by the city and other affected parties. Flooding due to break out of impounded water behind landslides (earthquake induced or otherwise) that occur in the canyon are likely to be catastrophic and little can be done to protect the well field at its present location. The inability of the Settlement Canyon Dam spillway to pass the probable maximum flood from Settlement Canyon without overtopping the dam is a serious hazard to both the dam and to downstream development. An investigation is recommended to determine what measures can be taken to mitigate the hazard.

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GLOSSARY

Active fault: A fault which has had surface displacement during Holocene time (the last 10,000 years).

Alluvium: Sedimentary deposits resulting from the operations of streams.

Anticline: A fold in rock strata that is convex upward.

Aquifer: A water-bearing formation sufficiently permeable to transmit and yield water.

Basin-and-range: Said of topography, landscape, or physiographic province characterized by a series of tilted fault blocks forming longitudinal, asymmetric ridges or mountains and broad, intervening basins; specifically the Basin and Range physiographic province in the southwest United States.

Caliche: Secondary accumulation of calcium carbonate developed in soils at or near the ground surface.

Colluvium: A general term applied to any loose, heterogeneous, and incoherent mass of soil material or rock fragments deposited chiefly by mass wasting, usually at the base of a steep slope or cliff.

Debris flood: A flood intermediate between the turbid flow of a mountain stream and a true debris flow.

Debris flow: A mass movement involving rapid flowage of debris under viscous conditions.

Dike: A tabular igneous intrusion that cuts across the planar structures of the surrounding rock.

Fanglomerate: A sedimentary rock consisting of heterogeneous fragments of all sizes, originally deposited in an alluvial fan and subsequently cemented into a firm rock.

Ground failure: A general term referring to earthquake induced landslides, liquefaction, and ground tilting exclusive of actual fault rupture.

Liquefaction: The sudden large decrease in the shearing resistance of a cohesionless soil, caused by a collapse of the structure by shock or strain, and associated with a sudden but temporary increase of the pore fluid pressure. It involves a temporary transformation of the material into a fluid mass.

Normal fault: A fault at which the hanging wall (block above the fault plane) has moved down relative to the footwall (block below the fault plane).

Potentially active fault: A fault that shows evidence of surface displacement during Pleistocene time (10,000 to 1.6 million years before present).

Sill: A tabular igneous intrusion that parallels the planar structure of the surrounding rock.

Surface faulting: Fault movement that breaks the ground surface.

APPENDIX

Geologic Time Scale

Modified Mercalli Intensity Scale

GEOLOGIC TIME SCALE

ERA	PERIOD	EPOCH	Age estimate of beginning (millions of years ago)
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	1.6
	Tertiary	Pliocene	5.0
		Miocene	22.5
		Oligocene	37.5
		Eocene	53.5
		Paleocene	65
Mesozoic	Cretaceous		135
	Jurassic		190-195
	Triassic		225
Paleozoic	Permian		280
	Pennsylvanian		320
	Mississippian		345
	Devonian		395
	Silurian		430-440
	Ordovician		500
	Cambrian		570
Precambrian			4500

MODIFIED MERCALLI INTENSITY SCALE OF 1931
(Abridged)

I. Not felt except by a very few under especially favorable circumstances.

II. Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.

III. Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration like passing of truck. Duration estimated.

IV During the day felt indoors by many, outdoors by few. At night some awakened. Dishes, windows, doors disturbed; walls made cracking sound. Sensation like heavy truck striking building; standing motor cars rocked noticeably.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed structures; considerable in ordinary substantial buildings with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Disturbed persons driving motor cars.

IX. Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks.

XI. Few, if any (masonry), structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into the air.

Source: Earthquake Information Bulletin; 6 (5), 1974, p. 28.