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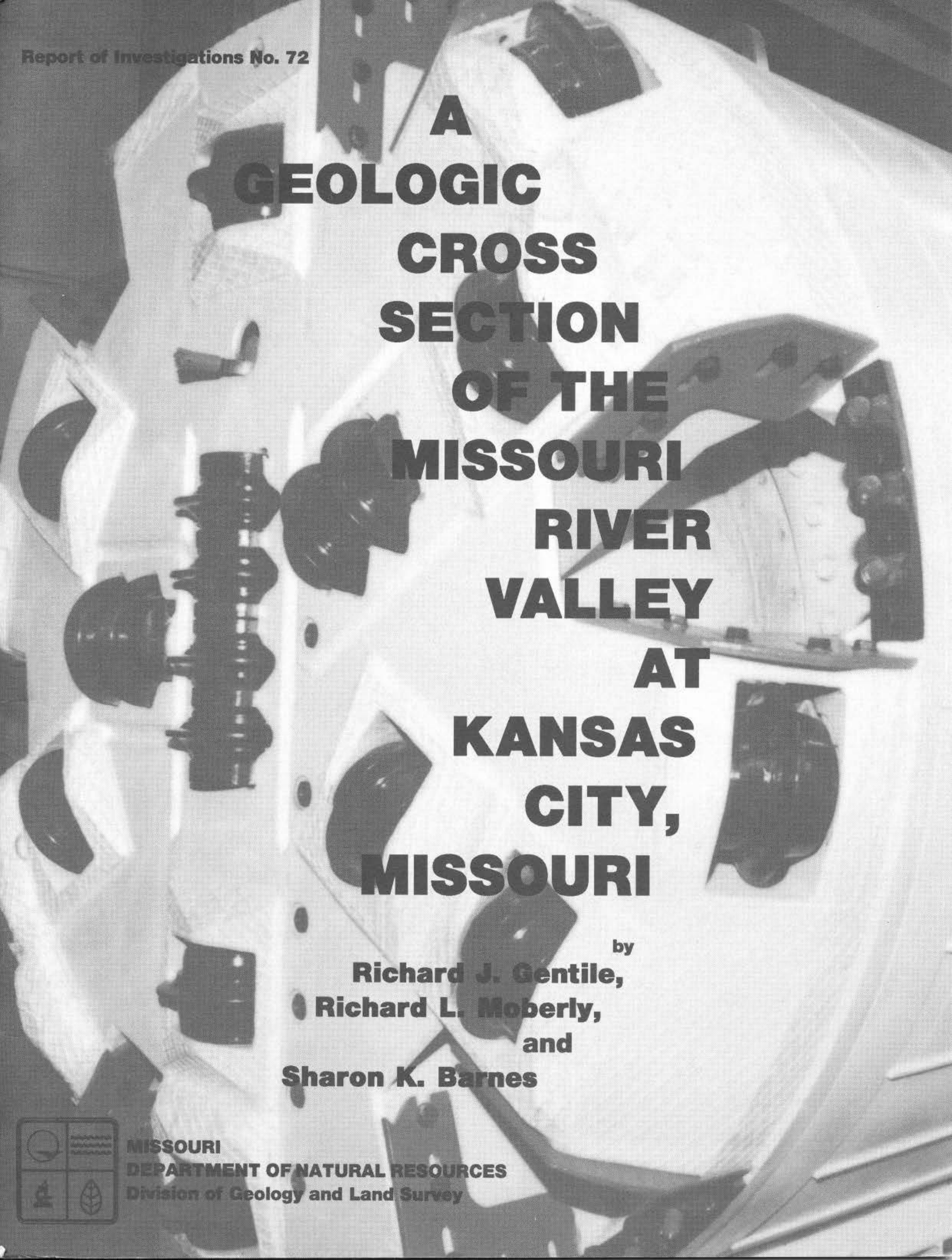

A GEOLOGIC CROSS SECTION OF THE MISSOURI RIVER VALLEY AT KANSAS CITY, MISSOURI

by
Richard J. Gentile,
Richard L. Moberly,
and
Sharon K. Barnes

MISSOURI
DEPARTMENT OF NATURAL RESOURCES
Division of Geology and Land Survey

Metropolitan

THE KANSAS CITY STAR

FRIDAY, June 19, 1992 ★ ★

That's it!

JOE LEDFORD/The Star

Big smiles brightened a tunnel 325 feet underground Thursday after Linda the tunnel-boring machine chewed through the upshaft well connecting both sides of the 2.8-mile Trans-Missouri River Tunnel. Oscar Clingon (right) and Tom Hartman were members of the tunneling crew that burrowed under Kansas City, North, and the Missouri River.

Linda chews her last bite of KC

Front Cover: *This tunnel boring machine, named Linda, chewed through 2.8 miles of underground Kansas City to create the Trans-Missouri River Tunnel.*

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by

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ABSTRACT

The geology of the Missouri River valley at Kansas City, Missouri, is shown in a north-south oriented cross section, 3.5 miles long and to a depth of several hundred feet. The stratigraphic section is divided into two broad categories (a) surficial materials and (b) bedrock. The surficial materials include unconsolidated to poorly-consolidated deposits of loess, alluvium, and glacial drift (Holocene and Pleistocene Series, Quaternary System).

The valley bluffs are formed of bedrock and covered by loess and glacial drift (till and outwash). The drift is patchy in areal extent; the range in thickness is 0 to over 20 feet. In places where the drift is absent, loess rests on the bedrock. The glacial till is dark bluish-gray and is composed of clay, silt and sand with a small percentage of gravel-sized material. The till is commonly leached and oxidized to shades of yellowish-brown to reddish-brown. Outwash in the form of poorly-sorted lenses of sand and gravel are interbedded with the till. Blanket-like deposits of loess are over 75 feet thick and are composed of even-textured, tan silt that has the property of standing in vertical face in excavations.

Surficial materials fill the lower part of the "buried" bedrock valley of the Missouri River to a depth of over 185 feet and consist predominantly of alluvium. The upper 10 to 35 feet of the alluvium is floodplain deposits of silty clay and fine-grained sand underlain by 75 to 100 feet of sand with lenses of gravel, that is in turn, underlain by about 5 feet of the boulders and coarse-grained sand, referred to informally as the "boulder bed." In general, the particle size of the alluvium increases with depth. Several feet of glacial till fills the lower part of a deep trench near the center of the "buried" bedrock valley. The depth, location, and extent of the deep trenches along the valleys of the lower Kansas River and Missouri River is of considerable importance in design of deep structures in the Kansas City area.

The section of bedrock is over 550 feet thick and consists predominantly of limestone and silty to sandy shale with a small percentage of the section composed of beds of siltstone, sandstone, conglomerate, coal, and underclay. The bedrock units are arranged in cyclical sequences commonly referred to as "cyclothems," and belong in ascending order to the Cherokee and Marmaton Groups, Desmoinesian Series; and the Pleasanton and Kansas City Groups, Missourian Series, Pennsylvanian System. The bedrock section is representative of the geology along the Kansas and Missouri River valleys at Kansas City.

A channel-fill deposit, predominantly sandstone, shale, and conglomerate with two or three thin coal beds over 100 feet thick, and located stratigraphically in the

lower part of the Labette Formation has replaced the beds of the Lower Marmaton Group and the Upper Cherokee Group. The Higginsville and Blackjack Creek Limestones thin in a northerly direction and are absent or a few inches thick along the line of the cross section.

Several wells about 100 feet deep supply large quantities of groundwater characterized by high hardness and iron content from the alluvial fill of the Missouri River valley. Several zones of low-gravity oil were recorded in test core samples, as well as small quantities of natural gas.

Data sources to construct the cross section included rock sections exposed during construction of the interstate highway system along the Missouri River bluffs and the rock samples from numerous boreholes located in a north-south line across the Missouri River valley. The major source of information was from the site investigation and the construction phase of the Trans-Missouri River Tunnel, an essentially horizontal 2.74-mile-long water tunnel completed in 1992. The 11 feet diameter tunnel bore is constructed in bedrock that is predominately silty to sandy, gray shale, and passes through a small oil and gas pool 325 feet below the floodplain of the Missouri River. The records from the construction phase of the Missouri Valley Tunnel, completed in 1928, and aligned parallel to the Trans-Missouri River Tunnel, provided a supplemental source of information.

The geotechnical properties of the stratigraphic units in the downshaft, tunnel bore, and the upshaft were recorded during construction of the Trans-Missouri River Tunnel.

INTRODUCTION

The cross section (Plate 1) shows in vertical plane the thickness and the composition of the stratigraphic units that underlie the floodplain and form the bluffs along the Missouri River valley at Kansas City. The cross section is oriented in a north-south direction and extends from Kansas City North to the central business district of Kansas City, covering a distance of 3.5 miles to a depth of several hundred feet. Reference should be made to the cross section while reading the text description of the rock formations.

The combined thickness of exposed stratigraphic units along the line of the cross section is about 220 feet, measured from the floodplain of the Missouri River to the tops of the highest river bluffs. An additional 400 feet of the section lies below the elevation of the floodplain and is reached by subsurface methods of investigation.

The stratigraphic section is divided into two broad categories (a) surficial materials and (b) bedrock. The surficial materials belong to the Holocene and Pleistocene Series, Quaternary System, and unconformably overlie bedrock assigned to the Missourian and Desmoinesian Series, Pennsylvanian System.

The surficial materials are unconsolidated to poorly-consolidated deposits of loess (windblown silt); alluvium (gravel, sand, silt, and clay transported and deposited by the river); glacial drift consisting of outwash (predominantly sand and gravel worked by glacial meltwater streams), and till (a heterogeneous mixture of boulder- to clay-sized material dropped from melting glacial ice).

The bedrock consists of consolidated layers of sedimentary rock, mostly silty to sandy, gray shale and limestone, with lesser amounts of sandstone, conglomerate, siltstone, coal, and underclay. Underclay is typically a relatively soft, blocky claystone with a variable amount of silt and sand, usually less than a few feet thick. As the name implies, it is found beneath a coal bed or at the horizon of a coal bed. It is the "soil" that supported the vegetation that has been altered to coal. Several of these rock types typically are arranged in cyclical sequences that are repeated throughout the section and are referred to as "cyclothems."

The Missouri River valley is several hundred feet deep and was formed by erosion of the Pennsylvanian bedrock by the Missouri River and its ancestral counterparts. The eastward-flowing lower Kansas River was the major drainage system before the Missouri River established its present course during the Pleistocene glaciations (Bayne et al., 1971). One can only speculate as to the amount of erosion that can be attributed to glacial ice and meltwater streams issuing from receding glaciers that once filled the valley and advanced 1 or 2 miles over the hills south of the river. The lower part of the bedrock valley is filled with surficial materials, mostly alluvium and lesser amounts of glacial drift. The river bluffs are composed of bedrock with a cover of glacial drift, loess, colluvium, and residual soil. Exceptions are the steep slopes, and excavations made for construction, in particular of the interstate highway system where the bedrock is exposed. Colluvium and residual soil are not discussed in this report.

The major subdivisions of the rock section shown in the cross section are representative of the geology along the Missouri and Kansas River valleys at Kansas City. The geotechnical information is important to organizations conducting site investigations for excavations into the surficial valley materials and the bedrock that underlies the city. The information in this report should not be considered as conclusive, but subject to modification as additional data become available.

ACKNOWLEDGMENTS

The assistance and information provided by the following individuals and organizations are gratefully acknowledged: Missouri Highway and Transportation Department; Gene Papinako and Chris Fitzgerald, Woodward-Clyde Consultants; Dave Malone, Dave Egger and Clay Haynes, Black and Veatch Consulting Engineers; Lem Hutton, Professional Services Industries; the joint-venture team of Mole Construction Company and the Kassouf Company; Karl E. Nuzman, Layne Geosciences Inc.; Paul L. Hilpman, University of Missouri-Kansas City; John E. Moylan, Woodward-Clyde Consultants; and Wallace B. Howe, James A. Martin, Ira R. Satterfield, and Jerry D. Vineyard, Missouri Department of Natural Resources' Division of Geology and Land Survey, who reviewed the manuscript and offered many helpful suggestions.

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We are indebted to the following employees of the Kansas City, Missouri, Water and Pollution Control Department for punctually supplying requested information and for reviewing the section of the report pertaining to the water supply system: Kenneth Burkhead, Franklyn W. Pogge, Victoria Frerichs, Connie Hull and Ray G. Seidelman.

The services rendered by the reference librarians at the Missouri Valley Room, Kansas City, Missouri Public Library were of vital importance to the completion of this report.

The authors want to thank the management of Black and Veatch Consulting Engineers and Woodward-Clyde Consultants for making available for publication the geotechnical information from the TMRT project.

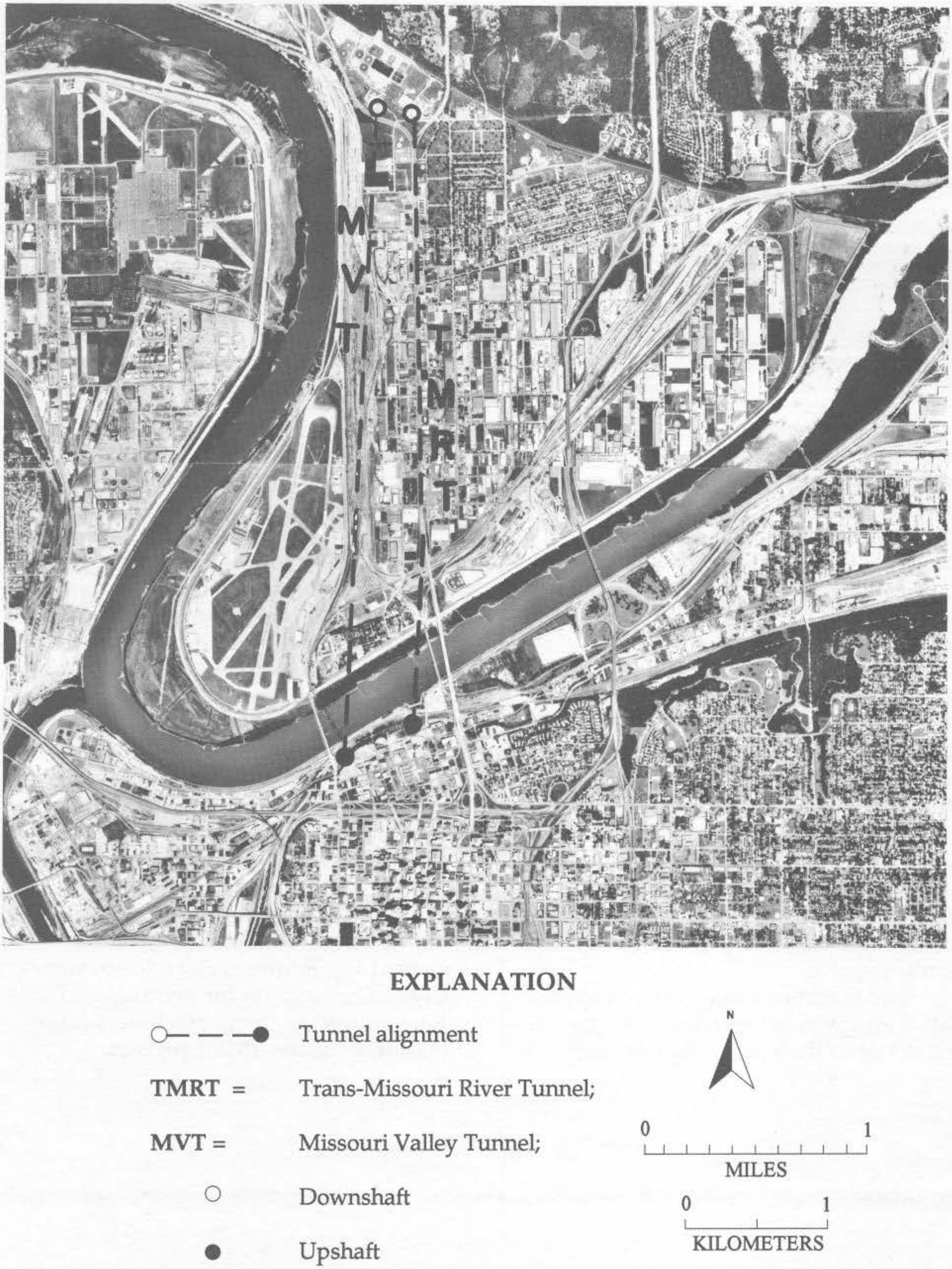

Figure 1. *Aerial photograph showing the location of the Trans-Missouri River Tunnel and the Missouri Valley Tunnel.*

SOURCES OF INFORMATION

The data to construct the cross section came from numerous sources including the site investigation reports for tunnels, bridges, and cable crossings; the records of wells drilled for groundwater and hydrocarbons on open file at governmental agencies; and the described sections of exposed rocks.

The majority of the data is from the interpretation of borehole samples. Information about selected borings is summarized in Table 1a. Each record is designated by a symbol which is shown on the cross section (Plate 1). The borehole data is supplemented with information from exposed rock sections listed by number in Table 1b and also shown on the cross section.

The major source of information was from the site investigation, construction phase, and unpublished reports of the Trans-Missouri River Tunnel (TMRT), a 2.74-mile-long water tunnel (Woodward-Clyde Consultants (1990, 1992). The alignment of the TMRT and the Missouri Valley Tunnel (MVT), a "sister" water tunnel constructed in 1928, are shown in Figure 1.

The Trans-Missouri River Tunnel (TMRT) is the most significant public works project to be completed in Kansas City in 70 years. It was five years in the planning and construction phase. The total cost was about $21 million (Black and Veatch, Engineers and Architects, 1993; Kansas City, Missouri Water and Pollution Control Department, 1993).

The 7.5 feet diameter TMRT is designed to supply 210 million gallons of water per day to about one-half million residents of Kansas City living south of the Missouri River. Water from the Kansas City, Missouri, Water Treatment Plant in Kansas City North reaches the tunnel via the downshaft located south of the treatment plant on the north side of 32nd St. near the junction of Missouri Highway 9 (Burlington Street) and Missouri Highway 283 (Oak Trafficway). It flows in a southerly direction following Burlington Street for over 2 miles. The tunnel changes direction and is oriented approximately south 5 degrees west from a point approximately 4000 feet north-northeast of the upshaft. Water in the tunnel passes under the Missouri River and emerges at the surface via the upshaft on the south bank of the river near 1st Street and Grand Avenue (Figure 1). Water is distributed from the upshaft through 54-inch diameter transmission mains to the East Bottoms Pumping Station and the Turkey Creek Pumping Station. From the pumping stations the water is pumped into the distribution system for consumers.

A comprehensive exploration program was planned and executed to evaluate the subsurface conditions for the TMRT. The Site Investigation Program for the TMRT included drilling 16 boreholes; core borings B-1 and B-5 at the downshaft and upshaft locations, respectively; core borings

Boring	Location	Surface Elevation (ft. m.s.l.)	Total Depth (ft)	Type of Sample Recovery	Date Drilled	Contracting Organization
A-1	NE¼, NW¼, NE¼ sec. 10, T. 50 N., R. 33 W.	890.7	200	NQ (2 in.) core	June 1964	Missouri Hwy. Commission, Kansas City, Mo. Core L-427
B-1	Downshaft, Trans-Missouri River Tunnel (TMRT) alignment. Kansas City, Mo. Water Treatment Plant, north side of 32nd St. near jct. Missouri Hwy. 9 (Burlington St.) and Missouri Hwy. 283 (Oak Trafficway)	741.1	405	0.0 ft - 116.0 ft Hollow-stem auger and rotary tri-cone roller bit 3.9 and 5.9 in. diam. 116.0 ft - 405.0 ft NQ (2 in.) core	April 1989	Woodward-Clyde Consultants
B-2	3,150 ft south of Downshaft on TMRT alignment	746.9	401.0	0.0 ft - 133.0 ft Hollow-stem auger and rotary wash; 133.0 ft - 401.0 ft NQ (2 in.) core	May 1989	" " "
B-3	2,775 ft south of Boring B-2 on TMRT alignment	741.1	400.0	0.0 ft - 137.0 ft Hollow-stem auger and rotary wash; 137.0 ft - 400.0 ft NQ (2 in.) core	May 1989	" " "
B-4	4,575 ft south of Boring B-3 on TMRT alignment	740.5	400.0	0.0 ft - 99.0 ft Hollow-stem auger and rotary wash; 99.0 ft - 400.0 ft NQ (2 in.) core	June 1989	" " "
B-5	Upshaft TMRT alignment; 1st Street and Grand Ave.	765.9	401.0	0.0 ft - 25.0 ft Hollow-stem auger and rotary wash; 25.0 ft - 401.0 ft NQ (2 in.) core	June 1989	" " "
C-1	Approx. 7,650 ft south of Downshaft	741.0	172.0	Hollow-stem auger and rotary wash	June 1989	" " "

C-2	Approx. 200 ft. south of Boring C-1	741.0	201.0	Hollow-stem auger and rotary wash	June 1989	" " "
C-3	Approx. 50 ft. south of Boring C-2	741.0	153.0	Hollow-stem auger and rotary wash	July 1989	" " "
D-1	Block 92 57.0 ft. west of centerline of Main St.; 49.3 ft. south of centerline of 11th St.	887.4 spudded in basement of demolished building	136.6	NQ (2 in.) core	April 1973	Altgar Enterprises (Core No. 4)
H-6	On levee (north), left bank	755.6	101.4	Rotary wash	1966	Missouri Hwy. Commission, Kansas City, Mo.
H-7	On levee, left bank	755.30	118.4	" "	"	" "
H-8	On levee, left bank	749.0	92.5	" "	"	" "
H-9	Left bank	734.50	95.6	" "	"	" "
H-10	Left bank	733.80	72.8	" "	"	" "
H-13	On river	730.95	99.3	" "	"	" "
H-15	On river	730.85	89.3	" "	"	" "
H-16	On river	730.24	86.2	" "	"	" "
H-18	On right (south) bank	736.00	71.0	" "	"	" "
South Bank (boring)	On south bank	754.20	135.2	" "	"	" "

Table 1a. *Sources of Information: Test borings.*

Location	Units Exposed	Date Selections Described; and Published References
1. Section along Main Street between Pershing and Grand Avenues and in excavation for Crown Center Complex in area bounded by Pershing Ave., Main Street and Grand Avenue, Kansas City, Jackson County, Missouri; SW¼, sec. 8, T. 49 N., R. 33 W.	Winterset Limestone Member, Dennis Formation to Argentine Limestone Member Wyandotte Formation, Pennsylvanian System	1971; Moore, 1936
2. Excavation for Interstate Route 670 through West Bluffs, 14th and Summit streets, Kansas City, Jackson County, Missouri; NW¼, SE¼, sec. 6, T. 49 N., R. 33 W.	Lane Shale to Argentine Limestone Member, Wyandotte Formation, Pennsylvanian System. Glacial till, paleosol, and loess (differentiated), Pleistocene Series	1981; Gentile, this report
3. Section along Beardsley Street near 12th Street Viaduct on West Bluff below West Terrace Park, Kansas City, Jackson County, Missouri; center sec. 6, T. 49 N., R. 33 W.	Westerville Limestone Member, Cherryvale Formation to Raytown Limestone Member, Iola Formation, Pennsylvanian System	1971
4. Excavation for Interstate Route 635, on West Bluff below Lewis and Clark Point (Jefferson and 9th Streets) to Beardsley Street and St. Louis Avenue; Kansas City, Jackson County, Missouri; SW¼, NE¼, NE¼, sec. 6, T. 50 N., R. 33 W.	Wea Shale Member, Cherryvale Formation to Argentine Limestone Member, Wyandotte Formation, Pennsylvanian System; Loess (undifferentiated), Pleistocene Series	1969
5. Bed and cut bands of southeast-flowing stream; on bluff above Kansas City, Missouri Water Treatment plant; Waterworks Park (NE¼, SW¼ sec. 11, T. 50 N., R. 33 W.), and Briarcliff Park (W½ NW¼, sec. 11, T. 50 N., R. 33 W.), Kansas City, Clay County, Missouri	Westerville Limestone Member, Cherryvale Formation to Raytown Limestone Member, Iola Formation, Pennsylvanian System	1994

6. Section exposed in bed and cut banks of southerly-flowing stream for distance of 1,500 feet, North Hitts Park, Kansas City, Clay County, Missouri; W½, NW¼ and SW¼, NE¼, SW¼, sec. 12, T. 50 N., R. 33 W.	Winterset Limestone Member, Dennis Formation to Cement City Limestone Member, Drum Formation, Pennsylvanian System	1994
7. Road excavation on northbound on-ramp to Missouri Hwy. 169 from Missouri Hwy. 9, Kansas City, Clay County, Missouri; NW¼, SE¼, NE¼, sec. 10, T. 50 N., R. 33 W.	Cement City Limestone Member, Drum Formation to Argentine Limestone Member, Wyandotte Formation, Pennsylvanian System	1986
8. Missouri River bluffs, excavation for Missouri Hwy. 9, Riverside, Platte County, Missouri; SW¼, SE¼, NW¼, sec. 5, T. 50 N., R. 33 W.	Fontana Shale Member Cherryvale Formation to Raytown Limestone Member, Iola Formation, Pennsylvanian System	1975; Gentile, 1988
9. Intersection of Interstate Route 435 and Missouri Hwy. 210, Raldolph, Clay County, Missouri SE¼ SE ¼, SW¼, NE¼, sec. 9, T. 50 N., R. 32 W.	Glacial outwash, paleosols and loess (differentiated), Pleistocene Series	Davis, 1970

Table 1b. *Sources of Information: Stratigraphic Sections of Exposed Strata.*

B-2, -3, and -4 along the proposed tunnel alignment; probe borings C-1, -2 and -3 in the vicinity of a suspected deep "buried" bedrock trench (the location along the TMRT alignment of Borings B-1, -2, -3, -4, -5 and C-1, -2, -3 is shown on Plate 1.); the drilling of five shallow borings B-5A, 5B, 5C, 5D and 5X in the vicinity of the upshaft; and three additional boreholes which served for installation of piezometers P-1, -2 and -3 around Boring B-1 at the proposed downshaft location.

In addition to the drilling program the site investigation included the following work: Pressure (packer) testing of selected intervals in the core borings; geophysical logging of the cored boreholes and piezometer test boreholes; evaluation of formational gas pressure in selected borings; obtaining a water sample in one boring; and laboratory testing of soil, rock, and water samples recovered during the field studies.

The site investigation for the TMRT included a review of site investigation and construction documents for the existing tunnel (MVT). The site investigation for the MVT included 23 borings along Swift Avenue, about 900 feet east of the TMRT alignment and 1,500 to 2,500 feet east of where the MVT was actually constructed (Fuller and Maitland Engineers, n.d.). The line of borings conformed to the early plans to locate the tunnel alignment along Swift Avenue with the upshaft at 1st and Cherry streets. Only eight borings were located along the tunnel route. With the exception of two borings along Swift Avenue that penetrated to the elevation of the tunnel, the borings were completed only to the top of bedrock. The Board of Fire and Water Commissioners Report (1924) included a generalized geologic cross section along the tunnel alignment at the Broadway Street Bridge that shows the location of boreholes, thickness of the valley-fill deposits, and the configuration of the "buried" bedrock valley. Unfortunately, the boring logs have been lost. A modified version of the cross-profile is in the report by Hasan, Moberly, and Caoile (1988).

In addition to the borehole information for the TMRT and MVT, the review included the records of over 100 borings. The boring logs, some of which are on open file at the office of the Missouri Department of Natural Resources' Division of Geology and Land Survey in Rolla included (a) eight oil and gas test wells that passed through the surficial material and were completed in bedrock at depths below the elevation of the TMRT alignment; (b) about two dozen high-yield water wells completed to the top of bedrock and producing from the section of surficial materials; (c) a linear series of 10 borings designated H-6 to -10, -13, -15, -16, -18 and South Bank drilled for the construction of the Missouri Highway 9, Heart of America Bridge, located adjacent to the TMRT, (Missouri Highway Commission, 1960); (d) several borings for a river crossing for an AT&T cable; (e) the records of several large coffer cells excavated through surficial materials to bedrock to serve as bridge piers; and (f) borings A-1 and D-1 located in the upland areas. Boring A-1 was drilled for the location of Missouri Highway 169 in Kansas City North, Missouri, 1.5 miles northwest of Boring B-1. Boring D-1 is located 0.75 mile southwest of Boring B-5 at a building construction site in the central business district of Kansas City.

Borings A-1 and D-1 provide information about the rock sections that form the bluffs along the river. The sections in borings A-1 and D-1 are supplemented with information mostly from numerous described rock exposures at construction sites for the interstate highway system beginning in the 1960s. The locations of described sections are shown by number on the location map for the geologic cross section (Plate 1) and listed on Table 1b.

Noteworthy sources of published information are reports by Fishel (1948); Heim (1961); Heim and Howe (1963 a,b); O'Connor and Fowler (1963); and Emmett and Jeffery (1969). These reports deal primarily with the surficial materials and the configuration of bedrock valleys. Searight and Howe (1961) reported on the stratigraphy of the bedrock; Thompson et al. (1993) includes the current classification of Pennsylvanian-age strata proposed by the Missouri Department of Natural Resources' Division of Geology and Land Survey; unpublished master's thesis by Simms (1975) described the thickness of surficial materials and the configuration of the bedrock valley; and a geotechnical report for the then proposed AT&T cable crossing by Terracon Consultants SE, Inc. (1983).

AREAL GEOLOGY

DESCRIPTION OF SURFICIAL MATERIALS

River Bluffs

The tops and moderate to gentle slopes of the river bluffs are covered by glacial drift and loess of Pleistocene age. A representative section of Pleistocene deposits uncovered in the early 1980s in the excavation for Interstate Route 670 near the central business district at Kansas City, Missouri is shown in the cross section (Figure 2) and the stratigraphic section is described in Figure 3. The Pennsylvanian bedrock has been deeply weathered. Solution cavities in the upper Argentine Limestone Member have dimensions of several feet and are filled with reddish-brown clay and fragments of glacial till, chert, limestone, and shale (Figure 4).

Glacial drift belonging to the Kansan Stage (middle Pleistocene) rests unconformably on Pennsylvanian bedrock. The thickness of the drift ranges from 0 to over 20 feet on the bluffs along the line of the cross section but increases to over 40 feet in places on the bluffs, several miles east of Kansas City.

The drift consists of till interbedded with lenses of outwash (stratified drift). The till is composed mostly of clay- to sand-sized particles but 10 to 20 percent is of gravel-size. Isolated boulders commonly occur in the fine-grained matrix, hence the name "boulder" clay.

The glacial drift has been deeply weathered. It has been oxidized to shades of yellowish-brown and reddish-brown and most carbonate rocks and minerals have been leached from the drift. The remaining non-resistant rocks and minerals are extensively altered. Granite and granodiorite crumble under slight hand pressure and limestone boulders and blocks are weathered to form nodules of soft, white calcium carbonate. The resistant rocks include gravel-size particles of pink quartzite, milky quartz, and chert.

Small isolated patches of unweathered till occur below or within the weathered drift. Unweathered till is dark gray; about 80-90 percent of the gravel-sized fraction is locally-derived pieces of limestone with lesser amounts of shale and sandstone. The resistant fraction consists of gravel-sized rock and mineral types with compositions similar to that found in weathered till.

Outwash (stratified drift) occurs as lenses of sand and gravel interbedded with the till. The sorting in outwash varies considerably but most outwash is poorly-sorted with gravel- and sand-sized particles intermixed. The lenses of outwash commonly are convoluted and distorted.

A localized patch of loess, several feet thick and assigned to the Illinoian Stage (Loveland Formation), was exposed in an excavation for highway construction on the bluff at the intersection of Interstate Route 435 and Missouri Highway 210 (SE¼ SW¼ NE¼ sec. 9, T. 50 N., R. 32 W.) about 5 miles east of the line of the cross section (Bayne et al., 1971). The Illinoian loess is separated from the Kansan till by a poorly-developed paleosol (Yarmouth). In most places, Illinoian loess has been removed by erosion or incorporated into the Sangamon paleosol. The Sangamonian Stage is represented by one of the most extensively developed and widespread of the Pleistocene paleosols. The Sangamon is recognized over large areas in northeastern Kansas and northern Missouri. Development of the Sangamon soil was so intense that in most areas where the intervening Illinoian loess (Loveland) was deposited, soil-forming processes extended all the way through the Illinoian loess and into the underlying Yarmouth paleosol (Bayne et al., 1971). The Sangamon paleosol is typically 1 to 3 feet thick, but the underlying zone of weathering extends to a depth of several feet in places where the paleosol is developed on glacial drift. The weathered zone is oxidized to shades of yellowish-brown to reddish-brown, leached of calcium carbonate minerals, and typically overlies dark- gray "fresh" unweathered till and outwash.

The Sangamon paleosol is overlain by a thick layer of loess assigned to the Wisconsinan Stage. The loess is over 75 feet thick in places along the bluffs and is easily recognized by the homogeneous texture, tan to yellowish-brown color, and the property of standing in vertical face in excavations. Most of the section of Wisconsinan-age loess is assigned to the Peoria Formation.

Along the Missouri River bluffs, in particular the central business district of Kansas City, the loess deposits have been extensively disturbed by industrialization. In the early days of Kansas City it was common practice to "push a hill into a valley" to make space for the construction of buildings and streets.

River Valley-fill Deposits

Variations in the thickness of surficial materials that fill the lower part of the bedrock valley of the Missouri River are controlled by erosional irregularities in the "buried" bedrock surface. Differences in surface elevation across the floodplain are relatively small and have little effect on the thickness of the valley fill materials.

The thickness of surficial materials varies considerably when traced from north to south across the valley. The thickness is controlled almost entirely by the topographic expression of the "buried" bedrock valley. The average thickness is 125 feet along the northern two-thirds of the valley, increasing to 186 feet in a deep, east-west trending trench and decreasing to 85 feet on an elevated surface south of the trench. The elevated surface is 30 feet higher than the bedrock valley north of the deep trench and is interpreted to be a bedrock terrace, an indication of more than one episode of valley erosion.

The major part of the surficial materials is classified as alluvium. These are the sediments that were transported and deposited by the Missouri and Kansas rivers and their ancestral counterparts. The alluvium is subdivided into three categories based on particle size, (in general, the particle size increases with depth): (a) The upper 10 to 35 feet of the alluvium is floodplain deposits of silt, clayey silt and fine-grained sand that settled from the backwaters when the Missouri River overflowed its banks. A soil profile has developed in the upper few feet. The floodplain deposits at Kansas City have been disturbed extensively by industrialization, including the construction of a system of earthen levees 20 feet high along the river. (b) The floodplain deposits are underlain by 75 to over 100 feet of sand with lenses of gravel. The gravel lenses are dispersed throughout the sand section and are rarely traceable for more than a few hundred feet. The maximum thickness of the individual gravel lenses ranges from a few inches to several feet. In places, isolated pebbles of gravel are scattered randomly throughout the sand section. The sand is predominantly quartz but a high percentage consists of fine-grained rock fragments and other minerals. Particles in the gran-

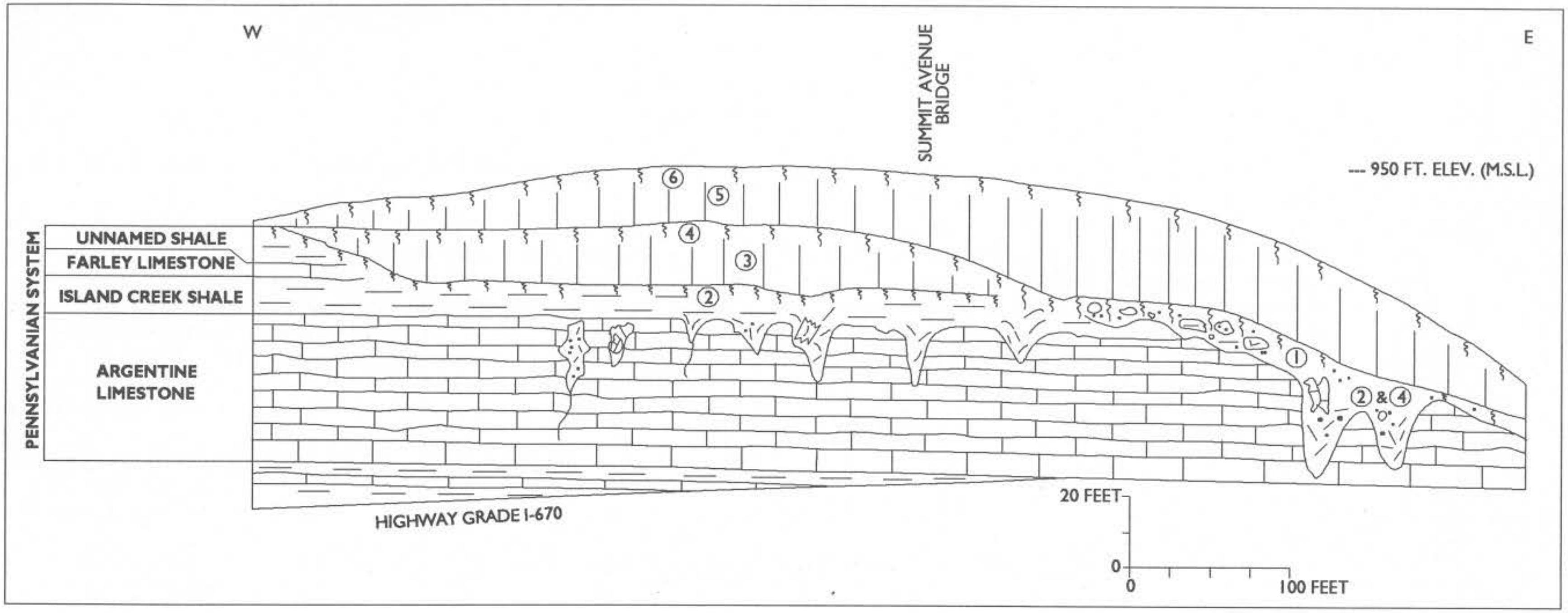

Figure 2. *Cross section of the Pleistocene-age deposits overlying bedrock in an excavation for Interstate Route 670, through West Bluffs, 14th and Summit Streets, Kansas City, Missouri, 1980. Lithologic descriptions are given in Figure 3.*

SECTION OF PLEISTOCENE UNITS

	Thickness (ft.)
Holocene Series	
6. Soil and fill material	3
Pleistocene Series	
Wisconsinan Stage	
5. Peoria loess Silt, yellowish-brown (10 YR 5/4)* to dark yellowish-brown (10 YR 4/4); homogeneous, noncalcareous; stands in vertical face in excavation.	15
Sangamonian Stage	
4. Paleosol Clay, silty, noncalcareous, yellowish-brown (10 YR 5/4); carbonized roots to .5 in. diameter and several inches long. Thickness increases to 5 ft in places where Loveland loess is absent or is indistinguishable and the Sangamon-Yarmouth paleosols merge. Color change to dark-reddish-brown (10YR 3/4) reddish-brown (10R 4/6); stone line near top	3+
Illinoian Stage	
3. Loveland loess Silt, moderate-brown (5 YR 4/4), clayey, homogeneous, vertical desiccation cracks, columnar jointing	11
Yarmouthian Stage	
2. Paleosol Clay, yellowish-brown, thin and poorly developed on shale bedrock	1 -2
Kansan Stage	
1. Till Clay, silty, sandy; leached of carbonates and oxidized to moderate yellowish-brown (10 YR 5/4); patches of medium gray, noncalcareous till near bottom. Pebbles and cobbles of quartzite; quartz with glacial striations and beveled edges, weathered granite; fragments of locally-derived shale (Island Creek), cross-bedded sandstone. Sinkholes, 20 ft deep and 35 ft wide, in Argentine Limestone filled with dark-reddish-brown (10R 3/4) clay, pieces of weathered till, oxidized to dark-yellowish-orange (10 YR 6/6); chert nodules, fragments of shale; lower part of sink fill is mostly hematitic clay with few granules of resistant rock and mineral types of glacial erratics	4 -35

*Colors of moist samples were described with the Standard Munsell Soil Color Charts (1975).

Figure 3. *Description of Pleistocene units shown in Figure 2.*

ule- to pebble-size range are mostly locally-derived chert and limestone, but a small percentage is pink quartzite, granite and gneiss that has been transported by continental glaciers from a northern source area, probably from as far north as Minnesota. Well-rounded small fragments of lignite are abundant at several horizons. (c) The lower (approximately) 5 feet of the alluvium contains isolated deposits of boulders with lenses of coarse-grained quartzose sand. The unit is informally called the "boulder" bed in reference to the large boulders and blocks that comprise a significant part of it. The largest boulders appear to be a few feet in greatest dimension and rest on the buried bedrock valley floor. The majority of the large boulders are limestone, but glacial erratics of pink quartzite, granite, and gneiss are common. The "boulder bed" is traceable intermittently in borings across the width of the valley. The association of boulders with lenses of coarse-grained sand indicates the deposit was worked by high-velocity currents. The large size and relationship of the boulders precludes distant transportation by running water and suggests that the boulder bed was derived from the glacial lobe that filled the deep trench with till.

The uppermost 15 to 30 feet of alluvium is classified as Holocene in age and includes the sediments underlying the floodplain, forming low terraces along the river, and in transport in the river channel.

The thick section of alluvium underlying the Holocene deposits is believed to be of Wisconsinan in age (Late Pleistocene) (Heim and Howe, 1963; O'Connor and Fowler, 1963, and Dort et al., 1987).

A Holocene and Wisconsinan vertebrate fauna has been collected from gravel bars along the lower reaches of the Kansas River (Martin et al., 1979; Johnson and Martin, 1987). Wisconsinan-age deposits are currently being eroded in response to an increase in channel depth brought on by deep-dredging operations for sand and gravel, and the construction of dams upstream, which has increased the scouring capacity of the river, resulting in erosion through the Holocene and into the Wisconsinan deposits.

The deepest part of the buried bedrock valley is filled with a heterogeneous mixture of clay- to boulder-size material, consisting of numerous rock and mineral types. The abundance of gray clay in a

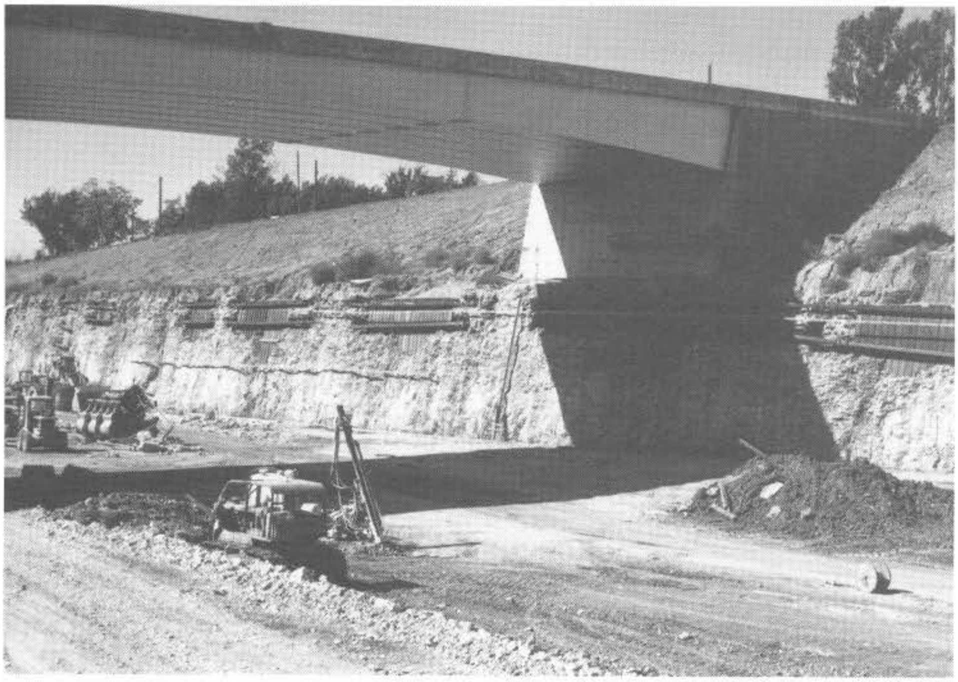

Figure 4.
Solution features in the upper Argentine Limestone Member. Excavation for Interstate Route 670 at the Summit Ave. Bridge, Kansas City, Missouri, 1981. The retaining forms cover the solution cavities and stabilize loose fill materials in them.

heterogeneous mixture of clay- to boulder-size particles suggests this material is a glacial till. The gravel-sized fraction includes glacial erratics of pink quartzite and locally-derived limestone. The glacial till underlies the alluvium and is about 15 feet thick. In comparison to the width of the buried bedrock valley, the portion that is filled with till is relatively narrow. In reality, the till fills the lower part of a deep trench eroded into the bedrock valley floor. Borings C-1, -2, -3 for the TMRT are located to give information about the deep trench. The drill in Boring C-3 penetrated 12 feet of limestone, interpreted to be a large boulder or block.

The bottom of the deep trench is about 90 feet below the surface of the bedrock terrace south of it, and 60 feet lower than the bedrock surface north of the trench. The till-bedrock contact at the bottom of the trench is 555 feet (m.s.l.). The section of till in the excavation for the I-670 Interchange (Figure 2) is about 950 feet (m.s.l.) near the highest elevation in Kansas City. The difference in elevation is almost 400 feet, an indication of the minimum thickness of the ice sheet that filled the Missouri River Valley and advanced southward over the highest hills. This figure is based on the assumption that the till at both places was deposited from the same ice lobe.

A deep comparable trench was encountered in boreholes during construction of the Intercity Viaduct for Interstate Route 70 across the Kansas River, approximately 2 miles upstream and southwest of the TMRT. O'Connor and Fowler (1963) report that the trench is 1,500 feet wide, 150 feet deep and is filled with glacial till. The elevation at the bottom of the deep trench is 515 feet (m.s.l.), a figure that compares somewhat favorably with the 555 foot elevation at the bottom of the deep trench recorded from borehole data during the site investigation for the TMRT. Sections of alluvium underlain by glacial drift with a total thickness of 150 to 200 feet have been recorded from borehole samples at several additional places along the Kansas and Missouri River valleys at Kansas City. These places of relatively thick sections of alluvium and glacial drift appear to be restricted to narrow, deep trenches. Most of the information about them is included in unpublished site investigation reports. Whether the deep trenches are integrated into a single system with a common base level has not been determined due to the lack of subsurface data. The depth, location and the extent of the deep trenches within the lower Kansas and Missouri river valleys are of considerable importance in design of deep structures in the Kansas City area.

There is general agreement that the deep trenches were eroded into the bedrock valley floor by large volumes of meltwater shortly before or during the maximum advance of the Kansan ice sheet (Fishel, 1948; O'Connor and Fowler, 1963; Heim and Howe, 1963b; Simms, 1965; Aber, 1988).

The Kansan (middle Pleistocene) was the most extensive Pleistocene glaciation and the only one to reach the Kansas City area (O'Connor and Fowler, 1963). Consequently, the glacial till filling the deep trench is assigned to the Kansan Stage. Also, it is reasonable to assume that at least part of the "boulder bed" that comprises the lower several feet of alluvium is of Kansan age and represents glacial outwash that was deposited from meltwater issuing from the receding ice lobe after it had advanced into the valley and filled the trench with till.

The Kansan drift has an age range between 0.7 to 0.6 million years B.P. (before present) based on radiometric dating of volcanic ash, biostratigraphy and paleomagnetism of till (Aber, 1991).

Revision of the standard classification system of Pleistocene units for the midcontinent U.S. has been proposed by Richmond and Fullerton (1986); Morrison (1991); and Aber (1991). Early and medial Pleistocene units have been assigned to the informal time division Pre-Illinoian and the name Kansan is abandoned. The chronostratigraphic equivalence of the glacial deposits at Kansas City, Missouri with sections in other areas of the midcontinent has not been determined. Until the matter is resolved, the Kansan, a well-established name, is retained in this paper for glacial deposits along the Missouri River bluffs and in the deep bedrock trench at Kansas City. The classification system of Bayne et al. (1971) is followed in this report.

DESCRIPTION OF BEDROCK UNITS

The bedrock addressed in this study comprises a sequence of strata over 550 feet thick that is divided into 75 formally-named stratigraphic units that consist of four lithostratigraphic groups (in descending order): the Kansas City and Pleasanton Groups, Missourian Series, and the Marmaton and Cherokee Groups, Desmoinesian Series, Pennsylvanian System. The stratigraphic classification of the Pennsylvanian System is undergoing revision by midcontinent geologists. The classification currently in use by the Missouri Department of Natural Resources, Division of Geology and Land Survey (Thompson, et al., 1993) is retained in this report until an agreement is reached among midcontinent state geological surveys.

A composite stratigraphic section of the Pennsylvanian-age bedrock units along the line of the cross section is included in Appendix 1. Included in the section are some of the proposed revisions in classifications.

The long cores (B-1, -2, -3, -4, -5) from the site investigation for the Trans-Missouri River Tunnel project provided the necessary data to make a detailed stratigraphic analysis of the subsurface bedrock units. Prior to the current investigation, there was insufficient detailed stratigraphic information concerning the approximately 300 feet of bedrock that comprise the Lower Pleasanton, Marmaton, and Upper Cherokee Groups in the vicinity of Kansas City. This rock sequence makes up the bedrock section that lies below the elevation of the major river valleys and is accessible only by subsurface methods of investigation.

Kansas City Group

The average thickness of the Kansas City Group is approximately 260 feet in the Kansas City area (Greene and Howe, 1952). The upper 50-75 feet has been removed by erosion along the line of the cross section. The middle part is exposed along the Missouri River bluffs and is approximately 150 feet thick; the lower 40 feet lies below the elevation of the floodplain of the Missouri River.

The Kansas City Group consists mostly of limestone and shale beds that alternate throughout the section. The Bethany Falls Limestone Member crops out on the south bank of the Missouri River and is the oldest exposed bedrock unit.

The Argentine Limestone Member is found near the tops of the hills and is deeply weathered, especially at places where the Island Creek Shale Member is relatively thin. Solution along joints has widened some of them to more than 2 feet and a pinnacled surface has developed on the Argentine at places where solution has been excessive. Cavities and solution-widened joints are filled with reddish-brown plastic clay. At a few places, glacial erratics of resistant rock and mineral types are embedded in the clay.

Pleasanton Group

The Pleasanton Group is about 110 feet thick and consists predominantly of gray shale with beds of sandstone near the top, middle, and bottom of the group.

The Exline Member, a thin, persistent bed of limestone, is a diagnostic marker bed in the lower part of the Pleasanton throughout northwestern and west-central Missouri.

The complete thickness of the Pleasanton Group was encountered in test boring B-5 and the lower part of the group in test borings B-1, -2, -3, and -4 for the TMRT.

Marmaton Group

The thickness of the Marmaton Group varies from 150 feet to over 360 feet. The upper part consists of an alternating sequence of limestone, shale, and sandstone beds with a total thickness of 150 feet. Most stratigraphic units of formation and member rank can be correlated between boreholes along the TMRT alignment. Diagnostic marker beds include, in descending order, (a) the thin black fissile shale bed of the Holdenville Formation; (b) a zone of maroon shale several feet thick in the upper Perry Farm Shale Member, Lenapah Formation; (c) the Bandera Quarry Sandstone Member, Bandera Formation; (d) the Mulberry coal bed, Bandera Formation; and (e) the thin black fissile shale bed of the Anna Member, Pawnee Formation. The maroon zone in the upper part of the Perry Farm Member is easily recognized in well samples. It is a diagnostic marker bed throughout the metropolitan Kansas City area and is used by drillers to mark the top of the Marmaton Group. The Bandera Quarry Sandstone Member is relatively continuous over large areas and appears to be a sheetlike deposit similar to the Hepler Sandstone Member. Core samples of the Bandera Quarry Sandstone Member along the TMRT alignment were impregnated with low-gravity oil. The Mulberry coal bed is relatively uniform in thickness, about 1 foot, along the tunnel alignment.

The lowermost 6 to 7 feet of the Marmaton Group consists of shale and thin limestone beds assigned to the Fort Scott Subgroup. The Fort Scott strata are recognized in borings B-l, -2 along the northern segment of the TMRT alignment. The Fort Scott Subgroup is relatively thin at Kansas City. The reduced thickness is the result of the thinning and "pinching out" of the Higginsville Limestone and Blackjack Creek Limestone in a northerly direction. The Fort Scott is approximately 50 feet thick along the outcrop belt that extends in a southwest-northeast direction from southeastern Kansas across Bates, Cass, and Johnson Counties, Missouri, only about 60 miles southeast of Kansas City. The Higginsville Limestone is 6 inches thick in boring B-1, but is 20 feet thick at numerous quarries along the outcrop belt southeast of Kansas City where the Higginsville is quarried commercially for aggregate. The Blackjack Creek Limestone is absent or it is 6 inches thick in borings B-1 and B-2, respectively, but it is several feet thick along the outcrop belt. The northward thinning of the limestone beds in the Fort Scott Subgroup has been recognized in test cores at Belton, Cass County, Missouri, approximately 20 miles south of the TMRT (Gentile, 1984b).

The Fort Scott Subgroup has been replaced by a thick channel-fill deposit that extends for a distance of over 2 miles along the southern tunnel alignment (Borings B-3, -4, -5). The channel-fill deposit has not been formally named. It is referred to informally in this report as the Unnamed Lower Labette channel-fill deposit because the deposit is situated stratigraphically in the lower part of the Labette Formation. The channel-fill deposit is over 100 feet thick and has replaced the strata comprising the Lower Marmaton Group below the Labette Formation to an unknown depth in the Cherokee Group. The deep cores for the TMRT did not penetrate the part of the section that comprises the lower part of the channel-fill deposit, consequently, the depth of the channel and the corresponding thickness of the channel-fill deposit could not be determined.

The Lower Labette channel-fill deposit is predominantly silty to sandy gray shale, but appreciable amounts of the deposit consist of sequences of strata several feet thick and a few tens of feet wide that include in ascending order: fine pebble conglomerate, cross-bedded sandstone, ripple-laminated sandstone, and silty shale. These fining-upward sequences of strata are interpreted to be point bar deposits. The sediments comprising them were deposited on the inside of stream meanders

(Davis, 1992). The conglomerate beds consist of subrounded to rounded granules and small pebbles of limestone, with lesser amounts of flattened clasts of shale to 2 inches long; angular pieces of coal and fossilized wood. The matrix is medium-grained quartzose sand with calcium carbonate cement. The gravel-sized sediment comprising the conglomerate beds were derived locally by erosion of older formations and were the first to be deposited on the bottom of the river channel. The fine-grained sediments were deposited successively higher in the section as the river current decreased. The silty to sandy gray shale is interpreted to be overbank deposits that were laid down on the river floodplain adjacent to the point bars. These sites eventually became peat bogs. The peat is represented in the section by thin coal beds.

The point bars were encountered at several places along the southern 2 mile segment of the TMRT that is constructed in the Unnamed Lower Labette channel-fill deposit. The point bars and associated overbank deposits are superimposed throughout the section and represent successive stages of deposition as a large river valley filled with sediment.

The Unnamed Lower Labette channel-fill deposit is believed to have filled a segment of a large meandering river valley oriented in a generally north-to-south direction along the Kansas-Missouri border. Several small oil and gas fields lie along the trend and include the Riverside (Belgium Bottoms) field, 4 miles north of the TMRT and the Clark-Miller (Knoche) field at Belton, Cass County, Missouri, 20 miles south of the TMRT. The wells in these two fields are producing, at least in part, from a channel-fill type sandstone body in the lower part of the Labette Formation (Deason, 1984; Gentile, 1984b).

A channel-fill sandstone in the stratigraphic position of the lower Labette Formation has been formally named the Englevale Sandstone Member, after the type locality near the town of Englevale, Crawford County, Kansas (Pierce and Courtier, 1935; Howard and Schoewe, 1965). A study needs to be made to clarify the equivalence of the Englevale Sandstone Member, upper Labette Formation of northwestern Missouri and the Englevale at the type locality in the lower part of the Labette Formation in southeastern Kansas.

Cherokee Group

The lower 100 feet of the deep cores (B-1, 2) included a predominatly shale and sandstone sequence belonging to the upper Cherokee Group. The Excello Formation, a persistent black fissile shale bed 1 or 2 feet thick in most areas of western Missouri, is represented by 0.1 foot of gray shale in boring B-2. The upper boundary of the Cherokee Group is arbitrarily drawn at the top of the Mulky coal in boring B-1 where the Excello Shale is absent.

The Mulky Formation is 55 to 60 feet thick and is composed of silty to sandy gray shale with several quartzose sandstone beds in the upper half of the formation. Thin beds and concretions of clay ironstone occur throughout the unit but are concentrated in the shale beds. The clay ironstone beds are a fraction of an inch to a few inches thick, and the concretions are typically flattened and range in largest dimension from less than an inch to over 1 foot. The hard, finely crystalline beds and concretions are composed of siderite, disseminated pyrite, dolomite, and calcite. Some of the concretions are laced with a boxwork of calcite or dolomite vein fillings and appear to be septarian nodules. Abundant sandy limestone nodules are present in the upper several feet of sandstone below the underclay of the Mulky coal. Several thin beds of dark-gray, fossiliferous limestone are interbedded with shale in the lowermost 20 feet of the formation.

The northern 0.74 mile segment of the TMRT is constructed predominatly in the section of silty to sandy, gray shale near the middle of the Mulky Formation.

The lower boundary of the Mulky Formation is placed at the bottom of the lowest limestone in a sequence of three or four thin, dark-gray, fossiliferous limestone beds separated by gray shale (Searight and Howe, 1961).

The Bevier and Lagonda Formations are included as one provisional unit because the Bevier coal bed has not been recognized in western Missouri, and as a result, the upper boundary of the Bevier Formation could not be established.

The Upper Cherokee Group is replaced by the Unnamed Lower Labette channel-fill deposit along the southern 2 mile long segment of the TMRT alignment.

The Cherokee Group in the metropolitan Kansas City area is approximately 400 feet thick; the portion of the group below the elevation of the cross section consists mostly of shale, sandstone, and coal beds that overlie unconformably thick limestone beds of the Mississippian System.

STRUCTURAL GEOLOGY

The regional dip of the bedrock in west-central and northwestern Missouri is typically less than 10 ft/mi. in a north-northwestern direction, toward the structural axis of the Forest City basin in northwestern Missouri. The northwesterly dip of the strata is modified by large, broad folds of county-wide extent (McCracken, 1971). Associated with these large folds are smaller folds of a few acres to over a mile in areal extent with structural axes that are randomly oriented. The line of the cross section lies along the axis of the northwesterly-plunging nose of the Centerview-Kansas City anticline, a broad, low, northwesterly-striking fold 15 to 20 miles wide and about 50 feet high that trends across western Missouri and plunges into the subsurface along the Kansas-Missouri border near Kansas City (Clair, 1943; McCracken, 1971). Using the base of the Bethany Falls Limestone as a datum, the beds at the northern end of the cross section are approximately 25 feet lower in elevation than at the southern end, an apparent dip of 7 ft/mi. averaged over the 3.5 mile long length of the cross section. The dip is not uniform. Gently folded strata were encountered during the site investigation for the TMRT. The beds are folded into a broad, low, asymmetrical anticline with the axis crossing approximately 5,000 feet north of boring B-5, drilled near the upshaft at the southern end of the TMRT. The southern limb of the fold has an apparent dip of 10 ft/mi. and the northern limb 30 ft/mi. The regional relationships of the fold could not be determined due to the lack of subsurface control in the bedrock units that underlie the alluvium of the broad Missouri River valley in the vicinity of the tunnel alignment. Several small folds were encountered in the borings for the TMRT and are believed to be genetically related to the larger fold mapped along the southern segment of the tunnel, but some of the folding may have resulted from slumpage and compaction of soft sediments shortly after deposition. Small-scale folded structures were also recorded in the northern end of the Missouri Valley Tunnel (MVT) located approximately 1,200 feet west of the TMRT (Fuller and Maitland Engineers, n.d.).

The gently-folded, northerly-dipping strata encountered in the TMRT project are representative of the structural geology in the Kansas City area.

A major joint set is oriented northeast-southwest, while a secondary set trends northwest-southeast, and a minor set has almost a north-south direction (Hinds and Greene, 1915). Joints occur in all bedrock units and are ubiquitous throughout the metropolitan Kansas City area. The joints are essentially vertical. The spacing between joints ranges from a few inches to several feet and is dependent on location, rock type, and bed thickness. The joints in black fissile shale beds and thin limestone beds are in most places regularly spaced and a few feet apart, whereas the spacing between major joints in thick limestone, gray shale, and sandstone beds is commonly more than 20 feet. High-angle normal faults with displacement ranging from a few inches to over 100 feet have been documented in literature at several locations in the metropolitan Kansas City area (Gentile, 1984b). The faults strike in the direction of small fold axes; consequently, the faults are related to the structural grain of the midcontinent. The faults strike in the direction of the major joints and small fold axes, NW-SE or NE-SW. The majority of the faults strike in a northwesterly direction and are traceable for several hundred feet. Faulting has not been recognized in the section of rock along the line of the cross section. However, the resident engineer's reports (Fuller and Maitland Engineers, n.d.), from the construction of the MVT, included a description of a structurally-disturbed section of the tunnel approximately 200 feet south of the downshaft. The structural disturbance described in the report is representative of a high-angle fault. The strata were displaced several feet along a fracture "pitching" at an angle of 60 degrees.

CONSTRUCTION OF THE TRANS-MISSOURI RIVER TUNNEL

The construction of the TMRT proceeded in four phases.

(1) Excavation of the 20 feet diameter downshaft. The upper 116 feet of the downshaft is constructed in alluvium. Ground freezing was used to stabilize the excavation. Ground freezing was accomplished by pumping a chilled solution of calcium chloride through a system of small-diameter pipes located around the proposed downshaft and drilled through the alluvium to bedrock. The freezing solution was circulated continuously through the network of pipes until instrumentation readings showed that fluctuations in water levels had ceased, an indication that a tube-shaped section of alluvium with walls about 3 feet thick had been frozen solid to bedrock depth. The water levels in the system of small-diameter pipes around the downshaft were subject to daily fluctuations lasting for several weeks, an indication that the section of alluvium was unfrozen. The perceived cause of the daily fluctuations was heavy pumping of high yield water wells in the Water Department's well field near the intake on the Missouri River 2,000 feet west of the downshaft. When the wells were turned off the fluctuations ceased and the alluvium froze in about one day. Groundwater movement was taking place through the four- to five-foot thick zone of coarse gravel at the bottom of the column of alluvium overlying bedrock. The freezing process was completed in about one day but only after the pumps on several nearby high-yield water wells were turned off. Presumably, the freezing process was severely curtailed because of the interference by the pumps which kept groundwater in continuous motion as it flowed around the system of small-diameter pipes and toward the well intakes. The alluvium within the tube of frozen alluvium was excavated with a tracked vehicle, "Alpine Roadheader" (Figure 5).

The lower part of the shaft is in bedrock and was excavated down to the invert of the tunnel with a 20 feet diameter laser-guided vertical boring machine (VBM). During excavation, unstable bedrock walls were reinforced with wire mesh, rock bolts, and 2-inch-thick fiber-reinforced shotcrete.

The upper 20 feet of the shaft was supported by steel liner plates. The remaining portion was lined with concrete.

(2) Excavation of the 11 feet diameter tunnel bore. Tunnel excavation was accomplished with a 129 in. diam.

Lovat Tunnel Boring Machine (TBM) with the nickname "Linda" (Figure 6). The 700 h.p. self-propelled machine was guided by a laser beam. The tunnel bore is slightly larger than the TBM-diameter because the forward thrust of the machine is accompanied by small lateral movements.

The TBM excavated about 110 feet during a 24-hour period. The work force typically consisted of two crews, each crew working a 10-hour shift. The TBM was in operation for about eight hours during each shift.

The elevation of the ground surface along the tunnel alignment ranges from approximately 740.0 mean sea level (m.s.l.) on the floodplain to 765.0 (m.s.l.) on the south bank of the Missouri River. The depth of the tunnel invert ranges from 325 feet at the downshaft to a minimum of 265 feet below the channel of the Missouri River to a maximum of 335 feet on the south bank of the river at the upshaft. The invert of the tunnel is 415.0 feet m.s.l. (-307.0 feet Kansas City, Missouri City datum) at the north end of the tunnel and 430.0 feet m.s.l. (-292.0 feet Kansas City-Missouri City datum) at the south end of the tunnel. The tunnel was bored upslope in order to better handle groundwater inflow. The tunnel slope is 0.1 percent downward to the north, a difference in elevation of approximately 15 feet over the 14,475 ft (2.74 mi) length of the tunnel. *

The excavated rock was removed in carts pulled by a diesel-powered tunnel train. Air was circulated through the tunnel at a rate of 200 ft/min. to remove concentrations of potentially noxious, mostly methane,

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* The Kansas City, Missouri City datum is a system used to establish elevations in the early days of Kansas City. The system has been retained and its use is required on city-financed projects. The Kansas City, Missouri City datum plane 0.0 feet elevation is established at +722.30 feet (m.s.l.).

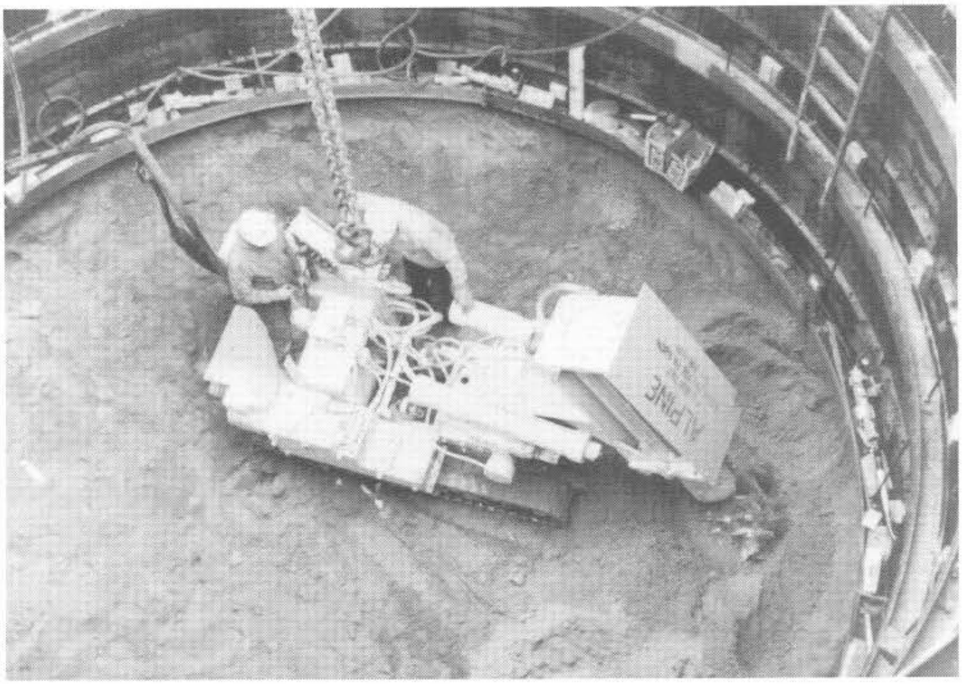

Figure 5.
Constructing downshaft of Trans-Missouri River Tunnel. Frozen alluvial sand and gravel at the periphery of the shaft is excavated with an Alpine Roadheader Vehicle.

gas. Three, 3 ft diam. air shafts were drilled between the downshaft and upshaft and lined with steel casing.

(3) Excavation of the 16 feet diameter upshaft. The upshaft, with the exception of the upper several feet of fill and surficial materials, is constructed in bedrock and was excavated with the vertical boring machine adjusted to fit the 16 ft diam. specifications for the shaft. During excavation, unstable bedrock walls were reinforced with wire mesh, rock bolts, and 2-inch-thick shotcrete.

(4) Installation of a concrete pipe liner. The tunnel and the vertical shafts were lined with 20 ft. segments of 29 ton, 8¼-inch-thick prestressed concrete cylinder pipe with an inside diameter of 90 inches and an outside diameter of 107 inches. The segments of pipe were transported in the tunnel on dollies, pulled by a train. The annular space between the liner and the rock wall is grouted with lightweight cellular concrete. The point of greatest water pressure, at the bottom of the upshaft, is reinforced with an extra liner of poured concrete capable of sustaining 215 lb/in^2 water pressure.

The construction phase of the TMRT project required approximately 16 months to complete. The excavations for the downshaft and upshaft began in February 1991 and October 1991 respectively. The excavation for the 2.74-mile-long tunnel began at the bottom of the downshaft in October 1991 and the tunnel "holed out" at the bottom of the upshaft on June 18, 1992 (Figure 7). The project was dedicated June 17, 1993.

Figure 6.
The 129-inch, self-propelled tunnel-boring machine "Linda," used to excavate the bore for the Trans-Missouri River Tunnel.

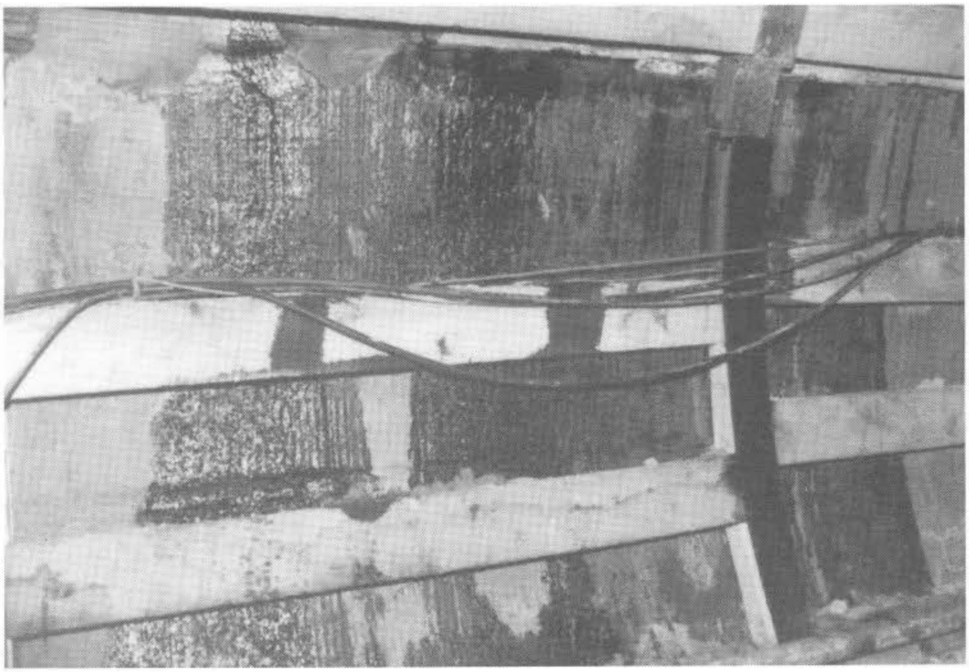

Figure 7.
The tunnel-boring machine "holes out" at the bottom of the upshaft, June 18, 1992.

ENGINEERING GEOLOGY OF THE TRANS-MISSOURI RIVER TUNNEL

The geotechnical properties of the rock units in the downshaft, tunnel bore and upshaft were documented by the junior authors of the paper and included the physical properties of the rock units, the orientation and spacing of joints and fractures, the location of oil, gas and groundwater seeps and quantity estimates.

During construction of the downshaft, small quantities of natural gas and 3 to 6 gal/min. of groundwater, estimated to be 90 percent of the water seepage into the downshaft, issued from the interval consisting of the Anna Shale Member, Pawnee Formation and the Englevale Sandstone Member, Labette Formation. A system of closely-spaced vertical joints in the black fissile shale portion of the Anna Member readily transmit groundwater under the head pressure of the gas. Gas-filled water bubbles seeped from the pores between sand grains in the Englevale Sandstone Member. Small amounts of gas were emitted from the Mulky coal bed.

Loss of integrity along joints and fractures caused spalling and caving during construction of the downshaft in the underclays of the Mulberry and Alvis coal beds. The loss of integrity is commonly highest in underclay. Small amounts of spalling and caving were also recorded in the Mine Creek Shale Member and the silty shale beds in the Mulky Formation.

The bore along the northern three-forths mile-long segment of the tunnel passed through beds of the Mulky Formation, Cherokee Group, whereas the southern extension of the tunnel, almost 2 miles long, is constructed in the Unnamed Lower Labette channel-fill deposit, Labette Formation, Marmaton Group. The apparent dip of the strata and the incline of the tunnel are in a north-northwest direction and of approximately equal magnitude. Consequently, the tunnel bore passed essentially parallel to the bedding. An exception is near the southern end of the tunnel, where several feet of older beds have been raised to the level of the tunnel bore in a small anticline at the southern end of the TMRT and described in the section on structural geology.

The stratigraphic interval in the bedrock sections that was selected for construction of the tunnel met the following three conditions: (a) the thickness of bedrock is over 100 feet between the top of the interval (the elevation of the tunnel invert) and the bottom of the deep trench filled with Pleistocene-age surficial deposits; (b) relatively low hydrocarbon concentration; and (c) rock properties favorable to the tunnel boring machine. The selected interval consists predominantly of silty to sandy, gray shale.

The Mulky Formation in the tunnel bore consisted mostly of silty to sandy, gray, micaceous shale with a small percentage of clay ironstone. The clay ironstone concretions typically were dislodged intact by the boring machine but had little effect on the cutting action of the machine.

Small amounts of low-gravity oil and groundwater seeped from sets of joints and fractures and a few pockets of natural gas were encountered in the silty to sandy, gray shale of the Mulky Formation (Figure 8). The quantities were too small to be recorded.

The trend of the joints mapped in the tunnel was NE-SW and NW-SE which approximated the direction of the joints mapped in surface rocks, but a large percentage of the joints in the tunnel had randomly oriented, steeply-dipping, joint planes. A number of them could have been fractures caused by the cutting action of the boring machine. Small areas of fall-out typically occurred in the wall rock at the tetrahedral intersections formed between closely-spaced joints, fractures and bedding planes.

The bedrock lithology is more variable at the place where the tunnel bore passed into the Unnamed Lower Labette channel-fill deposit. In addition to silty to sandy gray, micaceous shale, other lithologies include conglomerate, sandstone, thin beds of sandy, gray shale and thin coal seams with their associated underclays. The silty to sandy shale includes clay ironstone in thin beds and zones of concretions.

Intervals of silty to sandy, gray shale, several hundreds of feet wide, alternate with intervals of conglomerate and cross-bedded sandstone a few tens of feet wide. These sedimentary facies represent point bar deposits described in the section on Areal Geology. Oil and groundwater were emitted from interconnected pores and open spaces in the conglomerate and sandstone, whereas smaller amounts of seepage came from the joints. The intervals of shale appear to have acted as barriers to migration of fluids and gas.

At places, the rock section was folded into small anticlines that were traps for small quantities of natural gas, mostly methane. These pockets of natural gas were a threat to the health and safety of workers and required an elaborate moni-

Figure 8.
Low-gravity oil seeping through shale bedrock during construction of Trans-Missouri River Tunnel.

toring and removal system. A horizontal probe hole drilled 160 feet ahead of the TBM (tunnel boring machine) to locate pockets of gas had limited success. At some places, the probe successfully located the gas pockets (Frerichs and Eggers, 1993), but at other places, small anticlinal traps located below the probe were not detected. Some rapid emissions of gas, referred to as "blowouts," occurred in the tunnel wall behind the shield of the TBM.

Oil seepage was more of a nuisance than a threat. It coated workmen and equipment with black grime. The emitted oil was collected in straw mat absorbers and removed in railroad muck cars along with the 100,000 tons of excavated rock from the tunnel. The oil-contaminated spoil had to be visually separated from the non-contaminated material for disposal at a local landfill. The non-contaminated portion of the excavated rock was used on-site for backfilling purposes. Groundwater and the piped water used to operate the boring machine was pumped to a surface storage lagoon.

Small areas of collapse occurred in the tunnel roof typically at the intersection of joints and fractures in relatively weak shale. The wood logging system used for temporary support of the tunnel liner proved sufficient to contain collapsed areas.

The upshaft, with the exception of the upper several feet of fill and surficial materials is constructed in bedrock. The loss of integrity in the upper several feet of the Perry Farm Member, Lenapah Formation resulted in cavities that extended 4 feet into the wall of the shaft and were 6 feet wide. The cavities could be traced 12 to 13 feet along the circumference of the shaft. These areas required additional support during construction. The upper part of the Perry Farm is soft underclay and claystone, fractured to rubble by closely-spaced, randomly-oriented fractures. Slickensided surfaces reveal that movement has taken place along microfaults that were probably formed by differential consolidation of clay-rich rocks. The problem of slaking and caving was aggravated by the free movement of groundwater downward into the system of fractures from the overlying Holdenville Formation. The Holdenville, a thin, black fissile shale bed, readily transmits water along a set of vertical, closely-spaced joints.

Seepage of oil from the Hepler Sandstone Member formed rivulets and flowed down the walls of the upshaft excavation. Lesser amounts of oil issued from seeps in the Bandera Quarry Sandstone Member, the sandstone beds in the Mine Creek Member and the Unnamed Lower Labette channel-fill deposit. Special measures were employed to seal off the oil seeps in the shafts or tunnel.

The majority of bedrock units shown in the cross section are continuous and of relatively similar composition over large areas of the midcontinent (Searight and Howe, 1961 and Gentile, 1984 a,b). It is reasonable to assume that the geotechnical properties of rock units in other areas will approximate those encountered during construction of the TMRT.

THE MISSOURI VALLEY TUNNEL

The TMRT provides a redundant system to the Missouri Valley Tunnel (MVT), the sole conveyor of water to areas south of the Missouri River since completion in 1928 (Figure 1).

While the MVT is capable of meeting the water needs of the city, the integrity of the tunnel and the lack of a redundant system were the major concerns that provided incentive to construct the TMRT. Water pressure in the MVT has been maintained internally at about 150 pounds per square inch continuously for over 65 years, raising the fear that a reduction in water pressure would allow the tunnel and shafts to collapse and set off a chain of events that would result in a social and economic catastrophe of major proportions.

The MVT runs essentially parallel to the TMRT from 1,000 - 1,500 feet west of it. The 15,478 foot (2.93 mile) long, 7.5 ft diameter tunnel is connected with the surface through two 300 ft deep vertical shafts. The invert of the nearly horizontal tunnel is 460.3 ft m.s.l. (-263 feet Kansas City, Missouri City datum), about 30 feet higher in the section than the TMRT.

The tunnel connects the downshaft at the Kansas City, Missouri Water Treatment Plant in Kansas City North, Missouri, to the upshaft at the intersection of Front and Wyandotte streets in Kansas City, Missouri. The tunnel capacity is 220 million gallons per day.

Construction of the MVT was begun in July, 1925, with the major part of the excavation completed by late October, 1927. The contract was finalized in July, 1928. The cost of the project was $1,316,000.

The bedrock was excavated by typical mining methods of the day: drill, blast, and muck. Construction crews drilled and blasted from each shaft and "holed out" near the center. The work force was typically about 100 people working three eight-hour shifts. Under good working conditions, the total footage of the two headings was 30 to 40 feet during a 24-hour period. The liner of the tunnel and the shafts is cast-in-place concrete with a minimum thickness of 8 inches. The section of alluvium in the downshaft was excavated by sinking a reinforced concrete compressed air caisson.

The construction methods, equipment, and safety practices available in the 1920s made the excavation and lining of the tunnel a dangerous job. The relatively weak shale bedrock at the tunnel level was further weakened by overblasting and lack of adequate supports. Many injuries were reported from roof collapses. The company physician reported treating over 680 cases of personal injury during construction of the tunnel (Kansas City Star, 1927). In addition, lack of adequate ventilation and safety practices contributed to nine gas explosions that occurred during the initial stages of tunnel excavation. One explosion,

Figure 9. *Tunnel excavation crew poses for a photograph during drilling operations for the Missouri Valley Tunnel, circa 1925.*

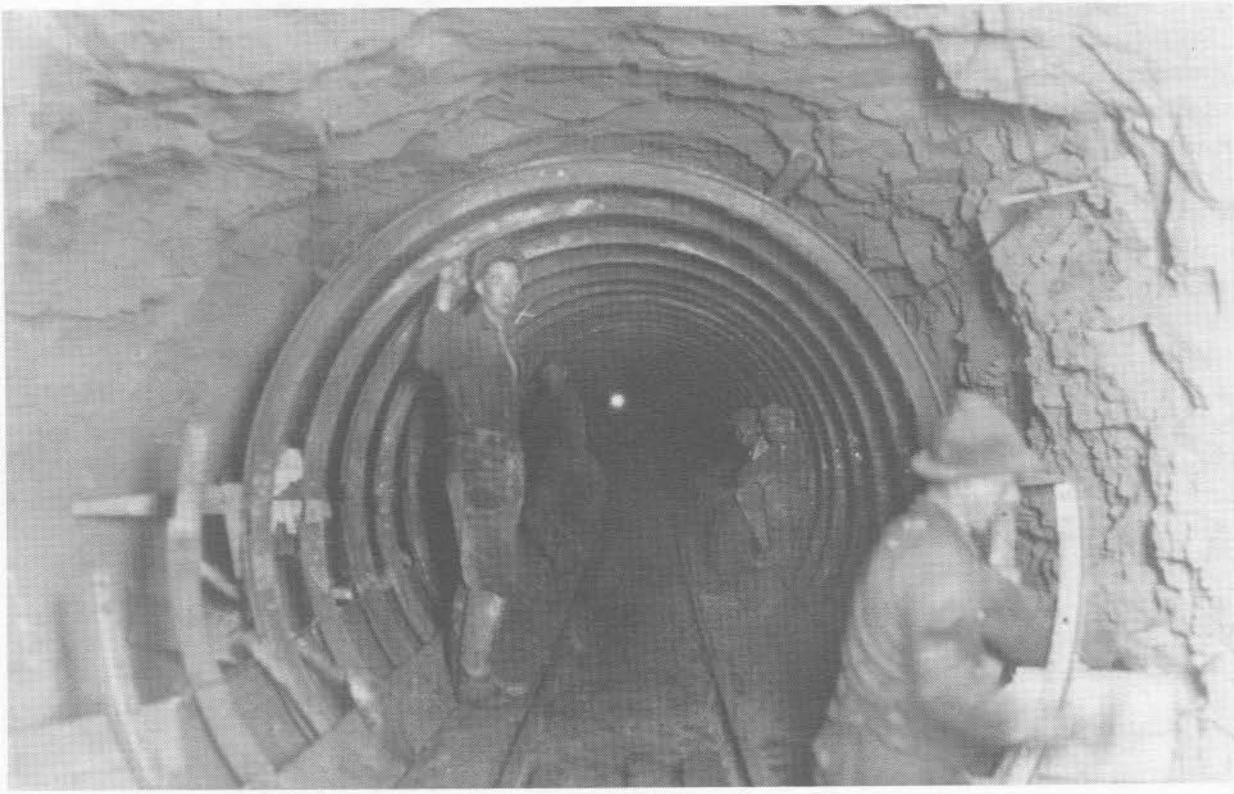

Figure 10. *Construction phase of the Missouri Valley Tunnel, February 12, 1926. View is along a segment of the tunnel about 1,400 feet from one of the shafts. The rock walls were supported with temporary forms until a finished concrete liner could be installed.*

which occurred after a failure of the ventilation system, was particularly severe and resulted in seven fatalities. After the fatal explosion occurred, better safety practices were employed and a back-up ventilation system was installed. The result was only one minor explosion during the remainder of the project (Kansas City Water and Pollution Control Department, 1993).

The TMRT project was a remarkably safe and efficient operation in comparison to the problems that plagued the builders of the MVT (Frerichs and Egger, 1993). The MVT and shafts were inspected after the TMRT went on line. The downshaft of the MVT was found to be out-of-plumb and water loss was occurring along a crack in the liner. The tunnel was inspected with an underwater camera system and it was found to be intact. Repairs have been made on the downshaft and the MVT is back on line on a limited basis.

Stratigraphic Designation	Core Boring #	Thickness of Zone (ft.)	Depth to Top of Zone (ft.)	Elevation Top of Zone (MSL)	Rock Type
Pleasanton Group Hepler Sandstone Member	B-4	5.0	126.0	614.5	Sandstone
	B-5	12.0	151.0	614.9	"
Marmaton Group Lenapah Formation Perry Farm Sh. Member	B-5	6.0	175.0	590.9	Sandstone
Bandera Formation Bandera Quarry Ss. Mbr.	B-1	15.0	215.0	526.1	Sandstone
	B-2	10.0	216.0	530.9	"
	B-3	9.0	195.0	546.0	"
	B-4	8.0	194.0	546.5	"
	B-5	5.0	225.0	540.9	"
Pawnee Formation Coal City Limestone Mbr.	B-1	3.0	240.5	500.6	Limestone
	B-2	2.0	242.0	504.9	"
Mine Creek Shale Member	B-2	3.0	248.5	498.4	Sandstone
	B-3	5.0	224.1	516.5	"
	B-5	4.0	251.0	514.9	"
Labette Formation Englevale Sandstone Mbr.	B-1	3.0	274.5	466.6	Sandstone
	B-3	8.0	253.0	488.0	"
	B-4	6.0	244.0	496.5	"
	B-5	3.0	301.5	464.4	"
"Unnamed Lower Labette channel-fill deposit"	B-3	24.0	355.0	386.0	Sandstone & conglomerate
	B-4	15.0	285.5	455.0	Sandstone
	B-5	5.0	320.5	445.4	
Cherokee Group Lagonda Formation Squirrel Sandstone Mbr.	B-1	13.0	370.5	370.6	Sandstone
	B-2	16.0	372.5	374.4	"

Table 2. *Stratigraphic Units Impregnated with Low-gravity Oil*

HYDROCARBONS

There are records of several oil and gas test wells that were drilled prior to World War II within one-fourth mile of the cross section. The wells were spudded on the floodplain and completed to a depth of several hundred feet. Poorly-kept records give only approximate locations of the wells. There were shows of oil and gas, but the wells never produced. Three or four wells were drilled on the south bank of the Missouri River several hundred feet south of the uptake shaft. Small quantities of gas were produced commercially, but there has been no production from the field for many years. The producing horizon could not be determined because of the poor quality of the drill records.

Shows of low-gravity oil were recorded from several stratigraphic zones in the test core samples for the site investigation for the TMRT. Information about oil-impregnated zones is summarized in Table 2.

The commercial production of oil and gas from several small fields in west-central Missouri is from one or a combination of the following units: Anna Shale Member (the "Lexington cap" of drillers); Englevale Sandstone Member, Unnamed Lower Labette channel-fill deposit; and the "Squirrel" Sandstone. The Anna Shale Member and the Englevale Sandstone Member are the reservoir rock for most of the gas produced in small fields in western Missouri in former times.

The highest-producing wells are found where Englevale Sandstone Member, Unnamed Lower Labette channel-fill deposit and "Squirrel" Sandstone Member are superimposed or "stacked" one above the other and comprise a sequence of hydrocarbon-bearing units over 100 feet thick (Gentile, 1984b).

Sandstone and conglomerate beds in the Unnamed Lower Labette channel-fill deposit are lithologically similar to those of the "Squirrel" Sandstone and cannot be distinguished from them by physical properties. In places where the hydrocarbon-bearing beds of the channel-fill deposit are at the stratigraphic position of the "Squirrel" Sandstone, it is reasonable to assume that at least some of the wells were producing from them.

GROUNDWATER

Alluvial Aquifers

The alluvial fill of the Missouri River valley is a major source of groundwater. There are records of about two dozen high-yield wells drilled on the floodplain within a distance of one-fourth mile along the length of the cross section. The wells typically yield 1,000 gal/min. The water is the calcium carbonate type, characterized by high hardness and high iron content, with dissolved solids content ranging from 275 to 1,000 mg/l (milligrams per liter).

Depth to groundwater typically ranges from 15 feet to greater than 30 feet. The water levels fluctuate seasonally and are influenced by river stage, recharge, pumping and evapo-transpiration cycles.

Information about groundwater from alluvial aquifers is found in reports by Fishel (1948) and Emmett and Jeffery (1970).

Bedrock Aquifers

The bedrock formations yield small quantities of groundwater, typically less than 10 gal/min, particularly from black, fissile shale and sandstone beds. Small quantities of fresh to slightly saline water is obtained from wells less than 100 feet deep and locally from wells as deep as 250 feet. Groundwater from wells deeper than 300 feet is moderately to highly saline and usually below the U.S. Public Health Service standards.

For information about groundwater from bedrock formations the reader is referred to publications by Fuller (1963); Knight (1963); Robertson (1963); Gann (1974); and Gentile (1984b).

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APPENDIX I

COMPOSITE STRATIGRAPHIC SECTION OF BEDROCK UNITS ALONG THE LINE OF THE CROSS SECTION.

A composite stratigraphic section of the Pennsylvanian bedrock units across the Missouri River valley along the line of the cross section. The total thickness of Pennsylvanian strata is approximately 560 ft.

Stratigraphic Designation	Lithologic Description	Thickness (ft)
Pennsylvanian System		
Missourian Series		
Kansas City Group		
Wyandotte Formation		
Farley Limestone Member	Limestone, med. dark-gray; cross-bedded, oolitic, *Osagia*.	3.0
Island Creek Shale Member	Shale, med.-gray; interbedded with thin laminae of siltstone, thickness increases to 20 ft on north bluff.	10.0-20.0
Argentine Limestone Member	Limestone, lt.-gray; thin wavy beds; thick-bedded top 2-3 ft; thin shale bed near bottom; thins to north; solution-widened joints.	20.0-45.0
Quindaro Shale Member	Shale, gray; interbedded with lt.-gray limestone; silty; diverse invertebrate fauna mostly bryozoans, crinoids.	0.5-3.0
Frisbie Limestone Member	Limestone, argillaceous; thick- to thin-bedded at top; phylloid algae; crinoids, brachiopods.	0.5-3.5
Lane Formation	Shale, med.-gray; silty near top; flattened ironstone concretions in upper half; thin zone of crinoids 10 ft from bottom.	20.0-26.0
Iola Formation		
Raytown Limestone Member	Limestone, lt.-gray, thick-bedded; abundant phylloid algae; large productid brachiopods at top.	5.0-6.5
	Shale, med.-gray; *Hustedia*, crinoid columnals.	0.3-0.6
	Limestone, med.-dark-gray; bioclastic, crinoidal.	0.3-0.7
Muncie Creek Shale Member	Shale, black, fissile; 1 in. diam. calcium phosphate nodules; upper 0.5 ft med.-gray with zone of *Conularia crustula*; lower 0.5 ft soft, med.-gray.	1.5-4.0
Paola Limestone Member	Limestone, dark bluish-gray, finely crystalline, hard, thick-bedded.	1.0-2.5

Chanute Formation	Shale, med.-gray	1.0-3.0
	Shale, sandy; grades locally into thin-bedded calcareous sandstone; lenticular; *Composita, Myalina, Derbyia*, some large gastropods of the genus *Worthenia* along north Missouri River bluffs.	0.0-3.0
	Coal; zone of carbonized plant fragments south of Missouri River.	0.0-0.1
	Underclay; carbonized roots.	0.0-0.6
	Shale, med.-gray; mottled maroon and greenish-gray; unstable, slumps.	3.0-8.0
	Shale, olive-gray; zone of silty to sandy limestone nodules near top.	1.0-5.0
	(Formation ranges in thickness from 6.0 to 18.0 ft. locally).	
Drum Formation		
Cement City Limestone Member	Limestone, lt.-gray; interbedded with thin beds of gray shale.	3.0-5.0
	Limestone, lt.-gray; weathers lt.-yellowish-brown; thin, wavy bedding, but outcrop appears as a single massive ledge; large "horn" corals of the species *Caninia torquia.*	4.0-5.0
Cherryvale Formation		
Quivira Shale Member	Shale, olive-gray; *Orbiculoidea.*	1.0-3.0
	Shale, black, hard, slightly fissile; small calcium phosphate nodules.	0.6-1.0
	Shale, calcareous; hard; forms ledge.	0.6-0.8
	Coal, discontinuous.	0.1
	Underclay, med.-gray; blocky.	0.6-2.0
	Shale, med.-gray; interbedded with thin-bedded to nodular limestone; brachiopods, bryozoans; scour surface to slight channeling at base.	5.0-8.0
Westerville Limestone Member	Limestone, lt.-gray, cross-bedded; bioclastic; oolitic; fusulinids.	2.0-3.5
	Limestone, lt.-gray; shale laminae near top and middle; chert nodules in upper part; thickness increases to north.	5.0-10.0
Wea Shale Member	Shale, med.-gray; flattened, clay ironstone concretions	15.0-20.0
	Shale, med.-gray, interbedded with beds and lenses of dark-gray limestone; abundant brachiopods of the species *Crurithyris planoconvexa* and encrusting foraminifera (ammovertellids).	5.0-8.0
Block Limestone Member	Limestone, med.-gray, weathers reddish-brown, blocky; brachiopods.	1.0-1.1
Fontana Shale Member	Shale, med.-dk.-gray, *Chonetina flemingi.*	3.0-3.5
	Shale, dark-gray, hard, siliceous; carbonized plants *Cordaites, Calamanites;* high-spired gastropods, bellerphonid gastropods replaced by white chert.	0.0-0.6
	Coal; discontinuous.	0.0-0.1
	Shale, with beds of conglomerate, cross-bedded bioclastic limestone; locally fills channel eroded into Winterset limestone.	4.5-6.0

Dennis Formation		
Winterset Limestone Member	Limestone, dark-gray; abundant lenses and nodules of dark-bluish-gray chert; interbedded with thin beds of shale.	4.5-6.0
	Limestone, lt.-gray; dark-bluish-gray chert nodules in upper part; interbedded with thin, gray shale beds; *Aviculopinna*.	4.0-5.0
	Shale, med.-gray; interbedded with limestone.	2.0-3.0
	Shale, med.-gray, becoming dark-gray at the top.	2.0-3.0
	Limestone, lt.-gray; weathers tan; lenses and nodules of brown chert in top 0.5 ft..	7.0-8.0
	Limestone, lt.-gray, with two beds of gray shale up to 0.5 ft. thick.	4.0-5.0
	(The thickness of the Winterset Member ranges from 25.0 to 30.0 ft.).	
Stark Shale Member	Shale, dk.-gray at bottom, becoming lt.-gray at top; sinuous trails.	2.0-3.0
	Shale, black, fissile, small nodules (.05 inch diam.) and laminae of calcium phosphate.	1.0-2.0
Canville Limestone Member	Shale, gray, and shaly limestone, *Derbyia, Composita, Curithyris*.	0.05-0.5
Galesburg Formation	Claystone, lt.-gray, becoming med.-gray at top; slickensides; soft.	2.5-3.5
Swope Formation		
Bethany Falls Limestone Member	Limestone, nodular; matrix of lt.-gray clay.	3.0-5.0
	Limestone, lt.-gray; thin, wavy beds, dk.-gray nodules.	8.0-10.0
	Limestone, lt.-gray; thin to medium, wavy beds to thick-bedded at bottom.	6.0-8.0
	(Thickness of member is relatively constant at 20.0 ft.).	
Hushpuckney Shale Member	Shale, med.- to dk.-gray in upper half; lower half black, fissile with small nodules of calcium phosphate.	3.8
Middle Creek Limestone Member	Limestone, dk.-bluish-gray, hard, finely crystalline; bryozoans; shale parting 0.3 ft. thick near middle; lower limestone bed 1.4 ft. thick, nodular, clayey.	2.9
Ladore Formation[1]	Shale, med.-gray; sparse limestone nodules in lower half.	2.9
Hertha Formation		
Sniabar Limestone Member	Limestone, lt.-gray, compact; upper few inches nodular, clayey; 0.1 ft. gray shale parting 2.2 ft. from bottom.	8.2
Mound City Shale Member	Shale, med.-gray, nodular, bioturbated; lower 0.5 ft. black, soft, with small, calcium phosphate nodules.	1.8
Critzer Limestone Member	Shale, med.-gray; small nodules of limestone in upper and lower few inches.	2.6

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[1] *The formational name "Elm Branch" has been proposed to replace Ladore (Watney et al., 1992)*

Pleasanton Group		
	Shale, gray, silty; a 6.0 ft thick bed of sandstone 4.5 ft from top.	26.9
	Sandstone, med.-gray, bioturbated; brachiopods ("Knobtown Sandstone Facies")	0.7
	Sandstone, med.-gray, micaceous, bioturbated (Warrensburg Sandstone Member)	7.7
	Shale, med.-gray; interlaminated with silty sandstone in middle part.	53.2
	Limestone, dk.-gray, shaly; gastropods, crinoid fragments, pelecypods.	0.0-0.10
	Coal[2]	0.0-0.05
	Underclay; carbonized roots.	0.6
	Shale, olive-gray; limestone nodules, silty.	0.0-1.0
	Sandstone, fine- to med.-grained, cross-bedded, micaceous; low-gravity oil show; unconformity at bottom (Helper Sandstone Member)	12.0-15.0
Desmoinesian Series		
Marmaton Group		
Appanoose Subgroup		
Holdenville Formation[3]	Shale, med.-gray, noncalcareous shale, black, fissile with laminae and nodules of calcium phosphate.	0.6-2.5
Lenapah Formation		
Sni Mills Limestone Member	Shale, med.-gray; fragments of shells.	0.0-0.2
Perry Farm Shale Member	Underclay, gray; carbonized roots; slickensides; crumbles easily.	1.0-4.0
	Shale, maroon and green (the maroon zone is an excellent subsurface marker); nodules of limestone; brachiopods; interbedded with siltstone and sandstone laminae.	8.0-12.0
	Sandstone, brown, fine-grained, cross-bedded; convoluted; load structures; oil stain to south; interbedded with gray shale.	14.0-22.0
	Shale, gray, silty.	1.0-14.0
	Thickness of Perry Farm Member ranges from 39.0 to 42.0 ft.	
Norfleet Limestone Member	Limestone, shaly, reddish-brown; bioclastic, crinoidal.	0.0-0.3
Nowata Formation	Shale, med.-gray, silty, sandy.	0.0-6.8
Altamont Formation		
Worland Limestone Member	Limestone, lt. gray; nodular with olive gray clay matrix; med.-bedded near middle; thickness increases to south along tunnel alignment.	2.3-6.0
Lake Neosho Shale Member	Shale, dk. gray to black in lower few inches; upper part fossiliferous; thickness increases to south.	0.8-2.0
Amoret Limestone Member	Limestone, nodular with lt.-gray to olive-gray clay matrix.	0.7-3.0

[2] *Howe, 1982, has proposed the name Grain Valley for this coal bed.*

[3] *A revised classification of the upper Marmaton Group along the midcontinent outcrop belt has been proposed by Heckel (1991). According to Heckel, the Holdenville Formation and the Sni Mills Member comprise the Lost Branch Formation. The lower part of the Holdenville Formation consisting of a thin, black fissile shale bed, a persistent marker bed in west-central Missouri, is correlated with the Nuyhaka Creek black shale bed, Lost Branch Formation.*

The Perry Farm Shale Member, Lenapah Formation is correlated with the Memorial Shale and the formational name Lenapah is restricted to the Norfleet Limestone Member in Missouri.

Bandera Formation	Sandstone, fine-grained, cross-bedded, micaceous; interbedded with shale; oil show; thickness increases to north (Bandera Quarry Sandstone Member).	7.0-25.0
	Shale, gray; excellent flora zone: *Cordaites, Lepidodendron, Neuropteris?*	5.0-7.0
	Coal; interbedded shale lenses (Mulberry Coal)	1.0-1.1
	Underclay; carbonized roots.	1.0-2.9
	Shale, lt.-gray to olive-gray.	0.0-3.9
Pawnee Formation		
Coal City Limestone Member	Limestone, lt.-gray; nodular with clay matrix; med.-bedded near middle; *Chaetetes milleporaceous*; oil show.	7.8-8.7
Mine Creek Shale Member	Shale and thin-bedded limestone, fossiliferous.	0.0-2.5
	Shale, med.-gray with sandstone facies in upper part 1.0 to 10.0 ft thick, stained with oil.	16.0-22.0
Myrick Station Limestone Member	Limestone, med.-bluish-gray, shaly; *Composita*, bryozoans, crinoid ossicles, small productid brachiopods.	2.0-4.0
Anna Shale Member	Shale, med.-gray, fossiliferous.	0.0-2.0
	Shale, black, fissile, with small, calcium phosphate nodules.	1.0-3.6
Labette Formation	Coal (Lexington Coal Bed)	0.0-0.1
	Sandstone, fine-grained; carbonized roots in upper few feet; oil show; interbedded with thin, gray shale lenses increasing downsection (Englevale Sandstone Member).	10.0-15.0
	Shale, gray; with two or three shaly limestone beds in upper part; brachiopods, two thin coal beds with associated underclays in lower few feet, lowermost coal 0.1 ft thick (Alvis coal); lower part grades southward along TMRT into sandstone and shale.	20.0-35.0
"Lower Unnamed channel-fill deposit"	Sandstone, fine- to med.-grained; shale, gray, silty to sandy; conglomerate (predominantly granule to fine pebble-size clasts of limestone, subangular to rounded, lt.-gray to tan; some flat, pebble clasts of coal and gray shale, matrix of med.-grained quartzose sand); two or three thin discontinuous coal beds and associated underclays; oil shows in beds of cross-bedded sandstone and conglomerate. Abrupt lateral and vertical facies changes. Replaces the Fort Scott Subgroup, Marmaton Group, Excello, Mulky, Lagonda-Bevier Formations, Cherokee Group along the southern alignment of the TMRT.	125.0+
Fort Scott Subgroup		
Higginsville Limestone	Limestone; nodular with olive-gray clay matrix.	0.5
Little Osage Formation	Shale, dk.-gray, fossiliferous; a 2.0 ft thick bed of limestone with small crinoid ossicles near middle (Houx Limestone Member).	5.0-6.0
	Shale, black, fissile; small ,calcium phosphate nodules.	0.6-1.0
Blackjack Creek Limestone	Limestone, med.-dk.-gray, shaly; brachiopods, crinoid fragments.	0.0-0.5

Cherokee Group		
Cabaniss Subgroup		
Excello Shale	Shale, med.-gray.	0.0-0.1
Mulky Formation	Coal.	0.05-0.1
	Underclay; carbonized roots.	0.6-1.0
	Sandstone, fine-grained, micaceous; interbedded with gray shale; zones of clay ironstone concretions; upper few feet with sandy limestone nodules (Breezy Hill Limestone Member).	25.0-35.0
	Shale, med.-gray; flora zones; silty.	0.0-8.0
	Shale, med.- to dk.-gray; interbedded with three or four thin, dk.-gray clayey, limestone beds with crinoid fragments, brachipods, gastropods. Formational boundary placed at bottom of lowermost thin limestone (Iron Post?).	21.0-23.0
Lagonda-Bevier Formations	Shale, gray; zones of clay ironstone concretions; 10-15 ft. of cross-bedded sandstone in middle and upper part; show of oil ("Squirrel" Sandstone Member).	30.0-55.0

Bottom of core borings

APPENDIX II

A Brief History of the Kansas City, Missouri, Water Supply System

The Early Years - Before 1874

Before construction of the first municipal water works in 1874, the residents of the City of Kansas (now Kansas City) obtained water from several sources. The most common practice was to construct a cistern for the storage of rainwater.

Groundwater emerged as springs along the river bluffs and in deep ravines and many of the early residents used the springs as a source of water. All of the springs were fed by precipitation that fell in local drainage basins. During wet seasons the flow reached several hundred gallons an hour, but slowed to a trickle, or the springs were dry during periods of low rainfall (Schweitzer, 1892). Many of the springs were believed to have medicinal properties (McCourt et al., 1917).

The springs issued from several stratigraphic horizons, but most of the flow was from near the contact of shale beds and loess (windblown silt). The loess layer is over 75 feet thick on the hill tops and is moderately permeable. Loess supports the downward passage of groundwater through interconnected pores. Upon reaching the impermeable shale layers that underlie the loess, the water moves laterally and is emitted as springs on the sides of the hills. The largest springs issue from the Argentine limestone/shale contact. The Argentine Limestone Member, Wyandotte Formation is 35-40 feet thick and underlies the loess throughout most of downtown Kansas City. A system of solution-widened vertical joints in the Argentine Limestone Member acts as a conduit for the passage of groundwater from the section of loess above the Argentine to the impermeable shale beds that underlie it.

Over the years the springs have been piped underground.

> *The town site had originally many fine springs bubbling out from the hillsides, but in the process of grading streets and excavation for buildings the springs were covered over and the veins laid bare and dried up (Case, 1888).*

Nevertheless, seepage of groundwater is a common occurrence in excavations at places where loess or limestone overlies impermeable shale beds.

Small quantities of mineralized spring water with a faint odor of hydrogen sulphide (H_2S) is emitted from exposures of thin, black, fissile shale, 1 or 2 feet thick, that comprise the Muncie Creek Member, Iola Formation, and the Quivira Member, Cherryvale Formation. The groundwater movement is through sets of interconnected closely-spaced vertical joints.

The dug wells ranged in depth from a few feet to 50 or 60 feet. Most of the wells in upland areas produced from near the bottom of the section of loess. In seasons of normal rainfall the quantity was sufficient for ordinary household use. Dug wells yielded relatively large quantities of groundwater from the alluvium in the valleys of the Kansas and Missouri rivers and the valleys of the larger tributary streams (McCourt et al., 1917).

A large supply of water came from the Missouri and Kansas rivers. The early settlements were built on low ground near navigable rivers. The people pushed small carts to near the edge of the river and loaded them with bottles and jugs of river water (Kansas City Star, September 16, 1935).

The First Municipal Water Works 1874-1886

In 1874 the population of Kansas City was 35,000. The city was growing rapidly and needed a reliable supply of potable water for daily consumption and for fire protection. On November 5, 1873, by a vote of 2,396 for and only 74 against, the people of Kansas City approved an ordinance to construct the first municipal water works. The National Water Company, a private business, prepared plans with the instruction "to receive, purify, store, conduct, and distribute water of a pure, well-settled and wholesome quality."

The water works, known as the Lower Turkey Creek Pumping Station, was built on the floodplain near the confluence of Turkey Creek and the Kansas (Kaw) River, at 23rd and Allen streets, a part of the city known as the West Bottoms (Figure 1).

Water from the Kansas River entered a double-deck receiving crib on the river bank and extending about 50 feet out into the river. The lower crib received water during low river stages and the upper one during high stages when the river carries considerable sediment near its bottom. From the receiving cribs the water flowed via siphon action through 1,320 feet of 24 inch inside diameter pipe into a receiving well located inside the pump house. From the pump house the river water entered an irregular-shaped reservoir, its shape conforming to the railroad tracks on the west side and Turkey Creek on the east. The reservoir varied in depth from 10 to 13 feet and covered two acres. The maximum capacity was 6,785,000 gallons. The reservoir had a dividing wall extending nearly the length of the basin. The only treatment the river water received was the removal of large-sized sediment by settling in the basin. The sediment-settling process began as the water entered the east half of the basin and flowed to the end and then back via the west side of the basin.

After reaching the end of the circuitous path, the sediment was reported to have settled and the water was ready for delivery to the public (Boyd, 1974). There was no other purification process. Little was known about the relationship between water-borne microscopic organisms, such as bacteria and disease.

The total pumping capacity was 4.5-million gallons a day. Twelve miles of flow lines conveyed the water to the consumers, and also provided the necessary fire protection (Boyd, 1974).

Cisterns, springs, dug wells and the major rivers continued to be used as a water supply for residents in areas not serviced by the pipelines from the municipal water works.

Extensive improvements were made in the 10-year period 1874-1884 to meet the increasing demands of a growing population and an expanding industrial base. An upper reservoir was built on the bluffs overlooking the West Bottoms, located at 21st and Holly streets. The cost of pumping one million gallons of water to the reservoir, named the Holly Street reservoir, against a head pressure of 323 feet was $7.04 (Kansas City Journal, May 26, 1903).

The Holly Street reservoir served Kansas City until in the 1920s when it was discontinued. The Lower Turkey Creek reservoir was increased to 15-million gallons and new pumps with a larger pumping capacity were added to those already in use.

The movement of Texas cattle through Kansas City to eastern markets, which began in 1868, assumed such proportions that it demanded additional accommoda-

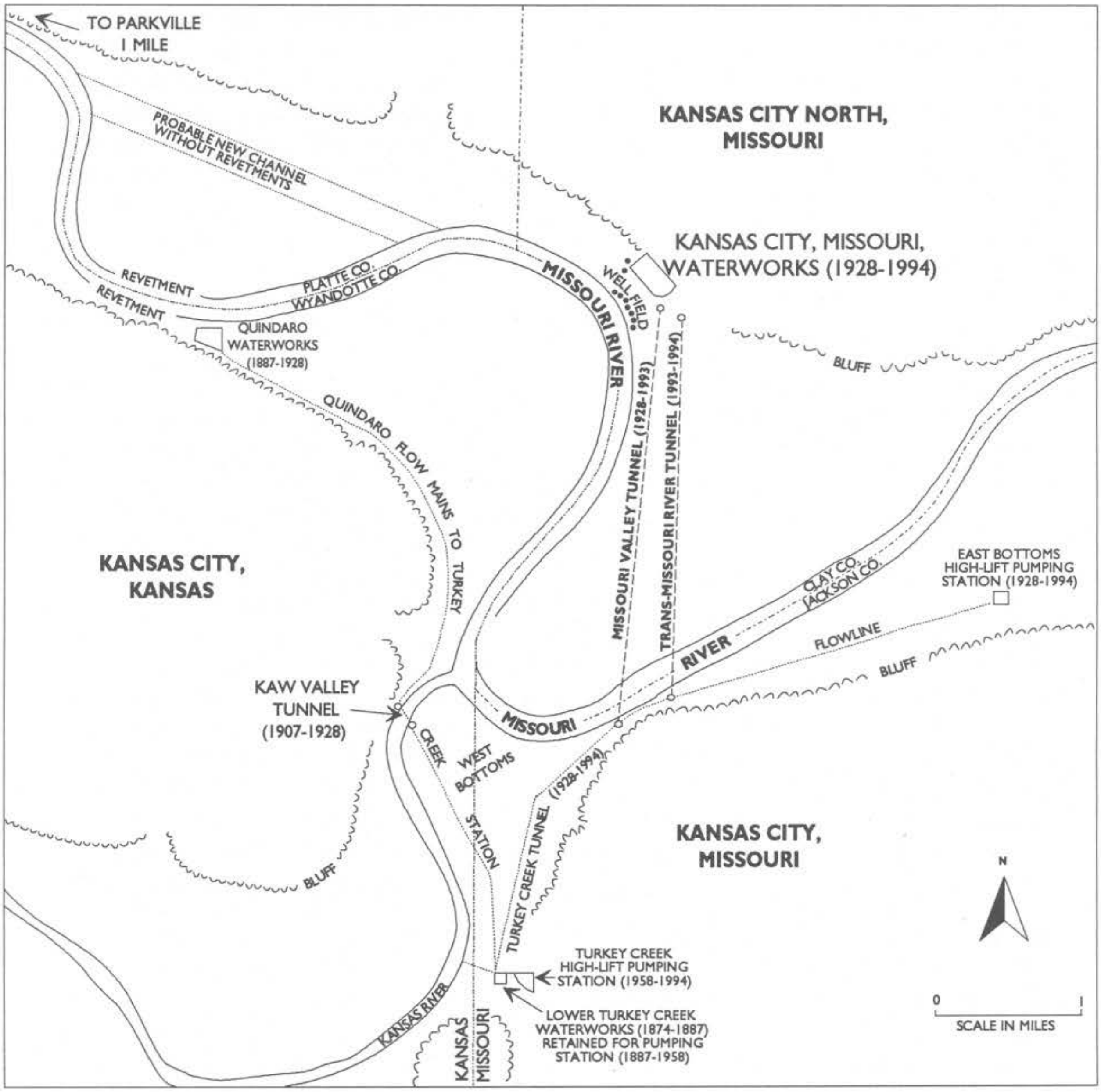

Figure 1. *Kansas City, Missouri, water supply system showing waterworks, pumping stations, tunnels, and flowline routes, 1874-1994.*

tions, and in 1870, the railroads extending eastward from this point, built stockyards for the reception and transfer of cattle (Case, 1888).

By the mid 1880s, the water supply from the Kansas River had become contaminated with industrial and residential waste and was declared to be unfit for human consumption. Untreated waste from the expanding stockyard and packinghouse industry on the West Bottoms found its way into the Kansas River. Sewers from residential areas flowed directly into the Kansas and Missouri rivers.

In the summer of 1887, the water supply problem reached crisis proportions. The following is an excerpt from an article in the *Kansas City Star* dated July 11, 1887.

> *Don't drink Kaw water!*
>
> *City Chemist Hunter detected unwholesome indications in the hydrant water last week and investigated the condition of the Kaw River at the point whence the supply is drawn by the National Water Works Company. He found that the high water in the Missouri had backed up the Kaw until the stream was stagnant and almost stationary. Rank vegetation grows in the water near the banks and the surface of the stream is covered with green fungus, the familiar characteristic of stagnant pools and swamps. Decayed refuse and offal floats here and there on the river and there is so much impurity in the water when delivered for use through the hydrants that it has unnatural and unattractive color.*
>
> *It has moreover a distinct and disgusting odor. A gentlemen who sprinkled the streets in front of his house with a line of hose and hydrant water, last night, declares that the stream could be smelled for a distance of a block or more. Even in small quantities, a glassful for instance, the water has a perceptible effluvia. The river itself emits a smell that amounts to a stench.*
>
> *Unless carefully filtered the water is totally unfit to use. Even then the necessities should be extreme before it is used as a beverage. Boiling is probably the most nearly effective manner of removing the impurities.*
>
> *A man who visited one of the spring-water offices this morning says there were 125 people in line awaiting a chance to get water.*

The city looked elsewhere for a clean supply of water. In 1886, plans were drawn up for the National Water Company to change from Kansas River water to Missouri River water. Missouri River water was considered to be of superior quality and the relatively large size of the Missouri River insured an adequate supply would be available for many years as the city expanded.

> *Hence, it became necessary, in order to give the city an adequate supply of good wholesome water, that the pumping works should be changed from Kansas to the Missouri River. This was done during the year 1887, and now no city in the country has a more ample supply of most excellent water, derived from the melting snows of the Rocky Mountains. It is rather hard for some purposes, but otherwise it is all that can be asked (Case, 1888).*

The Quindaro, Kansas Water Works 1887-1928

Kansas Citians used water from the Kansas River for the last time on September 1, 1887. A new pumping station, reservoir, and intake were constructed at Quindaro, Kansas, on the floodplain of the Missouri River about 4.5 miles north of the Lower Turkey Creek water works (Figure 1). After the Quindaro water works went on line the Lower Turkey Creek water works was converted to a pumping station. The pump house and flowlines at the Lower Turkey Creek Station continued in service until 1958 when the operation was moved to higher ground. The reservoir has been rebuilt and is still in use. It can be taken out of service in the advent of flooding.

The Quindaro water works was built up river where it would be safe from contamination by sewage from Kansas City. The sewage from cities further up the river was not considered to be a threat because early Kansas Citians mistakenly believed that harmful organic substances were eliminated from the waste before reaching Kansas City.

> *Sewage from higher sources having been entirely dissipated and neutralized by the character of the sediment carried in deposit by the river. This is one of the reasons why there have been no epidemics among those who consume the water of this perpetually renewing and self-purifying stream.*
>
> *The water of the Missouri River is not withstanding the great amount of suspended mud and sand carried in it free from unwholesome organic matter and well supplied with carbonic acid, which*

> *gives it snap and "taste." It is said that the water from the Missouri River is the only water that can be carried around the world and return home as sweet as when it started.*
>
> *While there can be no question as to the wholesomeness of Missouri River water, yet it must be cleaned before it is fit for human consumption." (Kansas City Star, April 31, 1899).*

The concentration and character of the sediment carried by the Missouri River varied greatly depending on the season of the year and the amount of precipitation in the drainage basin. Investigations were made as to the quantity and the quality of Missouri River water from October 4, 1906 to October 21, 1907. During this period the discharge of the Missouri River at Kansas City ranged from 15,500 to 229,600 cubic feet per second, averaging about 76,000 cubic feet per second. The river transported suspended matter at the rate of 1,000 to 2,606,000 tons per day, averaging 567,500 tons per day. The dissolved matter ranged from 3,320 to 187,320 tons per day, with a daily average of 102,000 tons. The average turbidity was 1,909 parts per million, and the average amount of suspended matter, 2,032 parts per million (Parker, 1911).

The plant and water processing procedure at the Quindaro Water Works were primitive by present-day standards, but for the latter part of the 19th century it was a state-of-the-art operation. There were four settling basins at the Quindaro plant with a combined capacity of 60 million gallons. The basins were numbered in sequential order, 1 through 4. The water from the river was pumped into settling basin no. 1, which had a capacity of seven million gallons. The remaining three basins were of about equal size and shared a common wall with basin no. 1. These three basins were linked in chainlike fashion, each a link in the chain that formed a semicircle around basin no. 1.

The water was "cleansed" with a coagulant as it flowed through the series of basins to remove suspended sediment. Upon reaching basin no. 4, the water was ready to be pumped to consumers.

The coagulant most commonly used was alum, sometimes referred to as sulphate of alumina. The alum reacted with calcium and magnesium carbonate and bicarbonate in river water to produce carbonic acid and hydrate of alumina. The suspended sediment adhered to the white flakes of hydrate of alumina and settled to the bottom of the basins in the form of a sticky white precipitate. Milk of lime was added in the process at times when there was a deficiency of calcium or magnesium bicarbonate in the river water. In addition to entering into the reaction that increased the amount of hydrate of alumina, the milk of lime, combined with carbonic acid. This reaction resulted in the removal of some of the calcium and magnesium bicarbonate, a common cause of water hardness, and the operation was known as the Clark's process of water softening. Carbonic acid in water makes it palatable and gives it sparkle and "taste." The carbonic acid that had been removed in the water softening process was restored by aeration, which was accomplished by tumbling the water over weirs located between the basins. The sheet of water passing over the weirs was .5- to 1-inch deep and the weirs ranged in length from 120 to 185 feet (Kansas City Star, April 30, 1899).

Clarifying 5.5-million gallons of water at the Quindaro plant in one year required 335 tons of sulphate of alumina and 40 barrels of slacked lime (Kansas City Journal, May 26, 1903). The water at the Quindaro plant was not filtered, the softening process was inadequate and very little was known about microorganisms that caused infectious diseases.

The heavy sediment load in the Missouri River required cleansing the basins at frequent intervals. A layer of sediment 4 feet thick settled to the bottom of the basins in a typical season. Eleven feet of mud accumulated in a basin after one season of heavy usage (Kansas City Star, April 30, 1899). The basins were cleaned twice during the year 1903-04 at the cost of less than $300. Over 30,000 cubic yards of mud were washed out of the basins and approximately an equal amount was carried out by gravity when the mud gates were opened (Kansas City Journal, May 26, 1903).

A laboratory at the pumping station tested the water to regulate the daily hardness and carbonic acid content, and to reduce the alkali and alum content to acceptable levels. The power for the pumps at the Quindaro plant was supplied by coal.

On September 1, 1895, the National Water Company sold the Kansas City Water Works to the City for $3,100,000 (Kansas City Times, August 13, 1923).

The flowlines from the Quindaro Water Works crossed the Kansas River on an old toll bridge. The flowlines were washed away during the flood of 1893 and the structure collapsed during the flood of 1903 (Kansas City Times, August 13, 1923). A temporary flowline was constructed across the Great Western Railway Bridge after the 1903 flood (Kansas City Star, October 15, 1905). The flood of 1903 also caused the curtailment of operations at the Turkey Creek reservoir for three days. Flood waters were 4 feet above the top of the reservoir.

The flowline across the Kansas River was a vital link in the water supply system. It connected the Quindaro Water Works with the Turkey Creek pumping station (Figure 1).

The incentive to constuct a tunnel under the Kansas River was prompted by the washing away of the 48-inch flow lines and bridge during the 1903 flood. The 1,125-foot-long tunnel, called the Kaw River Tunnel, was constructed during the years 1905-07. The 116-feet-deep downshaft was on the west bank of the Kansas River about 200 feet north of the James Street Bridge. The tunnel crossed diagonally under the bridge in a northwest-southeast direction. The 112-feet-deep upshaft was located on the east bank of the river just south of the bridge. The diameter of each shaft was 8 feet.

The site investigation consisted of five borings drilled to the elevation of the tunnel. The drillers described the following sequence of stratigraphic units in ascending order: *A 30-foot bed of soapstone, above that lies sandstone, above that gray soapstone then dark soapstone, then limestone, sand gumbo, and the surface earth.* The tunnel was constructed in the 30-foot bed of soapstone (Kansas City Journal, September 8, 1906).

The tunnel passed through gray shale beds (the 30 ft. bed of soapstone of the drillers reports) belonging to the Middle Pleasanton Group, Pennsylvanian System at an elevation of about 660 feet (m.s.l.), an interpretation based on a study of geologic reports during the current investigation (Fishel, 1948, and O'Connor and Fowler, 1963).

A maximum thickness of 93 feet of alluvium consisting of loose sand was encountered during construction of the upshaft (east shaft). The shaft was sunk with compressed air and the walls of the excavation reinforced with brick and concrete. A test boring drilled in the early 1960s for the construction of the Intercity (Interstate Route 70) Viaduct, approximately 800 feet north of the Kaw Valley Tunnel upshaft, located a deep trench eroded into bedrock and filled with 239 feet of glacial till and alluvium (O'Connor and Fowler, 1963). The deep trench is located about 1,000 feet east of the upshaft, an estimate based on projection of the trench in a southerly direction from the boring at the Intercity Viaduct. The bottom of the deep trench is 515 feet (m.s.l.), over 150 feet below the elevation of the tunnel. The location of the present channel, on the west side of the floodplain at a place where the alluvial fill of the bedrock valley is relatively thin, proved to be a fortunate coincidence for the builders of the Kaw Valley Tunnel.

Work began on both shafts on November 6, 1905 and the crews met in the tunnel on September 8, 1906. The rock separating the two crews was blasted away by 18 sticks of no. 2 (40 percent) dynamite.

The seven foot diameter horizontally aligned tunnel was of brick arch design with an outside liner of concrete. The total cost of the project was $78,000. Water from the Quindaro plant was delivered 3.5 miles to the downshaft by two flowlines, one a 48-inch steel line, and the other a 36-inch cast iron pipe. Two flowlines about .5 mile long from the upshaft conveyed the water to the Turkey Creek pumping station (Kansas City Journal, September 8, 1906). The first water was delivered to the city through the Kaw Valley Tunnel on May 15, 1907 (Kansas City Journal, May 15, 1907).

The water works at Quindaro was plagued by problems shortly after it was placed in operation. The plant was constructed on the floodplain without adequate protection from the periodic flooding that is common in low-lying areas.

A wall built around the Quindaro plant to a height above the 1903 flood level prevented surface overflow from the river, but the wall did not stop seepage into the basement through the loose alluvial sand during periods of high water level. The head pressure of the column of water on the floodplain forced water under the wall and into the pump house basement. An attempt in 1908 to pump out the basement caused part of the wall to collapse (Kansas City Journal, May 13, 1910). Consequently, the pumps were frequently submerged and made inoperable (Kansas City Journal, May 15, 1910). The technology available in the early 20th century did not lend a solution to the problem. The only recourse was to move the plant to higher gournd, a solution that would have been very expensive.

Erosion by the Missouri River just above the intake at the Quindaro plant was a constant menace to the city's water supply. The plant was located on the outside of a bend in the river (Figure 1). The bank, consisting of unconsolidated clay, silt and sand, was rapidly being eroded, especially during times of flooding when the current swept along the bank. Over 800 feet of the bank just above the plant intake was eroded away during the period 1889-1908 (Kansas City Journal, September 5, 1908).

The major concern of city officials was that the river could change course during a time of flooding. Two miles above the Quindaro plant, the Missouri River was rapidly eroding the east bank, raising the fear that the river would erode a new channel, and take a shorter course across the floodplain (Figure 1). The meander bend where the Quindaro plant was situated would be cut off and leave the intake high and dry. The new channel, shorter and straighter, would be over a mile from the Quindaro plant intake.

A total of several thousand feet of revetments were constructed to stabilize the bank above the plant and to prevent the river from changing course. The remedial efforts were only partially successful; large sections of the bank along with the revetments were washed away by subsequent flood waters. Many years passed before the banks were stabilized.

The belief that the water supply from the Missouri River was safe for human consumption soon proved to be false. Typhoid epidemics in 1903 and 1910-11 were especially devastating. In 1911 there were 2,140 reported cases of typhoid fever, resulting in 116 deaths. Deaths from typhoid fever totaled 1,133 during the interval 1900-1919. Water department chemists estimated there was a typhoid bacillus in every cubic centimeter of Missouri River water (Board of Fire and Water Commissioners, 1920). Countless others suffered from intestinal disorders caused by the germ *Bacillus coli*.

The source of the germs was the sewers of Leavenworth, Atchison, St. Joseph, Omaha and all the other towns and villages along the Missouri River above Kansas City (Kansas City Star, July 17, 1912).

Kansas City began chlorinating the water supply in 1911, a process that had proved to be highly successful in reducing epidemics in several large eastern cities. The chlorination process was inexpensive and very effective and resulted in a substantial reduction in the number of deaths from typhoid fever. Eight pounds of hypochlorite were added to one million gallons of water at a cost of 27 cents (Kansas City Star, July 17, 1912). The average yearly death rate from 1900-1911 before the water was chlorinated was 35.6 per 100,000 population. After introduction of the chlorinating process the average yearly death rate from 1912-1920 declined to 13.8 per 100,000 population (Board of Fire and Water Commissioners, 1920).

The number of cases of infection from sources other than the municipal water supply may never be known. Many residents in remote areas of the city not serviced by the city water mains drank water from cisterns, wells, and springs. A number of people may have been infected from germs in unpasteurized milk.

Several times during the years 1900-1920, the quantity of water supplied by the Quindaro plant was insufficient to meet the needs of the entire city. The population supplied by the Kansas City Water Department increased from 134,074 in 1900 to 334,192 in 1920. Remote parts of the city were being developed and the water supply system was continuously in need of expansion, in spite of numerous improvements that increased the supply and water quality. A major improvement was an increase in the number of settling basins from four to five with a corresponding increase in total reservoir capacity from 60 million gallons per day in 1900 to 80 million gallons per day in 1920. The water demand during peak usage days in 1922 was 75 million gallons which necessitated working all five of the settling basins.

The Kansas City water supply system in 1920 consisted of the following major components: the low pressure pumping station at Quindaro and five settling basins with a total capacity of 80 million gallons; flowlines 30- to 48-inches in diameter to the high pressure pumping station at Turkey Creek with an 18 million gallon reservoir; the Kaw Valley Tunnel; a nine million gallon reservoir at North Terrace Park (now Kessler Park) to supply the East Bottoms; a water standpipe 133 feet high and 40 feet diameter constructed in 1919 at 75th and Holmes streets that held one million gallons of water to supply southern sectors of the city, and 610 miles of 4- to 30-inch diameter water mains (Kansas City Star, October 15, 1920; Board of Fire and Water Commissioners, 1920).

The water supply problem became more critical with each passing year. The water quality from the Quindaro plant was at no time fully satisfactory, and during high river turbidity, or periods when certain units were out of service, the supply was unfit for human consumption. The times when the supply was inadequate in quantity, or the quality was objectionable or even dangerous began to reoccur with increasing frequency. As the margin between capacity and demand for water was rapidly reduced by the growing city, the time available for cleansing basins, repairing machinery and maintaining the plant was considerably reduced.

The settling basins at the Quindaro plant were used at maximum capacity even during periods of normal usage. When there was increased demand, the settling process was not allowed to proceed to completion before the water was chlorinated and pumped to the city for use. If the water taken from the river was more turbid than usual, or if one of the settling basins was emptied for cleaning, the capacity was lowered and the result was cloudy water pumped to the consumers. Under these conditions, the chlorilation process used to sterilize the water and kill harmful bacteria had little effect. The chlorination process works efficiently only in clear water.

In 1920, typhoid fever germs were found in samples of muddy water being pumped through the city water mains. Residents were advised to boil the water (Kansas City Star, July 7, 1920). Vendors of spring and distilled water reaped rich profits from the city's misfortune. Water sold for 30 cents a gallon and sales were discontinued only when the supply of empty bottles was exhausted (Kansas City Star, July 10, 1920).

Although Kansas City's water was "settled" and chlorinated before it was pumped through the mains, it was not filtered or softened. Filtration would eliminate color, turbidity, and dead bacteria from the water supply. The chlorination process kills bacteria, but they remain in the water. A water softening process would prevent incrustation from accumulating on the inside of boilers, cooking utensils, fuel systems, automobile radiators and pipes in homes, requiring an expensive removal process. Wear and tear on laundry would be reduced. In addition, soft water would considerably lower the cost of soap that was required in hard water.

City officials contracted the services of Fuller and McClintock Consulting Engineering Company to evaluate the water supply problem and to come up with a solution. From around the turn of the century and during the ensuing years, various individuals and citizen's groups advocated a change to an alternate water supply system, whereas others favored expanding and renovating the Quindaro Water Works. Some of the proposals appeared to have merit, whereas others bordered on the ludicrous.

The options for a water supply can be placed in several broad categories.

1. Distant sources of water supply
    (a) large springs in the Ozarks
    (b) the Missouri River above St. Joseph, Missouri
    (c) lakes on the Missouri River bottomlands south of St. Joseph
2. Local well supply
3. The Missouri River on the Missouri side of the river
4. Retain the Quindaro plant

The Fuller & McClintock Consulting Engineers carefully evaluated all the proposals during a 10-month investigation (Kansas City Times, December 23, 1920; Board of Fire and Water Commissioners, 1920).

DISTANT SOURCES OF WATER SUPPLY

Large Springs in the Ozarks

The alternate water source that received the most attention from local citizens was two large springs, Hahatonka and Bennett Spring, situated in the drainage basin of the Niangua River in the Ozark region over 100 miles southeast of Kansas City. The following article gave a glowing account of the water from Bennett Spring (Kansas City Star, September 20, 1914).

> *The water from Bennett Spring issues from the bowels of the earth, coming from beneath great rock formations, and there is absolutely not a trace of surface drainage, organic matter or any impurity in it. No water in the world is or could be purer. It is cold as ice water, sparkling like a diamond, and so clear that in a pool in the river it forms I could see the smallest pebbles on the bottom, twenty-two feet below the surface. The oldest native, some of them having observed this spring for forty years, have never known its water to be clouded or roiled, even after the heaviest rains. The volume of flow never varies summer or winter.*
>
> *Kansas City consumes for all purposes an average of 30 million gallons per day. The most used for any day was about 44 million gallons, so the spring flows nearly six times as much water as we would need. The daily flow at Bennett Spring was calculated by government experts to be 172,388,800 gallons.*

The chairman of a local citizens group committed to finding an alternate water supply to replace the Quindaro water works proposed the following system to bring water from Bennett Spring to Kansas City (Kansas City Star, September 20, 1914).

> *The mouth of the spring has an altitude above sea level of 940 feet, Kansas City is 721 feet above sea level, so this spring is 219 feet above Kansas City.*
>
> *Just south of the spring on the bank of the stream formed by it, is a bluff 150 feet high. My plan is to put a reservoir on top of the bluff, which would be 369 feet above Kansas City. The stream running from the spring would furnish the power to force the water up to the top of the reservoir. From the reservoir I would lay a 4-foot pipe straight north to Versailles, on the Rock Island Railway, in Morgan County, and from there the pipe would follow the Rock Island track to Raytown. I have already obtained from the Rock Island permission to lay the pipe along its right of way in consideration that we furnish its tanks with water. That would take a very small part of the flow through the pipe. It would be downhill all the way to Raytown.*
>
> *At Raytown we would have our big reservoir from which we would supply Kansas City, Independence, and all that part of the country that wanted our water.*
>
> *From the reservoir at Raytown the water would run in pipes downhill to every village and town in the county, including Independence, giving the whole county a constant supply of the purest spring water in the world, and that so cheaply that the present cost of water in Kansas City would be cut in two.*
>
> *I know there is a popular belief that our water is pure. That is false. The Missouri River is just a big sewer, and it's going to be worse as the towns up the river grow. . . .the whole cost of a plant to bring water from the Ozark spring to Raytown, including reservoirs would be about 5 million dollars.*

Procuring a municipal supply of water from sources many miles distant was a common practice in the late 19th and early 20th centuries. New York receives its water supply from reservoirs in the Catskill Mountains, a distance of over 100 miles. Los Angeles has a supply system with an aqueduct from the Sierra Nevada Mountains 257 miles long, and Denver impounded water in a deep mountain gorge 45 miles south of the city (Kansas City Star, September 27, 1908).

The investigation by the Fuller and McClintock engineers found that the alternate source most favorable to proponents for a change, Bennett Spring in the Ozarks, was not a feasible undertaking for several reasons. The investigation found that it was not possible to deliver water to Kansas City by gravity flow. Bennett Spring on the Niangua River was at a lower elevation than many parts of Kansas City. The elevation at Bennett Spring is less than 900 feet and on the interstream divides along the proposed route the elevation is over 300 feet higher. In southern Jackson County, the conduit would be at an elevation of over 1,000 feet (m.s.l.). A conduit 140 miles in length would be required. Due to friction in the conduit, as well as the difference in elevation, three pumping stations would be needed with an aggregate lift of 1,100 feet. Although New York, Los Angeles, and Denver procured municipal water supplies from distant places, the source areas are at sufficient elevation to allow the water to be delivered by gravity through long aqueducts and at sufficient pressure for distribution in the city.

Analyses of water from Bennett Spring were made by the Kansas City, Missouri, Water Department and the Kansas City Testing Laboratory (Board of Fire and Water Commissioners, 1920). The analyses showed that Bennett Spring is subject to considerable surface pollution and is sufficiently turbid at times so as to require filtration to render the water suitable for public use. Kansas City water department chemists also confirmed the presence of *Bacillus coli*, a leading cause of intestinal disorders, in Bennett Spring water.

Numerous gaging and estimates of discharge of Bennett Spring showed that the flow ranged from 60 to 300 million gallons per day. The flow of the spring depends directly upon the amount of precipitation. An estimate of flow during the dry season was 85 million gallons per day, a quantity that was exceeded during the days of peak usage at Kansas City in the 1920s. Consequently, reservoirs would be required for water storage. The large seasonal fluctuation in the discharge of Bennett Spring was verified by later investigations. The daily flow of Bennett Spring ranged from a minimum of 36,000,000 gallons on November 13, 1934, to a maximum of 1,098,000,000 gallons on April 30, 1970. The average over a 21-year period was 96 million gallons per day (Vineyard, 1974).

The cost of developing an Ozark water supply was estimated to exceed $70 million, well beyond the financial resources of Kansas City. In comparison, a surface supply from the Missouri River was estimated to cost $18 million. The annual cost would greatly exceed that from a Missouri River supply, without corresponding improvement in quality. Additional heavy expenditures would be entailed in rearranging the distribution system from a supply entering the city from the southwest.

Missouri River Above St. Joseph

An intake on the Missouri River above St. Joseph, Missouri would avoid the problem of sewage pollution from St. Joseph, Leavenworth, and Atchison, but the source would be brought closer to Omaha and Council Bluffs. Any improvement in water quality would be small and would not justify the great expense of an aqueduct over 70 miles long to bring the water to Kansas City.

Lakes in Missouri River Bottomlands South of St. Joseph

A number of the lakes on the floodplain of the Missouri River between Quindaro and St. Joseph were once considered as a source of water for Kansas City. The "lakes" are in reality cut-off meanders, or oxbow lakes, referred to locally as horseshoe lakes. These crescent-shaped bodies of standing water are the abandoned channels of a meander or bend in the river. After the river formed a neck cutoff, the ends of the original bend were silted up. One of the largest is Bean Lake, about 40 miles north of Kansas City. Bean Lake is about one-fourth mile wide, 3 miles long and has a maximum depth of 14 feet.

The combined capacity of several of the "lakes" would not have been sufficient to meet the requirements of Kansas City in future years. The quality of the water was questionable because the lakes are gradually being filled with clay and silt with the result that the water had a high amount of turbidity. The shallow depth of the lakes and the lack of water movement during certain seasons of the year made them susceptible to infestation of algae. Another limiting factor was the cost to construct an aqueduct over 40 miles long.

It is interesting to speculate about what would have been the result if the river had followed a shorter route 2 miles above the Quindaro intake. In all probability the ends of the meander would have silted up forming an oxbow lake, a condition similar to the proposal to tap the "lakes" 40 miles up river.

A Reservoir in the Kansas River Valley

This plan proposed to bring water to Kansas City in long canals or conduits from a reservoir created by building a dam across Wakarusa Creek, a tributary of the Kansas River, about 35 miles west of Kansas City. The proposed dam, built just west of Eudora, Kansas, would create a reservoir of about 30 square miles in areal extent and contain a sufficient supply of water to meet the needs of Kansas City for 20 to 30 years.

The investigation by Fuller and McClintock engineers into the feasibility of obtaining a surface supply from storage reservoirs in the Kansas River valley was not very promising.

The quality of the water was only slightly better than that of the Missouri River. The cost of procuring land for reservoirs, constructing dams, and building long canals or conduits to Kansas City would have been prohibitive. Furthermore, the water supply would be in the state of Kansas and not under direct supervision by Kansas City officials.

Conclusions About Distant Water Supplies

The investigation by Fuller and McClintock engineers concluded that a municipal supply from distant sources was not a feasible undertaking. The cost ranged from $25 million, to bring a supply to Kansas City by aqueducts from the Missouri and Kansas river valleys, to $70 million, to run a pipe line to the Ozark springs. Furthermore, the introduction of adequate filtration system technology and chemical purification processes in the early decades of the 20th century largely eliminated the need for cities located along major river systems to construct long aqueducts to bring water from distant sources.

LOCAL WELL SUPPLY

Proponents of this plan cited the large quantities of groundwater that are available to shallow depths from the alluvial-filled Missouri and Kansas river valleys. Wells commonly produce over 1,000 gallons per minute from the sand and gravel beds overlying bedrock at depths of 100 to 150 feet. The broad alluvial-filled valleys would support a large number of wells.

A well field, located on the West Bottoms and producing from the alluvial-fill of the Kansas River valley, would be in close proximity to the Turkey Creek pumping station. Consequently, the cost of conduits leading to the plant from the wells would be substantially less.

A well water supply from the alluvial deposits of the Missouri River valley was not considered to be a practical undertaking for the following reasons:

(a) The water is very hard, containing in excess of 500 parts per million of total hardness, and iron in the bicarbonate form is present to the extent of 30 to 60 parts per million. In order to satisfactorily render a supply from such wells for domestic and industrial use, it would be necessary to construct a water treatment plant to soften the water and aerate it for the removal of iron. The softening of the well water only to the average hardness of Missouri River water would involve a very heavy and constant expense.

(b) To secure a sufficient quantity of water, the wells would have to be scattered over a very large area, necessitating an expensive system of collecting conduits. Over 100 large-diameter wells would be needed and each well would have to be provided with its own pumping equipment. In order to secure a location of sufficient size within the state of Missouri, it would be necessary to go to the floodplains along the north bank of the river a considerable distance from the city. The floodplain at North Kansas City, although of sufficient size and relatively close to the city, was undergoing rapid development and many industrial wells were already in use there.

(c) The water from a well system would have to be pumped an additional 50 to 100 feet over the lift for a surface supply.

(d) The chemical properties of well water from the alluvial-fill deposits of the Kansas River valley approximate those from wells in the Missouri River valley. However, Kansas River valley water is also highly mineralized and would require softening and iron removal. The yields are only slightly lower in comparison to the wells of the Missouri River valley (Fishel, 1948). The microbiological quality was another matter. Investigations showed that the water from wells in the stockyard district of the West Bottoms were highly contaminated with *Bacillus coli* and unfit for human consumption.

The cost of a well supply from the alluvial deposits in the valleys of the Missouri and Kansas rivers would be substantially greater, both for initial investment and for annual fixed and operating charges, than would be necessary to secure an equally reliable and satisfactory supply from the Missouri River.

RENOVATE THE QUINDARO PLANT

Proponents of the plan to retain the Quindaro plant cited the large capital investment in the plant and emphasized that all the alternate plans involved the expense of purchasing land for the plant and flowline rights-of-way plus the construction costs for the new facilities.

The Fuller and McClintock report emphasized that a number of expensive improvements had to be made if the Quindaro water works was to have the capacity to meet the projected increase in demand. Major improvements included: purchase of additional land to expand the settling basin capacity; new and larger pumps; installation of a filtering system and modern water testing laboratory and equipment; additional flowlines; repair of the flowlines in service; and a redundant tunnel under the Kansas River. The capacity of the Quindaro plant, flowlines and Kaw Valley Tunnel was 80 million gallons per day. The peak demand was 73 million gallons per day. The entire system would have to be enlarged to meet future demands (Kansas City Star, October 15, 1920; Board of Fire and Water Commissioners, 1920).

The cost of acquiring land to expand the capacity of the water supply system would be prohibitive because the water department had no effective power of condemnation in the state of Kansas. Without a doubt, the asking price for land would be exorbitant.

The high taxes levied by Kansas was a compelling reason to move the water works to the Missouri side of the river. The tax burden projected over several years would eliminate the initial gain from retaining the plant in Kansas. With every new improvement came an increase in taxes.

The argument over taxation centered around a knotty problem that seemed to defy a solution--Should a public utility located and operated in one state but owned by a municipality in the other be exempt from taxation by state, county, township, or municipal government?

The issue was debated for over two decades by the state legislatures of Missouri and Kansas; the Kansas Supreme Court; the U.S. Congress; and the U.S. Supreme Court. A vote was taken by the people of Kansas, but the issue was never fully resolved.

THE MISSOURI RIVER ON THE MISSOURI SIDE

As early as 1905, Kansas City officials considered a plan to locate a pumping station and reservoir on the Missouri side of the river when the Kansas legislature passed a law that would impede improvements at the Quindaro plant (Kansas City Star, March 14, 1905).

After completing an extensive and comprehensive study of the proposed sources for a city water supply, the engineers for Fuller and McClintock favored moving the water works to the Missouri side and up river from the heavily-polluted segment of the river system at Kansas City.

A plant in Missouri would be free from taxation by another state and under local police and fire department protection. The power of condemnation would also be available in securing rights-of-way for flowlines and tunnels.

An $11 million bond issue to construct the new waterworks on the Missouri side of the river was approved by the voters on April 3, 1922 (Kansas City Star, May 15, 1923).

The original plan specified that the water plant would be built on the high bluff north of the intersection of 32nd Street and Swift Avenue. The tunnel alignment ran due south with the upshaft at 1st and Cherry streets on the south bank of the Missouri River. Considerable grading and leveling was done on the top of the bluff for the plant location and 23 borings were drilled along Swift Avenue for the location of the tunnel and upshaft before the plan was abandoned (upon the recommendation of a local engineering advisory board), and the plant and tunnel location were moved to the bottomland about 1,000 feet west of the former site at Swift Avenue. The new location was selected to save the expense of pumping water to a higher elevation. The buildings could also be rearranged in a pattern that would give the plant the capacity to produce 100,000,000 gallons of filtered water, instead of less than half that amount of unfiltered water at the Swift Avenue location on the bluff, or on the bottomland below the bluff (Kansas City Star, August 13, 1924). The site, on a bend in the Missouri River, was protected from river erosion by a heavily-ballasted railroad embankment.

The Fire and Water Commission approved the site recommended by the advisory engineering board for the location of the new plant (Kansas City Journal, September 7, 1924). The current water plant is constructed on the site north of 32nd Street between Missouri Hwy. 9 and Oak Trafficway, about 3.5 miles north of the central business district (Figure 1).

CONSTRUCTION PHASE OF KANSAS CITY, MISSOURI WATER WORKS
1925-1928

The proposed water supply system was electrically operated with power from the Kansas City Power and Light Company and included: the intake with low lift and secondary pumping stations and purification plant with 11 settling basins and a filtering system; a main pressure tunnel 7.5 feet in diameter and 3 miles long; a branch tunnel 6 feet in diameter and 11,000 feet long to the Turkey Creek High Lift Pumping Station; and the East Bottoms High Lift Pumping Station with a 14,000-foot-long flowline leading from the main tunnel.

The capacity of the system was 100,000,000 gallons of filtered water a day (Kansas City Times, July 14, 1924).

The Missouri Valley Tunnel (MVT)

A major component of the new waterworks was the 3-mile-long main pressure tunnel, known as the Missouri Valley Tunnel (MVT). The MVT is constructed in bedrock at a depth of about 300 feet and connects the downshaft at the water treatment plant on the north side of the river, to the upshaft at Front and Wyandotte streets, on the south bank of the river near the end of the Broadway Street Bridge.

Construction of the MVT was begun in July, 1925 and the major part of the excavation was completed by late October, 1927. The bedrock was excavated by the typical mining methods of the day--drill, blast, and muck. The work force was typically about 100 people working three 8-hour shifts. Under good working conditions, the total footage of the two headings was 30 to 40 feet during a 24-hour period.

The work crews, numbering about 10 men set dynamite charges and hauled away the loose rock after each blast. The construction methods, equipment, and safety practices available in the 1920s made the excavation and lining of the tunnel a dangerous job. The relatively weak shale bedrock at the tunnel level was further weakened by overblasting and lack of adequate supports. Many injuries were reported from roof collapses. The company physician reported treating over 680 cases of personal injury during construction of the tunnel (Kansas City Star, October 30, 1927). The lack of oxygen and pockets of methane gas made breathing difficult. The primitive ventilation system frequently failed. At times, the men wet handkerchiefs to hold over their faces to filter the air. The lack of adequate ventilation and safety practices contributed to nine gas explosions that occurred during the initial stages of tunnel excavation. One explosion, which occurred after a failure of the ventilation system, was particularly severe. It resulted in eight fatalities on September 15, 1926, when an electric spark from an engine ignited a pocket of gas in the tunnel 2,530 feet north of the upshaft at Front and Wyandotte streets (Kansas City Times, September 16, 1926). In those days there were no insurance benefits or public support. The wife of one of the victims and her four children went to the payroll office to pick up the three days wages her husband had earned. She received only two days pay. You see, they explained, he didn't complete the third day (Kansas City Star, March 15, 1989).

After the fatal explosion occurred, better safety practices were employed and a back-up ventilation system was installed. The result was only one minor explosion during the remainder of the project (Kansas City Water and Pollution Control Department, 1993).

Construction crews drilled and blasted from each shaft and "holed out" near the center on October 28, 1927. The following is a description of the "holing out" process:

> *Only a 7 foot wall of shale and rock separated the tunnel driven from the front of Wyandotte Street and the tunnel driven from North Kansas City. Each side of the wall was honeycombed with eighteen holes, into which had been driven about sixty pounds of dynamite. Then came the signal for the blast. For a moment the ventilation motors which shoot 4800 cubic feet of air into the tunnel every minute of the day and night were shut down. The cessation of the "blow line" was a signal to the "tunnel stiffs", the workmen underground, that the blast was coming. Officials of Smith Bros. Inc., the tunnel contractors, held watches on the two city officials who were to release the dynamite under the Missouri River. The blast was set off one minute after the cessation of the "blow line."*
>
> *Down underground the "tunnel stiffs" retreated into "shooting rooms," small concrete rooms set in the tunnel several hundred feet from the separating wall. These rooms are impervious to heavy blasts. "Hard air" which operates the air hammers is shot into them for ventilation. If the rooms should be buried*

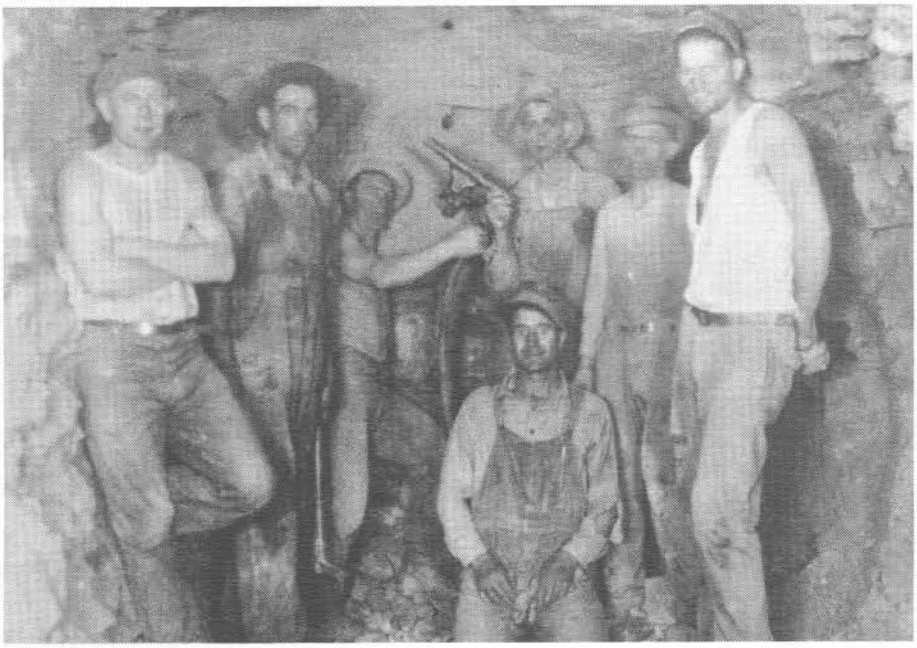

Figure 2. *Tunnel excavation crew poses for a photograph during drilling operations for the Missouri Valley Tunnel, circa 1925.*

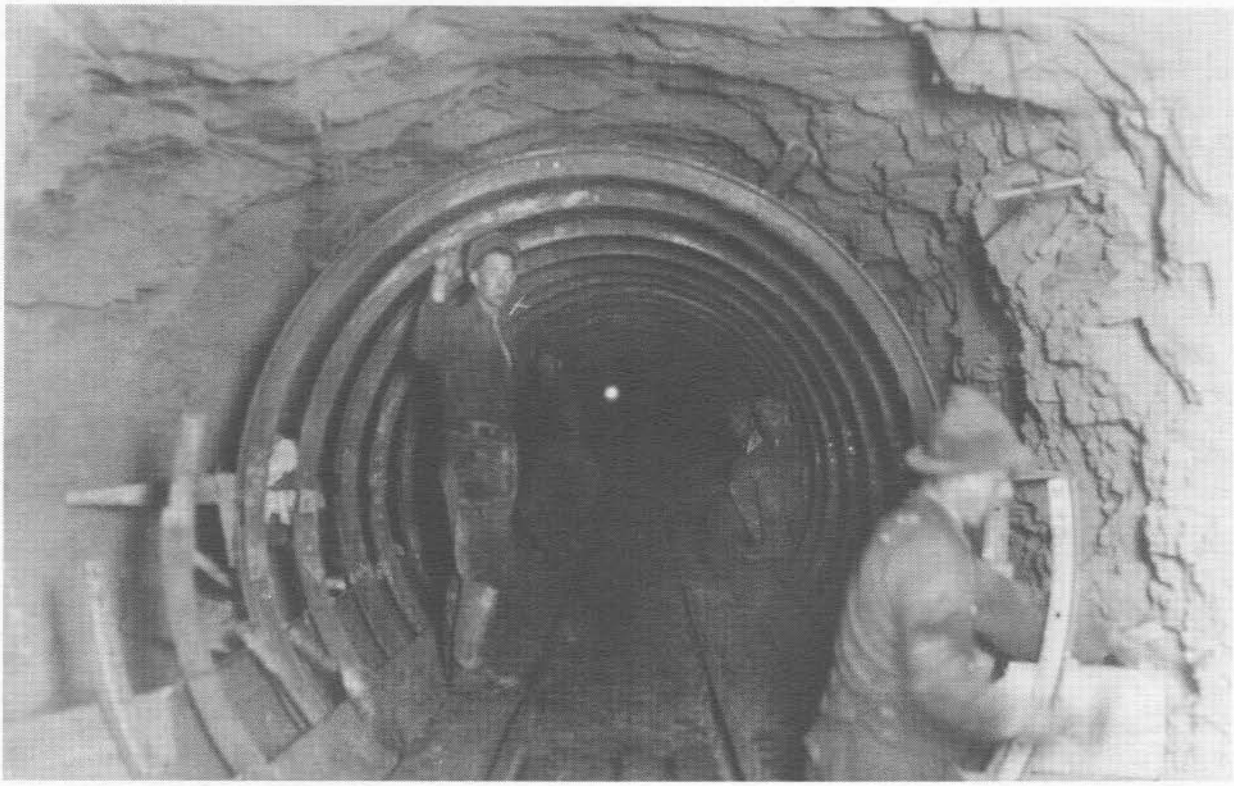

Figure 3. *Construction phase of the Missouri Valley Tunnel, February 12, 1926. View is along a segment of the tunnel about 1,400 feet from one of the shafts. The rock walls were supported with temporary forms until a finished concrete liner could be installed.*

by falling tunnel, the men inside might live for several days. One minute after the signal, Mayor Beach closed the switch. Presently there came up from the shaft out of the depths of the earth a sullen, soft, "Boom! Boom! Boom!" The remainder of the shots sounded dully at intervals (Kansas City Times, October 29, 1927).

The liner of the MVT and the shafts is cast-in-place concrete with a minimum thickness of 8 inches. The section of alluvium in the downshaft was excavated by sinking a reinforced concrete compressed-air caisson.

The contract was finalized in July, 1928. The total cost of the tunnel was $1,316,000.

Kansas Citians took the first drink of water from the new tunnel on July 5, 1928 an event they had awaited more than six years. The water was clearer and purer than that supplied by the Quindaro water works but still hard. Water softening facilities were not added for several years.

The Turkey Creek Tunnel (TCT) connects the upshaft of the MVT with the Turkey Creek Pumping Station in the West Bottoms (Figure 1). The TCT is 11,000 feet long and 6 feet in diameter. Workmen called "sand hogs" dug from both ends of the tunnel and "holed out" 147 feet beneath the Frisco Railroad yard tracks near 19th and Frances streets on September 1, 1926 (Kansas City Star, August 30, 1926).

A tunnel was constructed because of the difficulty in obtaining rights-of-way to install flowlines in surface cuts through the congested West Bottoms District.

In 1925, the Kansas City Water Commission drilled seven exploratory tests along the alignment of the TCT. The borings, on open file at the office of the Department of Natural Resources' Division of Geology and Land Survey, Rolla, Missouri recorded thicknesses of alluvium ranging from 60 to 70 feet to the top of bedrock. The tunnel is constructed in bedrock at elevation approximately 610 feet (m.s.l.). This figure is based on an average tunnel depth of 140 feet from the newspaper account (Kansas City Times, May 26, 1926) and a surface elevation ranging from 745-750 feet recorded on the boring logs. An interpretation of the local geology from drill records in adjacent areas places the tunnel at the stratigraphic position near the Pleasanton-Marmaton boundary.

The engineering reports documenting the technology used to construct the TCT or the rock materials that the tunnel bore passed through are no longer available.

The East Bottoms Pumping Station and 17 million gallon reservoir at Nickolson and Monroe streets went on line August 25, 1926. A 54-inch diameter, 14,000-foot-long steel flowline placed in an open cut a few feet below the surface, connected the high lift pumping station at East Bottoms with the large flowlines running between the Quindaro plant and the Turkey Creek Pumping Station at a point east of the Kansas River. The connection was abandoned in 1928 when the MVT was completed and the flowline from East Bottoms was connected to the upshaft of the MVT.

THE KANSAS CITY, MISSOURI WATER SUPPLY SYSTEM 1929 TO PRESENT

The capacity of the East Bottoms Pumping Station was doubled in 1938 to handle the extra water loads of a growing community. Also in 1938, a 10 million gallon reservoir was completed at the Waldo Pumping Station at 75th and Holmes streets to serve the southern areas of the city. The capacity of the plant was increased in 1958 to 48 million gallons a day (Kansas City Star, November 28, 1956).

The high standpipe at the Waldo Station has not been used since about 1940, but it has been retained for aesthetic purposes.

In the early 1940s water softening equipment was installed at the water treatment plant.

A water crises developed in 1951-53 when a combination of hot, dry weather, and population increases in suburban communities that purchased water from Kansas City, caused an increase in water usage during peak demand days. The city banned lawn watering, car washing, and non-recirculating air conditioners. The 120 million gallons per day capacity of the treatment plant was less than the demand. In 1956, the plant capacity was increased to 210 million gallons per day. Water shortages have occurred periodically during hot, dry summers in suburban communities in the southern part of the water district, after the plant capacity was increased in 1956, but these shortages have been the result of storage facilities, or supply lines that are too small to meet peak demands (Kansas City Star, July 19, 1974; Kansas City Times, August 28, 1980).

Over 112,639 tons of suspended solids, mostly mud, were removed from the settling basins at the treatment plant during the processing of 38 billion gallons of raw Missouri River water in fiscal year 1953-54 (Kansas City Mo. Water Dept., 1954).

The Turkey Creek Pumping Station was moved to higher ground in 1958. The cost of the electrically-operated plant and 15 million gallon reservoir was about $5 million. The site of the new plant is a 5.5-block area between Allen and Holly streets from Twenty-fifth Street to Twenty-third Street Terrace ,about 1,000 feet east of the old plant on the bottomlands. City officials were prompted to move the plant to higher ground after it was put out of commission temporarily during the 1951 flood. The 18 million gallon reservoir at the former site is still in use and can be taken out of service during a flood. The new Turkey Creek project was financed with $12 million in revenue bonds (Kansas City Times, October 7, 1954).

The water department's material storage and service facilities were consolidated in an all-new structure on a 5.5-acre site on the southeast corner of 18th and Olive streets (Kansas City Star, March 17, 1963).

On April 9, 1981, Kansas City began continuous fluoridation of the water supply. Fluoridation was first introduced in the 1960s but was never continuously implemented until 1981.

Water main breaks are becoming a major problem in the city's aging network of 2,100 miles of pipes. The city repairs about 900 breaks a year, mostly in mains smaller than 6 inches in diameter. Once a year, on average, a main of 20 inches or larger will rupture (Kansas City Star, July 7, 1991).

The population of Kansas City has been declining steadily and to keep production costs down water is being sold to other cities. In 1991, Kansas City sold 20 percent of its water to 20 suburban communities. Among the purchasers of water from the city are: Jackson County District 1, Lee's Summit, Blue Springs, Belton; Raytown, Raymore, Platte City, rural Clay County districts, and Weatherby Lake. The money the city earns from the sale of water reduces the bills paid by city residents (Kansas City Star, October 24, 1991).

A $110 million water bond issue was approved by the voters in March, 1988 to update the city's water supply infrastructure. Among the projects funded by the bond issue was the $21 million Trans-Missouri River Tunnel; an appropriation for $5.6 million for an Environmental Quality Control Laboratory; and a state-of-the-art computerized control system at the treatment plant.

The Trans-Missouri River Tunnel (TMRT) is a redundant or "sister" tunnel to the Missouri Valley Tunnel (MVT) completed in 1928. The 2.74-mile-long, 7.5-foot diameter tunnel runs parallel to the MVT. The tunnel went on line in June, 1992 and was dedicated June 17, 1993.

The Trans-Missouri River Tunnel (TMRT) is the most significant public works project to be completed in Kansas City in 70 years. It was five years in the planning and construction phase. The total cost was about $21 million (Black and Veatch, Engineers and Architects, 1993; Kansas City, Missouri, Water and Pollution Control Department, 1993).

The informaton from the site investigation and construction phase of the TMRT has been used to describe the geology of the Missouri River valley, the subject of this report.

The summer 1993 flood caused problems at the waterworks but there was no interruption in service to the consumer. The Environmental Quality Control Laboratory was relocated temporarily by moving essential testing equipment to higher ground. The laboratory continued to function during the entire flooding period. A bolted manhole cover on the plant's 54-inch gravity effuent sludge line broke as a result of being surcharged by high river water. An earthen surface reservoir was constructed around the manhole to control local flooding which occurred during filter backwash. Three 10,000-gallon-per-minute diesel pumps were used to pump the plant's sludge over the levee into the Missouri River. As a precautionary measure, the waterworks was protected by a hastily-constructed breastwork of sandbags, in the event the 17-foot-high levee protecting the floodplain was breached by flood waters.

Water is drawn from the Missouri River by a six-pump intake structure, referred to as a low-lift pumping station, located on the bank of the Missouri River. The raw water is pumped through 1,000 feet of force mains into which water from 11 wells can be injected. The wells were drilled to diameters of 48 and 54 inches. The well screens range in diameter from 24 to 36 inches. The annular space between the casing and the screen is gravel-packed. The wells yield 1,500 to 4,500 gallons per minute from the alluvial gravel and sand layers overlying bedrock at depth of approximately 100 feet. The turbidity and microbiological counts of the well water are less than from Missouri River water and after the wells are pumped for about two weeks the chemical quality approximates that of the river water. A comparative analysis of well water and Missouri River water for 1993 is shown in Table 1.

Well water is blended with river water at times of low water stage caused by drought or ice jams in the river above the intake. Well water is also injected into the system periodically in winter when river water is abnormally cold, to prevent freezing in the pipes. The wells add about 30 to 40 million gallons per day to the system. There are plans to add three more wells in 1995. The new wells will be drilled to 60 in. diameters with 36-inch-diameter screens and will add 10 million gallons per day to the present capacity.

The raw river and well water is conveyed through force mains to the treatment plant where various processes are applied to clarify and soften the water, remove color, and purify it. The water plant purified 38,434.1 million gallons of raw water in 1993. The raw water entering the settling basins contained 142,799.3 tons of contaminants, mostly in the form of clay, silt, and dissolved carbonates. The contaminants are processed and returned to the river.

The treated water is stored in a 10 million gallon reservoir until being pumped to consumers. The secondary pumping station houses 17 large pumps, eight of which deliver water to Kansas City, north of the river and nine which pump to Kansas City and other communities south of the river. The southbound water is pumped through force mains to the downshaft of the TMRT and the MVT. About 70 percent of the water supplied by the treatment plant is pumped through the tunnels to about one-half million residents living south of the Missouri River.

The new Environmental Quality Control Laboratory located at the treatment plant was completed in December, 1992. Over 25,000 laboratory tests of samples taken in the treatment process and from the distribution system are analyzed each month by the staff of 20 to 25. The rapidly growing list of regulations for testing water required that the city test for 85 contaminants. In 1995, 111 contaminants will be regulated in accordance with the current Safe Drinking Water Act (Kansas City, Missouri, Water Department Summary of Tap Water Characteristics, 1993).

In 1993, the Water Supply Division treated and pumped an estimated 105 million gallons of water per day to 148,000 customers, of this amount about 85 percent are homes and the remaining 15 percent are commercial enterprises.

The maximum daily consumption in 1992 was 160 million gallons per day. A maximum daily consumption of 180 million gallons per day was recorded in 1991, a relatively dry year. The pumping capacity of the plant is 220 million gallons of treated water per day, an amount substantially above current demand.

In addition to the treatment plant, there are 16 pumping stations, 2,275 miles of water mains, and 17,808 fire hydrants. The Water and Pollution Control Department has about 800 employees (Water and Pollution Control Department, City of Kansas City, Missouri, 1993).

Substance or Property Tested		Wells[2]			Missouri River[3]		
		Max.	Min.	Ave.	Max.	Min.	Ave.
Ph	s.u.	7.7 (5)[4]	7.1 (6, 7)	7.4	8.3 Feb, May, Jun, Aug-Dec	8.2 Jan, Mar, Apr, Jul	8.3
Silica (SiO_2)	ppm	insig.[5]	insig.	insig.	63.7 July	10.7 Jan	31.9
Magnesium (Mg)	ppm	30.5 (6)	20.2 (2)	24.0	30.4 Jan	18.3 Jul	26.4
Calcium (Ca)	ppm	117.0 (6)	61.1 (5)	78.5	90.9 Dec	53.2 Jul	77.4
Aluminum (Al)	ppm	insig.	insig.	insig.	23.4 Jul	0.8 Nov	9.7
Manganese (Mn)	ppm	0.790	0.284	0.441	0.764 Jan	0.037 Sept	0.363
Chloride (Cl)	ppm	25.0 (2)	75.0 (6)	33.0	34.0 Jan	19.0 Jul	26.0
Fluoride (F)	ppm	insig.	insig.	insig.	0.56 Jan	0.35 Mar	0.45
Iron (elemental)	ppm	11.091 (6)	0.157 (2)	4.154	26.1 Jul	1.07 Nov	11.0
Sulphate (SO_4)	ppm	insig.	insig.	insig.	167.0 Jan	58.0 Mar	118.0
Nitrate (NO_3)	ppm	insig.	insig.	insig.	3.51 Jun	0.91 Mar	2.40
Nitrite	ppm	insig.	insig.	insig.	0.052 Aug	0.011 Nov	0.037
Total Alkalinity	ppm	330.0 (7)	108.0 (1)	213.0	228.0 Dec	126.0 Jul	193.0
Phenol. Alkalinity	ppm	0.0	0.0	0.0	2.0 Oct	0.0 Dec-Mar	1.0
Total Coliform[6]	/100 ml	0.0	0.0	0.0	9414.0 Sept	1839.0 Oct	4279.0
Fecal Coliform[7]	/100 ml	0.0	0.0	0.0	4355.0 Jan	1034.0 Nov	2526.0
Total Hardness[8]	ppm	446.0 (6)	252.0 (2)	300.0	351.0 Dec	202.0 Mar	291.0
Total Solids[9]	ppm	1145.0	396.0 (5)	536.0	1635.0 Jun	550.0 Jan	948.0
Suspended Solids	ppm	0.0	0.0	0.0	684.0 Apr	49.0 Jan	333.0
Turbidity	ntu	insig.	insig.	insig.	692.0 Jul	22.0 Jan	298.0
Temperature	deg F	57.0 (6, 7)	47.0 (1)	52.0	80.0 Aug	34.0 Jan	56.0
Flow	cfs	NA[10]	NA	NA	242,719.0 Jul	25,417.0 Jan	84,859.0

[1] Kansas City, Missouri, Water and Pollution Control Department, Environmental Quality Laboratory Control Reports for 1993
[2] Analysis of 11 wells in 1993
[3] monthly averages, 1993
[4] (5) = well number in a total of 11 wells
[5] insignificant, same amount as in delivered water
[6] total bacteria
[7] bacteria from warm-blooded animals
[8] calcium, magnesium, iron, and aluminum
[9] suspended solids and dissolved solids
[10] N.A. = not applicable

Table 1. *Comparative Analysis of Well Water and Missouri River Water for 1993*[1]

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