LAKE ALAN HENRY WATER QUALITY PROTECTION PLAN

Prepared for the

Brazos River Authority
Waco, Texas

and the

Texas Water Development Board
Austin, Texas

By:

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EXECUTIVE SUMMARY

The Brazos River Authority of Texas (BRA) and the Texas Water Development Board (TWDB) authorized this water quality planning study of the Lake Alan Henry Reservoir basin under a matching fund agreement dated April 25, 1990. Subsequently, the BRA contracted with Freese and Nichols, Inc., to perform the study. The notice to proceed was issued by the BRA on May 24, 1990.

This study was conceived by the BRA and the City of Lubbock as a pro-active approach to water quality management in the Lake Alan Henry watershed. Several potential pollution sources that could impact water quality are found in the watershed. These potential sources are both natural and cultural in origin and include features such as geology, soils, oil fields, transportation facilities, and agricultural activities. The Authority and the City decided to evaluate these potential sources and formulate alternative strategies, as warranted, to minimize or control the sources before they could adversely impact the water supply. The TWDB's principal interest in the study was based on the potential regional applicability of the results.

The primary purpose of this study was to develop a site-specific water quality management plan that would address potential pollution sources in the Lake Alan Henry watershed. An underlying goal of the study was to develop a basic approach that would also be applicable to other reservoirs in Texas. Three basic tasks were employed to accomplish the study objectives: 1) identification of land uses; 2) water quality sampling and analysis; and 3) identification and evaluation of alternative pollution control measures.

The study area included the 394 square mile contributing drainage area of Lake Alan Henry. The contributing watershed includes the area below and immediately adjacent to the rim of the Caprock on the High Plains and extends into portions of five counties, including Garza, Kent, Scurry, Borden, and Lynn Counties. Based on information published by the U.S. Geological Survey, an additional 1,222 square miles are found within the drainage basin that do not contribute to flow at the dam site. The non-contributing area lies above the Caprock where runoff is captured in local playa lakes.

The watershed is rural, with ranching, farming, and petroleum production forming the principal land use activities within the basin. No industries and no large cities are located within the watershed. The nearest towns with sizeable populations and commercial activities are Post and Snyder, and the City of Lubbock is located approximately 45 miles northwest of the northern watershed boundary.

A stream sampling program was designed to characterize the water quality associated with various segments of the watershed. Samples were collected at seven sites during baseflow and high flow periods and were tested for 30 parameters, including inorganics, organics, nutrients, heavy metals, and microbiological constituents. The samples were analyzed by the City of Lubbock water and wastewater treatment laboratories, which also performed a detailed hydrocarbon scan on several of the low-flow and high-flow samples.

The sampling results indicated that dissolved minerals are the primary water quality concern in the Lake Alan Henry area. The concentrations of total dissolved solids are high during low flow and decrease significantly during high flow. Computer model projections of total dissolved solids, chloride, and sulfate concentrations in the reservoir under variable demand operation indicated that these constituents would be within or slightly above secondary drinking water limits most of the time. The simulation indicated that the median dissolved solids would be approximately 250 mg/l lower in Lake Alan Henry than in Lake Meredith, the City of Lubbock's existing surface water supply source. In addition, sulfates would be about two-thirds lower in Lake Alan Henry, and chlorides would be approximately 50 mg/l higher in Lake Alan Henry.

Few hydrocarbons and organics were detected, and when they were detected, the concentrations were minimal. No pesticides were found. Cadmium and selenium concentrations were found in some of the stream samples at levels exceeding drinking water standards. Copper, chromium, and silver levels, although within drinking water limits, exceeded the human health criteria of the Texas Surface Water Quality Standards. Each of these metals is expected to diminish significantly in the reservoir water column through adsorption and settling. Filtering during the water treatment process would further reduce any remaining metals. Sampling results also indicated that nitrogen, phosphorus, and suspended solids and turbidity levels were elevated in the stream samples, but the reservoir configuration is expected to minimize the impact of these constituents in Lake Alan Henry.

Alternative pollution control measures that were evaluated included source elimination, and physical and institutional controls. Source elimination included removal of pipelines and plugging of oil wells, which the BRA is currently undertaking. Physical measures that were evaluated consisted of pipeline improvements, detention structures, bridge improvements, reservoir operation, and water quality monitoring. Institutional controls that were evaluated included public information and education, zoning, federal and state pollution control regulations, emergency action planning, and establishment of a Water Quality Protection Task Force. In addition, the probable effect of not implementing any of the alternative control measures was evaluated.

It was concluded that elevated concentrations of dissolved minerals, nutrients, and the few metals were primarily due to natural sources, and a combination of pollution control measures should be implemented that would be adequate to protect water quality in Lake Alan Henry. The measures recommended included continuing the source elimination activities that have been initiated; operating the reservoir in a variable demand mode; establishing a water quality monitoring program; developing a public information and education campaign; encouraging zoning to protect water quality; implementing emergency action planning; and establishing a local Water Quality Protection Task Force.

Although the Lake Alan Henry watershed does not contain all types of land uses found in other reservoir drainage basins across the state, the land uses that are present are common to many areas in Texas. Therefore, the results and recommendations of this water quality management plan for Lake Alan Henry should be applicable, with appropriate site-specific modifications, to many reservoir basins in Texas.

1. INTRODUCTION

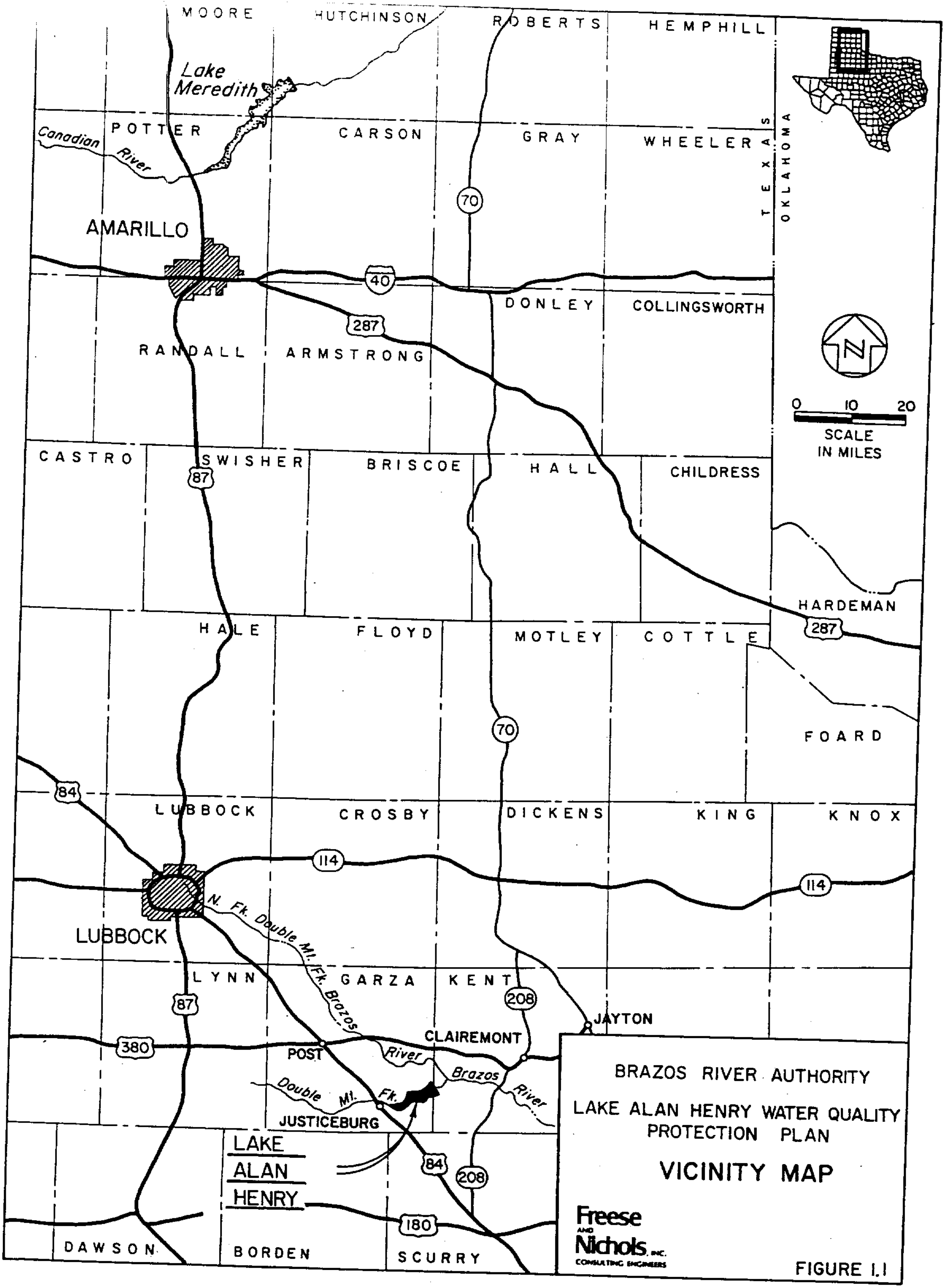
The Brazos River Authority of Texas (BRA) and the Texas Water Development Board (TWDB) authorized this water quality planning study of the Lake Alan Henry Reservoir basin under a matching fund agreement dated April 25, 1990. Subsequently, the BRA contracted with Freese and Nichols, Inc., to perform the study. The notice to proceed was issued by the BRA on May 24, 1990.

1.1 Purpose and Need

This study was conceived by the BRA and the City of Lubbock as a pro-active approach to water quality management in the Lake Alan Henry watershed. Several potential pollution sources that could impact water quality are found in the watershed. Recognizing this possibility, the Authority and the City decided to evaluate these potential sources and formulate alternative strategies, as warranted, to minimize or control the sources before they could adversely impact the water supply.

The Lake Alan Henry watershed, located approximately 45 miles south of Lubbock in northwest Texas (Figure 1.1), contains a number of potential point and non-point sources of water pollution that are endemic to other reservoir basins in Texas. These potential sources are both natural and cultural in origin, and include features such as geology, soils, oil fields, transportation facilities, and agricultural activities.

It was recognized at the outset that several existing regulations and programs are applicable for water quality protection in the Lake Alan Henry



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VICINITY MAP

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FIGURE 1.1

basin. However, no watershed-specific, cohesive management strategy had been devised prior to this study. The primary purpose of this study was to develop a site-specific water quality management plan that would address potential pollution sources in the Lake Alan Henry watershed. An underlying goal of the study was to develop a basic approach that would also be applicable to other reservoirs in Texas.

Although the Lake Alan Henry watershed does not contain all types of land uses found in other reservoir drainage basins across the state, the land uses that are present are common to many areas in Texas. Therefore, the results and recommendations of this water quality management plan for Lake Alan Henry should be applicable, with appropriate site-specific modifications, to many reservoir basins in Texas.

1.2 Description of the Lake Alan Henry Project

Construction of the John T. Montford Dam and Lake Alan Henry began in February 1991 and is expected to be completed by August 1993. Upon completion, the lake will inundate approximately 2,884 acres at the conservation elevation of 2220 feet mean sea level (ft. msl; Figure 1.2). The reservoir will contain approximately 115,937 acre-feet when filled to the top of the conservation pool, and the maximum depth near the dam will be approximately 100 feet. The 100-year flood elevation is 2240 ft. msl. The expected average yield of the reservoir, based on an approved overdraft operation plan, is 30,200 acre-feet per year (Freese and Nichols, 1978).

The reservoir was originally known as Justiceburg Reservoir, named for the

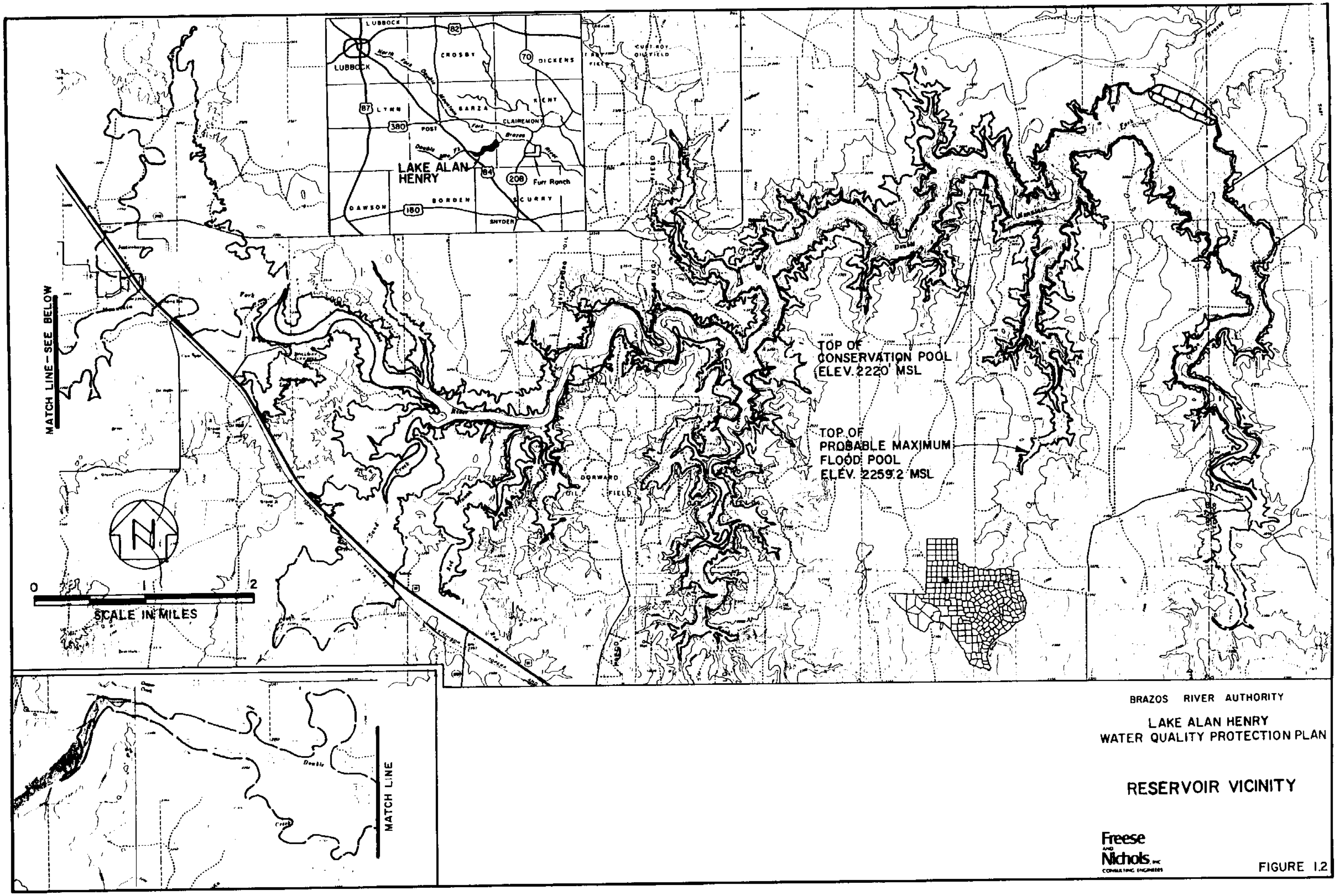

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FIGURE 1.2

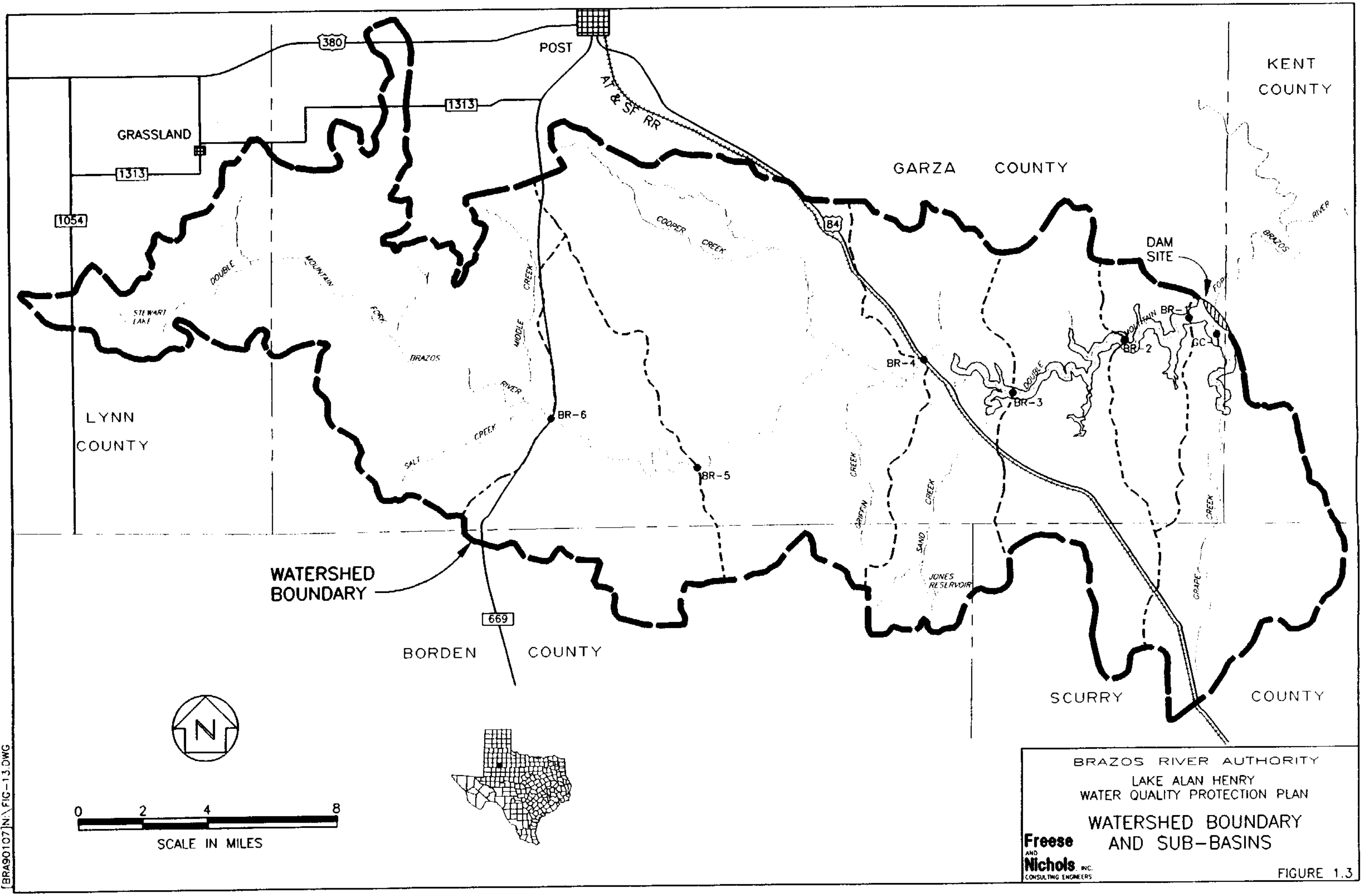
nearby town of Justiceburg, Texas. In 1989, the project was renamed Lake Alan Henry, in honor of the former mayor of Lubbock whose insight and attention to the future water supply needs of the city were instrumental in making the project a reality. After obtaining the required permits to construct the dam, the City formed an agreement with the BRA to construct and operate the project. It is anticipated that the City will begin using water from the reservoir by the year 2000.

1.3 Planning Area

The planning area for this study included the 394 square mile contributing drainage area of Lake Alan Henry. The contributing watershed includes the area below and immediately adjacent to the rim of the Caprock on the High Plains and extends into portions of five counties, including Garza, Kent, Scurry, Borden, and Lynn Counties (Figure 1.3). Based on information published by the U.S. Geological Survey (1990), an additional 1,222 square miles are found within the drainage basin that do not contribute to flow at the dam site. This area lies above the Caprock where runoff is captured in local playa lakes.

For purposes of this study, the basin was divided into seven sub-basins, which are denoted by water sampling points GC-1 and BR-1 through BR-6 on Figure 1.3. The water quality sampling program is described in Chapter 3.

The watershed is rural, with ranching, farming, and petroleum production forming the principal land use activities within the basin. No industries and no large cities are located within the watershed. The only community is the town of Justiceburg, which consists of a U.S. Post Office, several abandoned



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WATERSHED BOUNDARY AND SUB-BASINS

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FIGURE 1.3

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buildings, and some scattered residences. The nearest towns with sizeable populations and commercial activities are Post and Snyder. Post is the county seat of Garza County and has a population of 4,012. Snyder is the county seat of Scurry County, with a population of 12,894. The City of Lubbock is located approximately 45 miles northwest of the northern watershed boundary and has a population of approximately 190,000.

2.0 IDENTIFICATION OF POTENTIAL POLLUTION SOURCES

2.1 Non-Point Sources

2.1.1 Geology

Non-point source pollution can occur from natural conditions as well as man's activities. One potential source of pollution within the Alan Henry watershed is the geology. Some geologic formations are potential sources of contaminants because they contain minerals which tend to dissolve in water.

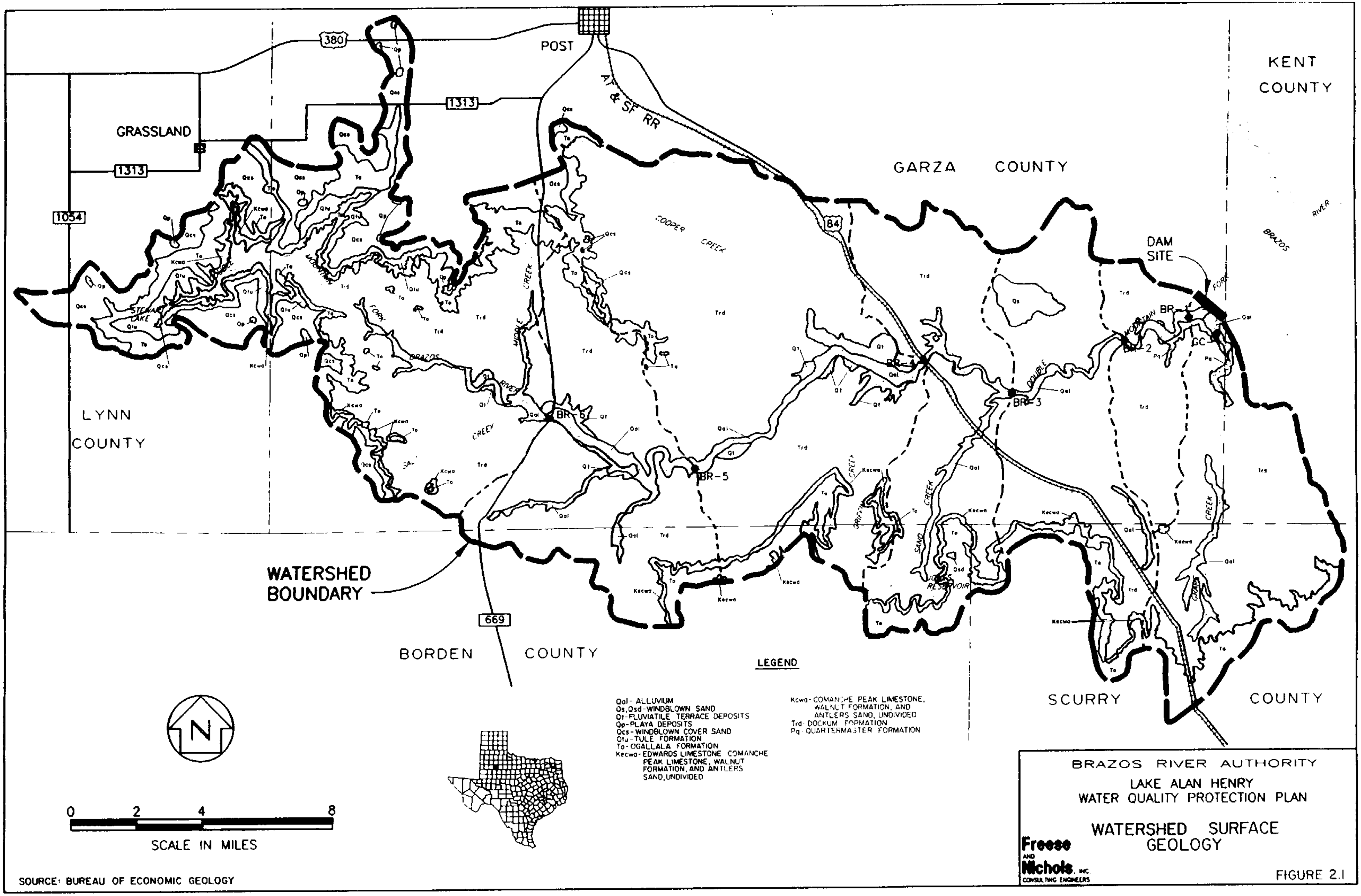
The surface geology of the Lake Alan Henry watershed is shown in Figure 2.1. The outcrop areas and the percentage of the area covered by the formations in each sub-watershed are presented in Table 2.1.

Alluvium and fluviatile terrace deposits are floodplain deposits which are found throughout the watershed in and near stream channels. These deposits consist of gravel, sand, and silt. Windblown sand and silt, which occurs in sheets, is found mainly in the BR-6 watershed, with smaller areas also found above BR-5, BR-4, and BR-2.

Playa deposits are found in the watershed above BR-6. These are primarily clay and silt deposits in shallow depressions.

A very small area of the Quaternary age Tule formation is found above BR-6 in the western extreme of the watershed. The formation includes sand, silt, and clay with a gravel base.

The Tertiary age Ogallala formation is present along the outer edges of every sub-watershed except BR-1. The Ogallala consists of fluviatile sand, silt, clay, and gravel capped by caliche.



SOURCE: BUREAU OF ECONOMIC GEOLOGY

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WATERSHED SURFACE
GEOLOGY

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FIGURE 2.1

Table 2.1

Surface Geology in the Lake Alan Henry Watershed

Formation	BR-6 (Sq.Mi.)	% of Area	BR-5 (Sq.Mi.)	% of Area	BR-4 (Sq.Mi.)	% of Area	BR-3 (Sq.Mi.)	% of Area	BR-2 (Sq.Mi.)	% of Area	BR-1 (Sq.Mi.)	% of Area	GC-1 (Sq.Mi.)	% of Area
Alluvium & Terrace	2.45	5.4	1.22	2.8	0.48	2.8	2.34	5.7	3.26	3.2	5.0	10	6.25	6.5
Windblown Sand	0.00	0.0	2.02	4.6	0.00	0.0	.00	0.0	23.46	23.4	0.37	0.7	0.44	0.5
Playa	0.04	0.1	0.00	0.0	.00	0.0	.00	0.0	.13	0.1	0.00	0	.0	
Tule	0.00	0.0	.00	0.0	.00	0.0	.00	0.0	6.60	6.6	0.00	0	.0	
Ogallala	4.12	9.1	4.12	9.4	0.00	0.0	5.65	13.6	19.57	19.5	1.70	3.3	6.32	6.6
Edwards Group	2.70	6.0	2.34	5.4	0.00	0.0	.10	0.2	3.80	3.8	0.65	1.3	.48	3.6
Dockum	35.72	79.3	34.00	77.8	16.02	94.0	32.33	78.1	43.56	43.4	43.09	84.7	79.05	82.7
Quarter-Master	0.00	0.0	.00	0.0	.54	3.2	0.99	2.4	0.00	0	.00	0	.0	
Total Area	45.03	100.0	43.70	100.0	17.04	100.0	41.41	100.0	100.38	100.0	50.90	100.00	95.54	100.0

The Cretaceous age Edwards group and Antlers Sand are found in all the sub-watersheds except BR-1. The Comanche Peak Limestone, Walnut formation, and the Antlers Sand are found along the southern edges of the watersheds containing the Edwards group. The Edwards Limestone member is found only in the BR-6 sub-watershed. These formations include limestones, shales, marls, sand, sandstones, siltstones, conglomerate, and quartzite.

The Triassic age Dockum group covers the largest area of the Alan Henry watershed. This group is found in each of the sub-watersheds and consists of clay, shale, sandstone, and conglomerate.

The Permian age Quartermaster formation is found in the general area of the reservoir impoundment area in the eastern portion of the watershed. This formation is comprised of shale, siltstone, sandstone, gypsum, and interbedded dolomite. The dam site was selected to minimize potential problems from the gypsum component.

2.1.2 Soils

Another natural factor that influences water quality is soils. The amount of sediment transported in runoff can have a profound effect on water quality. The sediment itself can represent a water quality problem. In addition, many pollutants, including certain nutrients, metals, and pesticides, become attached through a process known as adsorption to soil particles and are transported into streams when soils are eroded.

The Soil Conservation Service (SCS) has classified each soil series by one of four hydrologic groups. Soils are classified as A, B, C, or D based on infiltration rate and runoff potential (Richardson et al., 1965). Group A is characterized by highly porous soils, which have the greatest infiltration capacity and the lowest runoff potential. Runoff potential increases for soils B through D, with Group D having the lowest infiltration capacity and the highest runoff potential. Acreages of the four hydrologic soil groups were measured from SCS soil maps of the Lake Alan Henry watershed (Richardson et al., 1965; Dixon, 1975; Richardson and Girdner, 1973; Dixon et al., 1973; and Mowery and McKee, 1959). These soil areas were compared to selected water quality sampling parameters to attempt to identify correlations between pollutant levels and generalized soil types. The areal distribution of the general soil types within the watershed is presented in Table 2.2.

Group A soils consist of very porous materials such as sands and gravel that have high infiltration rates, even when thoroughly wetted. The only soil series in the Lake Alan Henry watershed that is classified in group A is the Lincoln series. The Lincoln soils are located in floodplains along streams and are easily eroded (Richardson and Girdner, 1975; and Richardson et al. 1965). Group A soils cover approximately four percent of the watershed.

Group B soils have moderate infiltration and water transmission rates. The following soil series in the Lake Alan Henry watershed are classified in hydrologic soil group B: Amarillo, Berda, Bippus, Cobb, Colorado, Frio, Mansker, Miles, Mobeetie, Patricia, Polar, Portales, Posey, Spade, Spur, Veal, Weymouth, and Zita. These soils are characterized as moderately deep to deep and range from moderately well drained to well-drained soils. Textures range from moderately fine to moderately coarse. Soils within this hydrologic group range from highly erodible to moderately erodible. Soil series in group B, such as the

Table 2.2

Incremental and Cumulative Acreage of Soil Types in Sub-basins of the Lake Alan Henry Watershed

Incremental Average

General Soil Type	BR-1 Acres	%	BR-2 Acres	%	BR-3 Acres	%	BR-4 Acres	%	BR-5 Acres	%	BR-6 Acres	%	GC-1 Acres	%	Total Acres	%
Hydrologic Soil Group:																
A	287	3	795	3	1,674	6	2,469	4	2,465	8	1,488	2	42	0	9,220	4
B	2,751	25	6,198	22	10,478	36	11,866	24	7,593	23	21,813	34	9,588	36	73,288	29
C	2,296	21	7,214	26	3,724	13	6,582	11	4,939	15	,344	24	8,930	34	49,029	19
D	3,086	28	7,085	25	7,368	26	24,217	40	10,403	32	10,736	17	6,361	24	69,258	27
Other Soils:																
Badland	0		788	3	515	2	1,496	2	1,501	5	841	1	237	1	5,378	2
Rough	2,487	23	5,884	21	5,058	18	11,513	19	5,675	17	14,024	22	1,347	5	45,989	18
Total	10,908		27,965		28,817		61,143		32,577		64,246		26,505		252,161	

Cumulative Acreage

General Soil Type	BR-1 Acres	%	BR-2 Acres	%	BR-3 Acres	%	BR-4 Acres	%	BR-5 Acres	%	BR-6 Acres	%	GC-1 Acres	%	Total Acres	%
Hydrologic Soil Group:																
A	9,179	4	8,891	4	8,096	4	6,422	4	3,953	4	1,488	2	42	0	9,220	4
B	63,700	28	70,536	30	54,750	29	44,272	28	29,405	30	21,813	34	9,588	36	73,288	29
C	40,099	18	46,733	20	30,589	16	26,865	17	20,283	21	15,344	24	8,930	34	49,029	19
D	62,896	28	59,810	26	52,724	28	45,357	29	21,139	22	10,736	17	6,361	24	69,258	27
Other Soils:																
Badland	5,142	2	5,142	2	4,354	2	3,839	2	,343	2	841	1	237	1	5,378	2
Rough	44,641	20	42,154	18	36,270	19	31,212	20	19,699	20	14,024	22	1,347	5	45,989	18
Total	225,656		233,266		186,783		157,966		96,823		64,246		26,505		252,161	

Mobeetie, are highly erodible because of their sandy texture and steep slopes. This group of soils accounts for approximately 29 percent of the contributing drainage area.

Group C soils consist of the Abilene, Arvana, Kimbrough, Lea, Olton, Potter, Rowena, and Slaughter series in the Lake Alan Henry watershed. The infiltration and water transmission rates are slow in group C soils due to two possible factors. One reason for slow infiltration rate might be the presence of a layer that impedes the downward movement of water, such as in the Abilene and Potter soils. Another possible impediment to water movement into and through these soils is the fine to moderately fine textures of these soils, as with the Olton and Rowena soils (Richardson, et al., 1965). Except for the Potter soils, which have a high water erosion hazard, group C soils have a slight wind erosion hazard and a slight to moderate water erosion hazard. The group C soils comprise approximately 19 percent of the total watershed and are generally favorable for engineering uses in waterways.

The following soil series in the Lake Alan Henry watershed are classified in hydrologic soil group D: Dalby, Latom, Mangum, Randall, Stamford, and Vernon. These soils have very slow rates of infiltration and water transmission. Any of several features may impede infiltration and water movement in these soils, including a high percentage of clay and a high shrink/swell potential, a claypan or clay layer at or near the surface, or the presence of relatively shallow soils over an impervious layer (Richardson et al., 1965). A seasonal high water table can result in a group D classification; however, none of the project area soils exhibits this characteristic. The potential for water erosion in these soil types ranges from slight to moderate. The soil erosion potential is a slight hazard. The group D soils cover approximately 27 percent of the total watershed area.

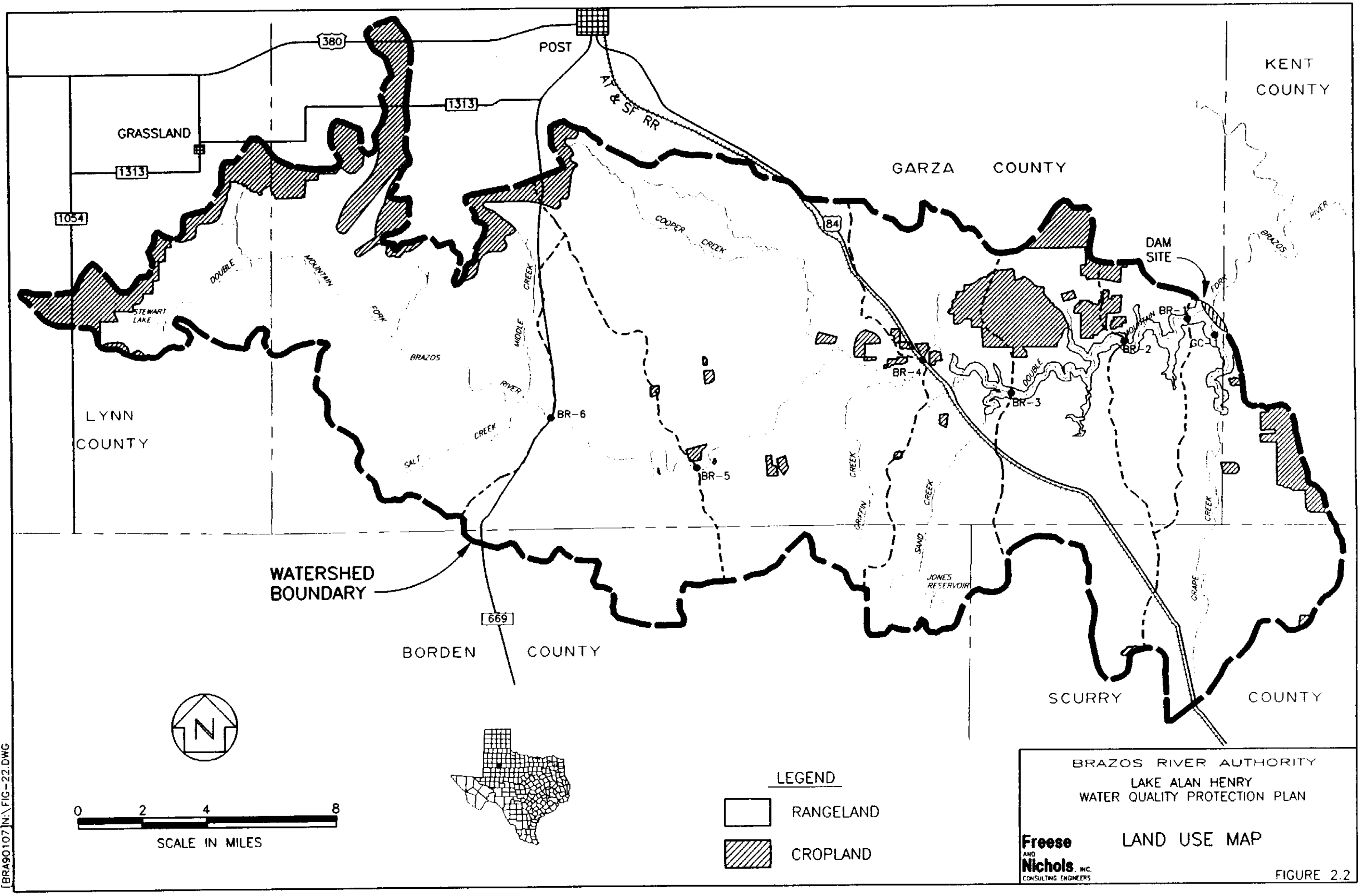
Badland and rough broken land comprise the remainder of the watershed acreage. Badland soils consist of severely eroded and gullied areas in clay or shaly clay red beds. Soil development in these areas is lacking, and vegetation is very sparse. Slopes range from one to 50 percent, giving rise to rapid surface runoff and excessive erosion. Badlands make up only about two percent of the watershed.

Rough broken lands consist of steep slopes along escarpments and drainageways. These areas develop in either red clay beds or caliche and have slopes ranging from five to 80 percent. Erosion has shaped these areas and is still active. Rough broken land occupies approximately 18 percent of the contributing drainage area.

Approximately 53 percent of the soils range from moderate to high erosion potential. This estimate is based on the assumption that hydrologic soil groups A and B, plus the Badland and Roughland soils, comprise the moderate to high erosion potential category.

2.1.3 Land Use

Man's activities can influence the types of pollutants that reach surface waters. Land use in the Lake Alan Henry watershed is characterized by cropland and rangeland (Figure 2.2). Rangeland is the dominant land use, comprising approximately 93 percent of the total area. The remaining seven percent is primarily cropland. Land use acreages within the project area are presented in Table 2.3.



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LAND USE MAP

FIGURE 2.2

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Table 2.3

Total Land Use Acreage within the Lake Alan Henry Watershed

Above	Cropland				Rangeland			
Site	Increm.	(%)	Cumul.	(%)	Increm.	(%)	Cumul.	(%)
BR-6	7,710	12	7,710	12	56,537	88	56,537	88
BR-5	0		7,710	8	32,577	100	89,114	92
BR-4	2,018	3	9,727	6	59,125	97	148,239	94
BR-3	1,239	4	10,966	6	27,578	96	175,817	94
BR-2	4,922	18	15,888	7	23,043	82	198,860	93
BR-1	513	5	16,401	7	10,395	95	209,255	93
GC-1	2,253	9	2,253	9	24,252	92	24,252	92
	18,654	7			233,506	93		

Approximately 18,654 acres of the total 252,160 acres is used as cropland. Drainage area BR-6 contains the largest amount of cropland with 7,710 acres. It is also the largest sub-drainage area, with 64,246 acres. Most of the cropland within this drainage is in the area above the caprock in the western portion of the watershed.

The dominant crops in the five-county region are cotton and wheat (personal communication with Steve Wesley and Terry Hefner, SCS, March 6, 1991). Cotton is planted in March or April and harvested in November. Wheat is planted in September and is used primarily for cattle grazing. Wheat that is not grazed out is harvested in June. Additional crops grown in the region include grain sorghum and small grains.

Approximately 235,506 acres of the contributing watershed are comprised of rangeland. These areas are used primarily for cattle grazing. Various types of herbicides are used in small quantities and in limited areas to control problem brush species (personal communication with Gary Dean, SCS, March 8, 1991).

A cafe and U.S. Post Office located in the town of Justiceburg are the only business establishments within the watershed. Ranch houses and other residences are scattered throughout the area. No concentrated animal feeding operations are located in the watershed.

2.2 POINT SOURCES

No permitted industrial or municipal wastewater dischargers are located within the Lake Alan Henry watershed. However, other potential point sources of pollutants relating primarily to the oil industry and transportation facilities exist. Oil wells and tank batteries, pipelines, railroads, and roadways are the principal potential point sources.

2.2.1 Oil Fields

Oil field operations represent a number of potential point sources within the Lake Alan Henry watershed. These potential sources might include leaks in well casings or flow lines, improper maintenance of pump equipment and tank batteries, or improper plugging of abandoned wells. The Texas Railroad Commission (RRC) requires casing integrity testing of wells every five years to reduce the risk of leaks to groundwater. This requirement and the RRC's stringent cleanup requirements for spills reduce the risk of contamination of subsurface and surface water in the watershed. The risk of contamination from oil field sources depends largely on the accuracy and dependability of spill reporting by the owners and operators of oil field equipment. The RRC indicated that the owners and operators in the project area generally have proven reliable in reporting releases, which has minimized pollution problems in the area (personal communication with Barry Wood, Texas Railroad Commission, August 12, 1992).

Oil well locations were determined from maps developed by Midland Map Company, using Texas Railroad Commission well data posted through February 20, 1991. Approximately 1,558 oil wells, both active and inactive, are distributed throughout the watershed (Figure 2.3). Of this total, 382 are dry holes, 407 have been abandoned and plugged, and the remaining 769 are actively producing wells. The distributions of these wells are shown in Figures 2.4 through 2.6. Dry holes are exploratory well sites that have never produced and have been plugged. The abandoned wells were economically viable producers in the past, but have since declined in production and have been plugged. It should be noted that no gas wells are located within the watershed. The distribution of oil wells by drainage area is presented in Table 2.4. The BRA has purchased several producing wells within the conservation pool and is negotiating the purchase of the remaining producing wells within this area. These wells will be plugged in accordance with the Texas Railroad Commission requirements.

The sub-basin within the Lake Alan Henry watershed with the most wells, active and inactive, is BR-2. There are 672 wells in this sub-basin, averaging 15.3 wells per square mile (wells/sq.mi.). The sub-drainage above BR-1, with 34 wells, has the lowest number of wells in the watershed, while the area above BR-6 has the lowest density of wells with 1.2 wells/sq.mi.

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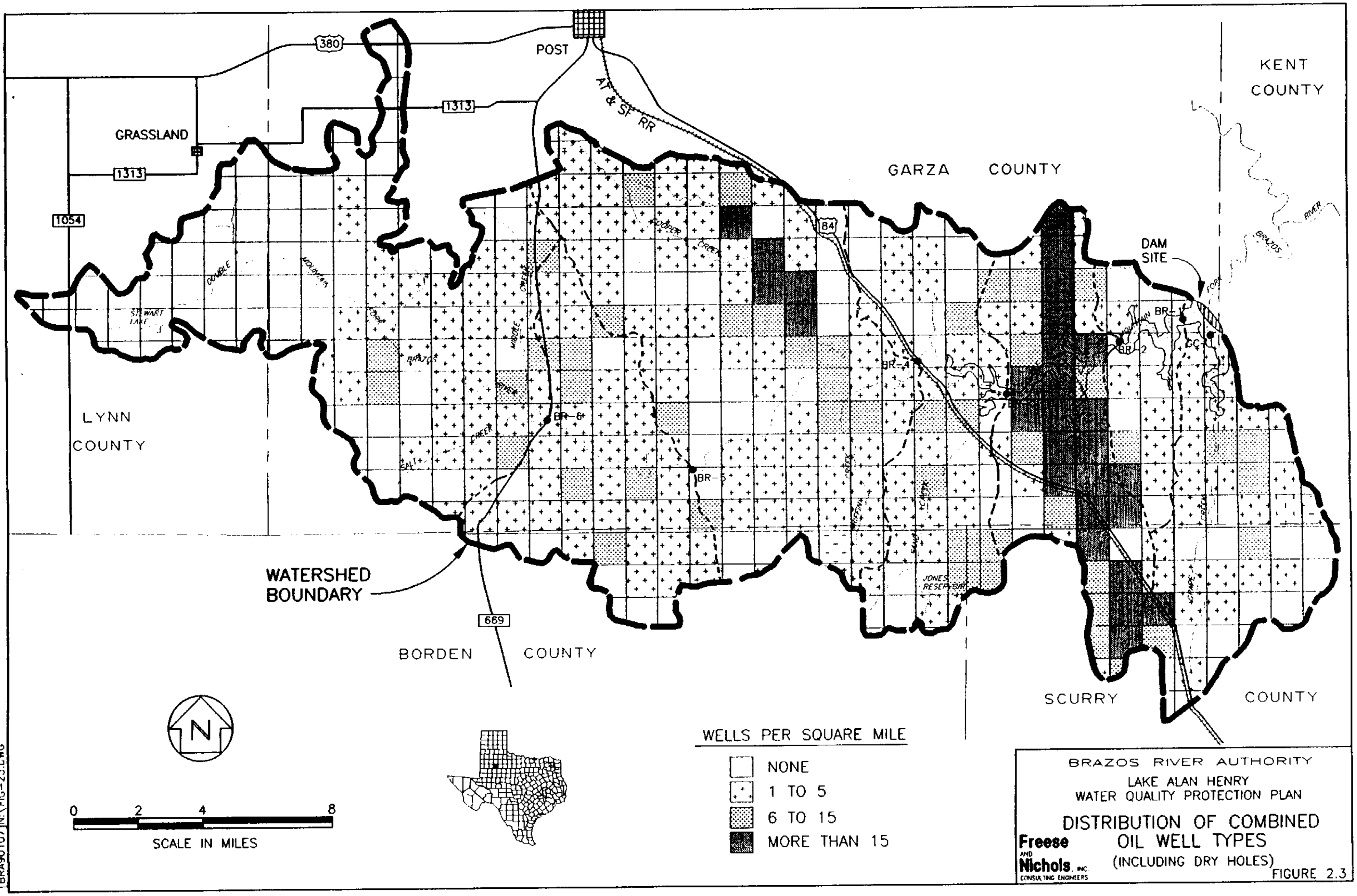

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DISTRIBUTION OF COMBINED OIL WELL TYPES (INCLUDING DRY HOLES)

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FIGURE 2.3

ACAD\MLP (8-25-92)
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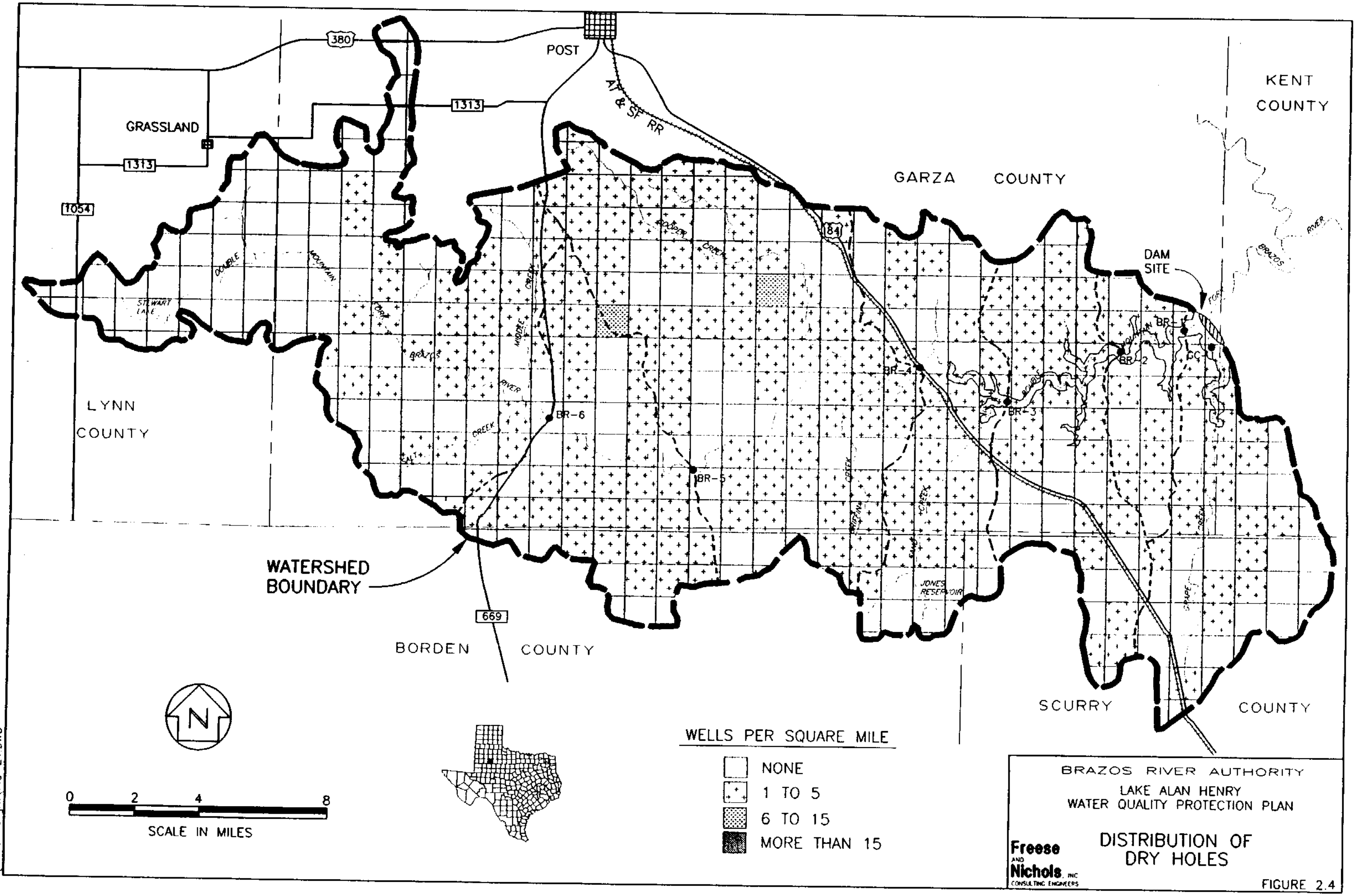

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DISTRIBUTION OF DRY HOLES

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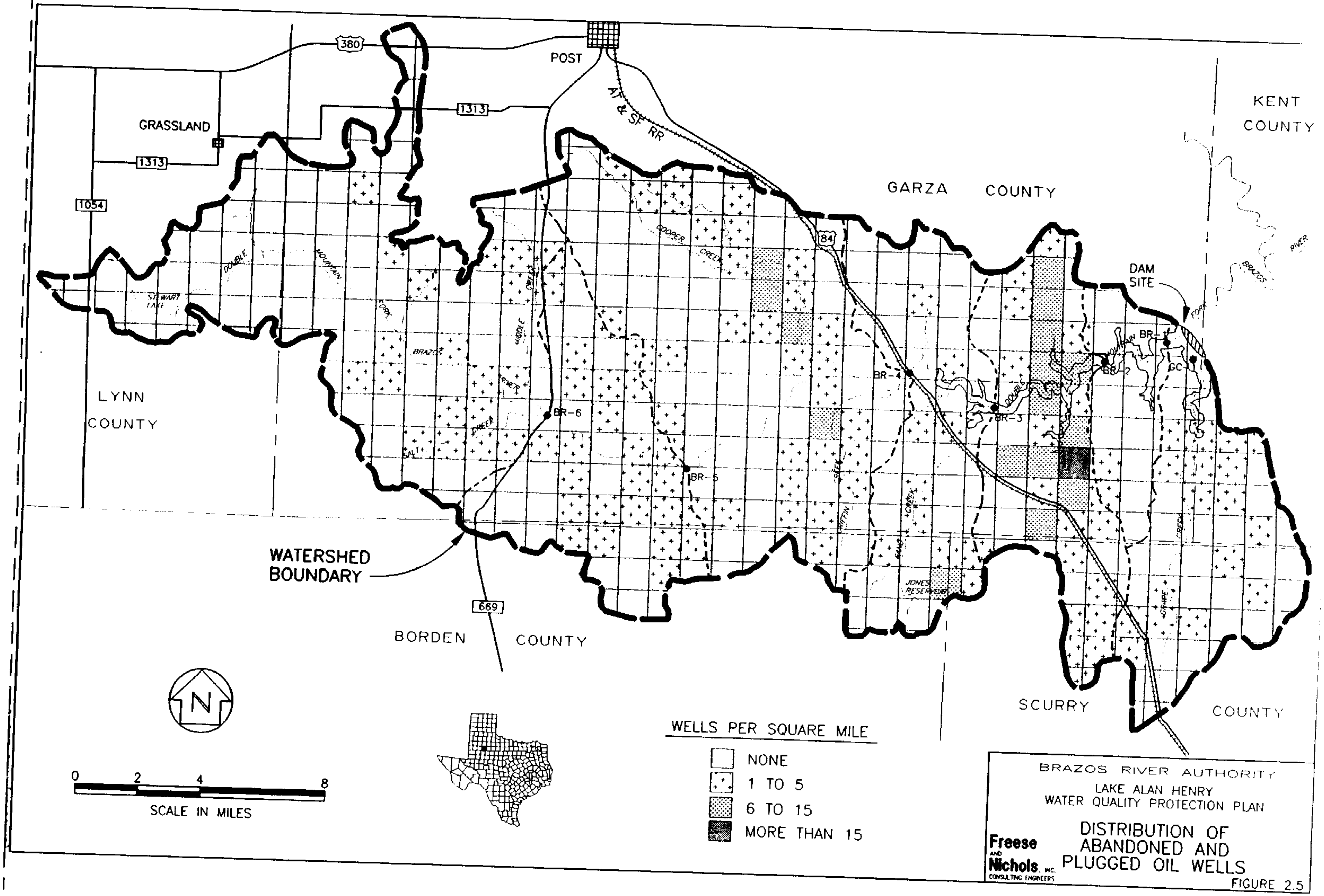
CONSULTING ENGINEERS

FIGURE 2.4



BRAZOS RIVER AUTHORITY

LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

DISTRIBUTION OF
ABANDONED AND
PLUGGED OIL WELLS

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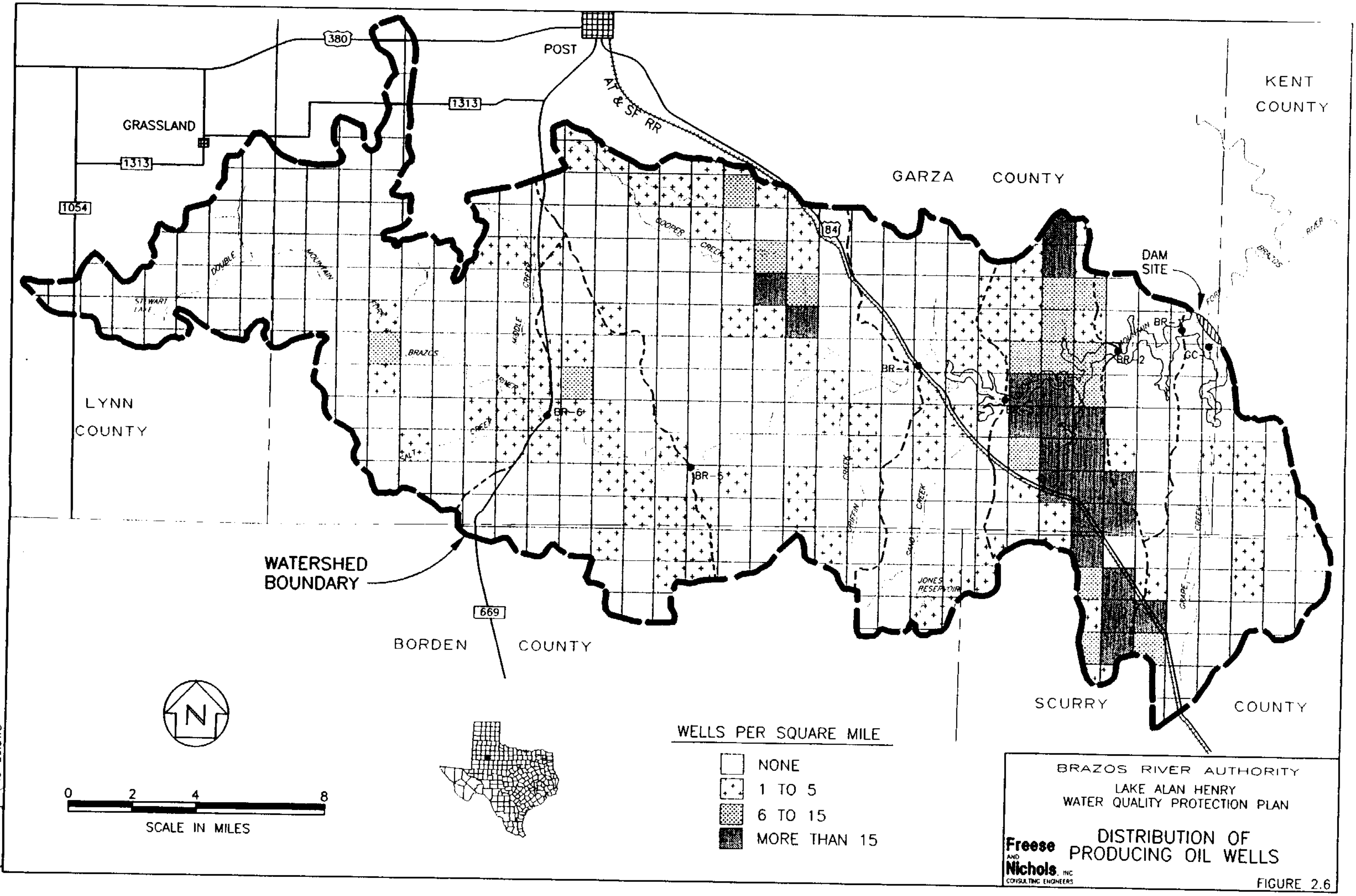
CONSULTING ENGINEERS

FIGURE 2.5



BRAZOS RIVER AUTHORITY
LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

DISTRIBUTION OF PRODUCING OIL WELLS

Freese and Nichols, Inc
CONSULTING ENGINEERS

FIGURE 2.6

ACAD\MLP (8-25-92)
[BRA90107]N:\FIG-26.DWG

Table 2.4

Inventory of Oil Wells in the Lake Alan Henry Watershed as of June 1991

Above Site	Dry Holes Incr.	Dry Holes Cumul.	Abandoned and Plugged Wells Incr.	Abandoned and Plugged Wells Cumul.	Producing Wells Incr.	Producing Wells Cumul.	Totals Incr.	Totals Cumul.
BR-6	50		31		40		121	
BR-5	55	105	49	80	51	91	155	276
BR-4	147	252	97	177	156	247	400	676
BR-3	45	297	31	208	27	274	103	779
BR-2	41	338	165	373	466	740	672	1451
BR-1	16	354	4	377	14	754	34	1485
GC-1	28		30		15		73	
Dam	382		407		769		1558	

Note: Incr. = Incremental number of wells in sub-basin above site
Cumul. = Cumulative number of wells in the watershed above site

The sub-basin that contains the greatest number of producing wells is BR-2, with 466 wells. The sub-watersheds above BR-1 and GC-1 contain the least number and density of producing wells with 14 wells (0.8/sq.mi.) and 15 wells (0.4/sq.mi.), respectively.

The area above BR-2 has the most abandoned wells with 165 wells. Sub-basin BR-1 has four abandoned wells, the least of all the sub-basins.

Dry holes are most numerous in the BR-4 sub-watershed with 147 present. The least number of dry holes, 16, occur in the sub-drainage area above site BR-1.

2.2.2 Pipeline Crossings

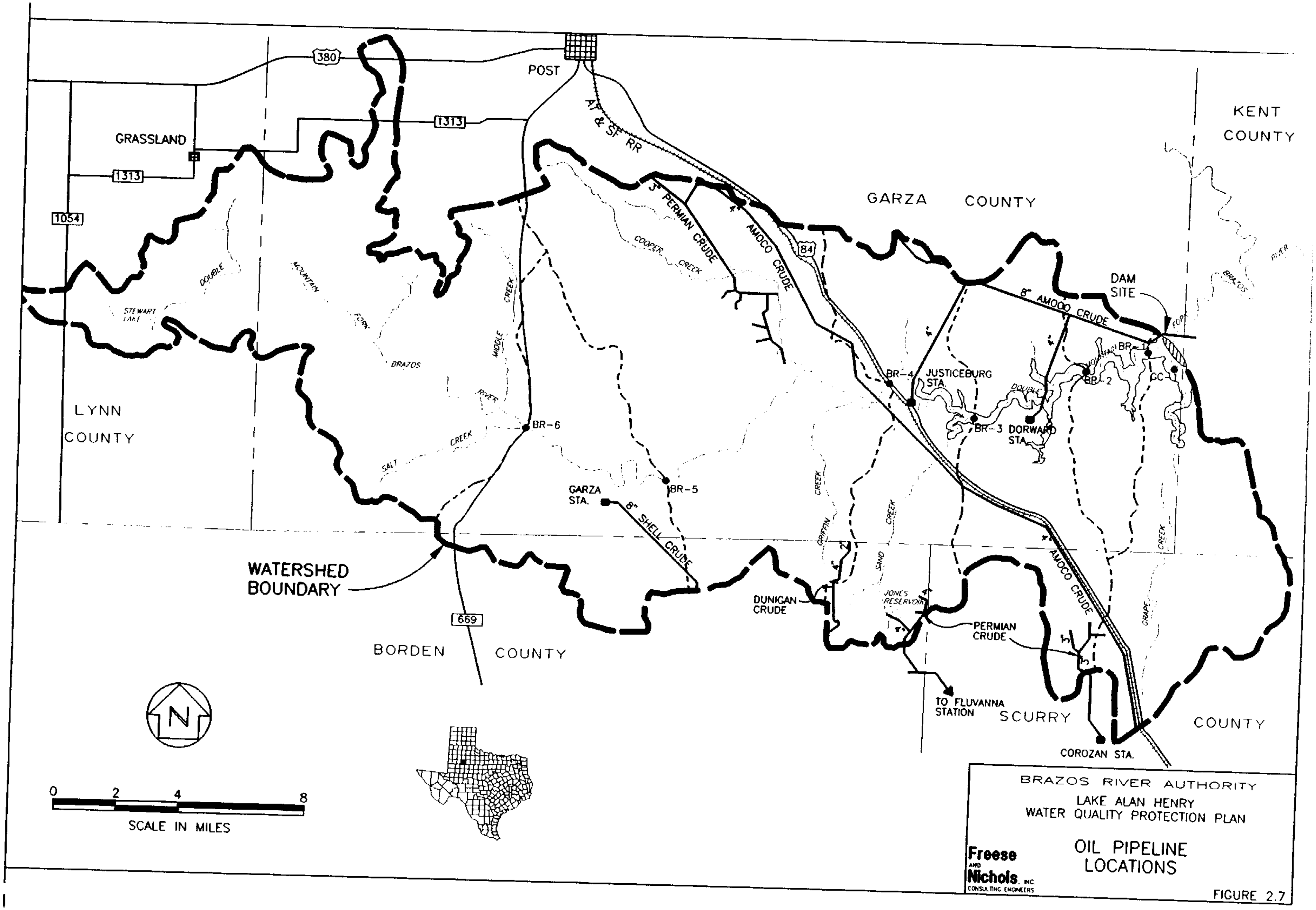
Several crude oil pipelines cross the Double Mountain Fork of the Brazos

River or lie within its watershed (Figure 2.7). Accidental releases could result from various causes along these pipelines. A leak or a pipeline break would pose a potential threat to water quality in Lake Alan Henry, especially if the oil were released into or reached a tributary, the main river, or the lake directly.

As part of the study for the Lake Alan Henry watershed, oil companies that own pipelines within the drainage area of the reservoir were surveyed regarding policy and present activity within the basin. The companies in the survey included AMOCO Pipeline Company, Shell Crude Pipeline Company, Scurlock Permian Pipeline Company, and Dunigan Operating Company.

The relative potential hazards of the pipelines were analyzed assuming that the closer a pipeline is to the reservoir, especially where the line crosses a tributary to the lake, the greater the potential that a release from the pipeline would reach the lake and adversely impact water quality. AMOCO's 8-inch pipeline and the two 4-inch lateral lines east of U.S. Highway 84, and the 4-inch AMOCO line that parallels U.S. Highway 84 would pose the greatest risk of contamination. The 3-inch Permian crude oil line along Cooper Creek would rank second to the AMOCO lines based on proximity to the reservoir. The 8-inch Shell Crude line in the BR-5 sub-watershed would follow the Permian line in degree of risk, based on the size of the Shell line and its proximity to the Double Mountain Fork of the Brazos River. The remaining oil pipelines along the southern watershed boundary would pose the lowest risk of contamination compared to the previously mentioned pipelines.

Another risk factor that was considered was the number of times that each pipeline crosses the Double Mountain Fork of the Brazos River or a tributary of



BRAZOS RIVER AUTHORITY
LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

OIL PIPELINE LOCATIONS

Freese and Nichols, Inc.
CONSULTING ENGINEERS

FIGURE 2.7

the river. The number of crossings of each pipeline and the minimum stream distances from the downstream-most crossing of each pipeline to the edge of the conservation pool of Lake Alan Henry and to the dam site are presented in Table 2.5. The distance from the crossing to the dam site is of interest because the water supply intake will be located near the dam. AMOCO's 4-inch pipeline from the Post Station presently crosses the river and its tributaries the most frequent of all lines in the watershed with 23 crossings. The minimum distances for the farthest downstream crossing of this line is 14 miles from the dam site and 1.2 miles from the edge of the conservation pool. Scurlock Permian's 3-inch line from the Post Station crosses streams 10 times and lies approximately 19 miles from the dam site and 6 miles from the edge of the conservation pool. The 8-inch AMOCO line from the Post Station and the 2" - 4" Dunigan line in northeast Borden County cross six and seven times respectively. The present 8-inch AMOCO line from Post Station crosses the river between one and eleven miles from the dam site, while the 2" - 4" Dunigan line is between 20 miles from the dam site and is not expected to be used much longer (personal communication with Gary Smith, Dunigan Operating Company, June 1, 1992). Pipelines that cross the Double Mountain Fork and its tributaries four times or less include the 8-inch Shell crude line from the Garza Station (26 miles from the dam site), the 3-inch Scurlock Permian line from the Corozan Station in Scurry County (17 miles from dam site), and the 4-inch AMOCO lines from the Justiceburg Station and the Dorward Station (1 to 14 miles and 1 to 8 miles from the dam site, respectively). The 3-inch Scurlock Permian line from the Corozan Station is expected to be abandoned during the summer of 1992, while the 4-inch line from the Fluvanna

Table 2.5

Pipeline Crossings on the Lake Alan Henry Watershed

Pipeline Company	Line Size	Crossings	Minimum Distance to Edge of Conservation Pool	Minimum Distance to Dam	Station or County of Origin
Shell Crude	8"	3	15 miles	26 miles	Garza
Scurlock Permian	3"	10	6 miles	19 miles	Post
Scurlock Permian	4"	Abandoned	7 miles	18 miles	Fluvanna
Scurlock Permian	3"	2	8 miles	17 miles	Corozan
Dunigan	2-4"	6	8 miles	20 miles	Borden County
Amoco Pipeline	4"	23	1.2 miles	14 miles	Post
Amoco Pipeline	8"	To be relocated	0 miles	0 miles	Post
Amoco Pipeline	4"	To be relocated	> 1	16 miles	Justiceburg
Amoco Pipeline	4"	To be relocated	0 miles	8 miles	Dorward

NOTE: The relocation of the Amoco pipelines within the reservoir is presently under negotiation between the Brazos River Authority and Amoco Pipeline Company.

Station in northeast Borden County was abandoned in 1991 following procedures required by the Texas Railroad Commission (personal communications with Mike Harris, Scurlock Permian Pipeline Company, May 20 and August 12, 1992).

As of June 1992, the Brazos River Authority and AMOCO Pipeline Company were negotiating an agreement to remove pipelines and pump stations from the reservoir pool area below elevation 2245 feet mean sea level. The final pipeline alignments and minimum distances from the edge of the conservation pool and the dam likely will be different from those reported here.

2.2.3 Railroad Crossings

Pollution risk factors for railroads include the number of stream crossings, the proximity of the crossings to the reservoir and the water supply intake, and the type of materials transported on the rail line. The Atchison, Topeka and Santa Fe Railroad crosses the Double Mountain Fork Brazos River immediately upstream of site BR-4. The railroad crosses 24 tributaries of the Double Mountain Fork. The minimum distances from the railroad to the edge of the conservation pool and dam site are 0.4 miles and 13 miles, respectively. Numerous types of cargo are transported along this route. Spills from railroad cars could cause pollutants to be discharged into the river or tributaries. For example, a train derailment in 1987 resulted in a spill of acrylic acid near Justiceburg, Texas. Emergency response crews quickly contained and cleaned up the spill, and none of the contaminant entered the waterways (personal communication with Delbert Rudd, Post Volunteer Fire Department, September 6, 1991). However, if a derailment occurred on a bridge immediately upstream from the reservoir, such as Sand Creek or the Double Mountain Fork, any material released would have a high potential of reaching the reservoir and possibly resulting in adverse impacts on the water supply.

2.2.4 Road Crossings

The pollution risk factors for roadways are similar to those discussed for rail lines. Several paved roadways pass through the watershed and cross the river. U.S. Highway 84 (U.S. 84) travels north-south through the region and crosses the river just above site BR-4. The highway crosses tributaries 24 times, and it crosses the Double Mountain Fork of the Brazos River once. The minimum distances from U.S. 84 to the edge of the conservation pool and to the dam site are 0.4 mile and 13 miles, respectively. U.S. 84 serves as the main corridor for travelers between Lubbock and Sweetwater. State Highway 669 (S.H. 669) is a significant paved roadway that crosses the river at site BR-6. S.H. 669 crosses the tributaries of the Double Mountain Fork eight times, with the minimum distance to the edge of the conservation pool being 17.5 miles. The minimum distance from the dam site to S.H. 669 is 30.5 miles. The speed limit on both of these highways is 55 miles per hour. Various types of materials are transported along U.S. 84 and S.H. 669. Therefore, the potential exists for an accidental spill to occur, releasing pollutants into the waterways.

A number of rural access roads, including county roads and ranch roads, are located within the watershed of Lake Alan Henry. Because of the lower volume of traffic and slower speeds on these roads, the potential for release of pollutants that would reach the reservoir is less in comparison to S.H. 669 and U.S. 84.

Relative to comparable lakes in Texas, the number of road and rail crossings over Lake Alan Henry and its tributaries is low. The threat of contamination from a spill is relatively mild in this watershed; however, the potential remains.

2.3 Ranking of Potential Pollution Sources

The potential sources of pollution within the drainage area of Lake Alan Henry can be categorized as either chronic or acute hazards. Chronic hazards pose constant or recurring threats to water quality in the reservoir. Potentially chronic hazards include the non-point sources of contamination: soils, geology, and land uses. Acute hazards are episodic and accidental in nature. Potentially acute hazards include point sources within the watershed such as chemical transport vehicles, pipelines, and oil wells. A release of toxic substance from a point source could have a potentially greater impact on water quality of the reservoir than a non-point source because of the acute nature of the release. The closer an accidental release occurs to the reservoir or its tributaries, the greater the potential threat to water quality. The potential pollution sources are identified and ranked in this chapter, and pollution control measures are discussed in Chapter 5.

Of the potential chronic sources of contamination in the drainage area, the soils and geology would pose the greatest threat to water quality. Highly erodible soils, which are abundant in the watershed, are a chronic threat to turbidity, suspended solids, and increased nutrient levels in the reservoir and its tributaries. Minerals in geologic formations may dissolve in water and be transported to the reservoir. The dissolution of these minerals and the erosion of soils in the area are ongoing processes. The degree of erosion is affected by the weather, land use, and the physical nature of the soil. If not controlled, the erosion of soils could create a threat to water quality.

Cropland and rangeland pose lesser threats to water quality than do other non-point sources in the watershed. Runoff water contaminated with nutrients or pesticides is the primary example of a threat to water quality from cropland. Because cropland comprises only seven percent of the land use in the contributing drainage area, it is not considered to be a significant non-point source.

Rangeland constitutes the dominant land use in the watershed. Potential threats to water quality include herbicides used for brush control and soil erosion due to over-grazing by cattle. Herbicide use for brush control is limited in the watershed and is not considered to be a significant non-point source. Erosion due to over-grazing is a more likely problem in rangeland, especially in localized areas on highly erodible soils.

The point sources that pose the most severe acute hazard to water quality in Lake Alan Henry are the highways and railroad. The threat to water quality is considered to be greater for the transportation of materials by truck or rail than for oil leaks from pipelines because the transportation of chemicals includes a wide variety of hazardous and toxic substances which may be more difficult to contain and remediate should a release occur. Trucks transporting large quantities of toxic materials on U.S. Highway 84 or F.M. 2458 could create an immediate threat to water quality in the event of an accident and subsequent release of material. Accidents on the highways farther from the reservoir would pose a lower hazard due to longer travel times.

The Atchison, Topeka and Santa Fe Railway would pose a similar acute hazard. Rail cars transporting toxic substances across the Double Mountain Fork of the Brazos River and its tributaries would create an immediate threat to water quality in Lake Alan Henry should an accident, such as derailment, occur.

Oil pipelines rank second to highways and the railroad as potential point sources of contamination. Release of oil from the lines, especially in locations of crossings with tributaries or the reservoir itself, occur at high pressure. Such releases may persist for a period of time before the leak is detected and remedied.

Oil wells and related facilities, such as tank batteries, are another potential source of acute hazards to water quality in the drainage area. The threat due to oil wells was not considered to be as severe as the previously mentioned point sources for several reasons. A leak from a well would be noticed, and hopefully corrected, soon after the release because the wells are inspected frequently by the owner or operator of the well. In addition, earthen berms surrounding many of the oil wells and tank batteries would help physically contain or restrict the migration of any released oil or brine. Because oil is insoluble and floats on water, it is more amenable to cleanup than other soluble chemicals. Brine would tend to become diluted in the reservoir. However, significant flow from a well over an extended period could cause substantial impact in a lake cove or stream.

In the event of a significant accidental release from a point source, the Lake Alan Henry water supply can be shut down for the spill to be contained and remediated. Lubbock and the surrounding cities can depend on other sources of water in the area to compensate for the interruption of diversions for water supply from the lake. Groundwater reserves could serve as an additional source of water supply for the area. The secondary sources of water reduce the need for major expenditures by the Brazos River Authority for standby emergency equipment and materials.

3. BASELINE WATER QUALITY

The background water quality of the Double Mountain Fork of the Brazos River was evaluated by reviewing historical data and by collecting samples during runoff and baseflow conditions. Previous sampling and studies by the U.S. Geological Survey (USGS), the City of Lubbock and Freese and Nichols formed the basis of the historical data review. Sampling efforts under the present study provided an update on many of the historical water quality constituents, and several parameters that were not sampled in previous investigations were included in this study.

3.1 Previous Monitoring

Water quality monitoring on the Double Mountain Fork at U.S. Highway 84 at Justiceburg has been conducted periodically by the USGS and the City of Lubbock since the mid-1960s. In 1975, the City began sponsoring a comprehensive, ongoing monitoring program by the USGS that includes measurement of chemical quality and streamflow. The City of Lubbock performed concurrent sampling for dissolved minerals in the river both at Highway 84 and near the proposed dam site eight times in 1978. Each of these data sources was used to characterize historical surface water quality.

While groundwater data for the immediate project area were not readily available, information published by the Bureau of Economic Geology and the Texas Water Development Board for nearby areas provided insight into the local groundwater quality.

3.1.1 Surface Water

Streamflow data indicate that the Double Mountain Fork of the Brazos River is a flashy stream with little baseflow, as is typical of many West Texas streams. The maximum recorded discharge was 49,600 cubic feet per second (cfs) in May 1969, while the median daily flow at the gaging station was only 0.05 cfs, based on measurements from December 1, 1961, through September 30, 1990 (USGS, 1962-1990).

The USGS collected water samples from the Double Mountain Fork at Justiceburg on 16 occasions between December 1964 and March 1966 (Freese and Nichols, 1978). These samples were analyzed for pH, specific conductance, hardness, total dissolved solids (TDS), and 10 dissolved constituents, including chloride, sulfate, nitrate, and fluoride, among others. Streamflow on the sampling dates ranged from 0.02 cfs to 220 cfs. The sampling data indicated that concentrations of dissolved minerals were inversely related to flow, with concentrations of TDS ranging from 300 to 400 mg/l when flows exceeded 100 cfs, up to 16,400 mg/l during periods of extremely low flow. Chloride concentrations ranged from 39 to 9,180 mg/l; sulfate ranged from 43 to 887 mg/l; fluoride ranged from 1 to 2.1 mg/l; and nitrate-nitrogen ranged from undetectable to 0.5 mg/l.

The eight samples collected and analyzed by the City of Lubbock in 1978 allowed comparison of quality between the USGS gage and the dam site (Freese and Nichols, 1978). The results indicated that dissolved mineral levels were lower near the dam site during baseflow periods. The data also revealed that concentrations of total dissolved solids were substantially lower along the river during high flows and that concentrations near the dam were somewhat higher than at the gage at such times. The TDS levels at the gage ranged from 324 to 9,717 mg/l, while the concentrations at the dam site ranged from 435 to 3,956 mg/l.

The USGS measures the specific conductance at the Justiceburg gage on a daily basis and periodically collects water samples and analyzes them for a number of parameters, including specific conductance, chlorides, sulfates, and total dissolved solids. The periodic sampling data are entered into the U.S. Environmental Protection Agency's national computer data base, STORET. An inventory of the EPA's STORET computer files was performed to evaluate chemical characteristics at the Justiceburg gage (Table 3.1). The water quality samples were collected during flow conditions ranging from 0.01 cfs to 18,400 cfs. The flow-weighted concentrations of TDS, chloride and sulfate were 454 mg/l, 90 mg/l, and 52 mg/l, respectively.

Flow-weighted average concentrations provide an indication of dissolved mineral levels that would be expected to occur if the runoff at a site was impounded in a reservoir. This is because flow-weighting gives greater significance to the concentrations that occur during high-flow events, which will contribute most of the reservoir contents. Considering the entire stream reach in the project area, high flows generally have much lower dissolved mineral levels than low flows.

A more complete estimate of dissolved mineral levels at the Justiceburg gage was available from monthly flow-weighted concentrations of chloride, sulfate, TDS, and hardness reported by the USGS based on continuous monitoring of conductivity at the Justiceburg gage. Using the periodic sampling data, the USGS updates regression analyses every two years to predict TDS, chloride, sulfate,

Table 3.1

Selected Water Quality Characteristics of the Double Mountain Fork of the Brazos River at Justiceburg, Texas Based on USGS Sampling between 1975 and 1991

	Average	Median	25th Percentile	75th Percentile	Range	Samples	Period
Temperature, °C	16.3	17	7	24	0 - 35	112	10/01/75-09/18/91
Conductivity, umhos	651*	5,280	731	16,600	356 - 27,700	102	10/01/75-09/18/91
Chloride, mg/l	90*	1,700	95	5,600	31 - 9,500	98	10/01/75-09/18/91
Sulfate, mg/l	52*	340	59	640	32 - 1,800	98	10/01/75-09/18/91
Total Dissolved Solids, mg/l	454*	1,450	445	9,820	229 - 18,300	53	10/01/75-12/14/82
Suspended Solids, mg/l	37,398*	10,800	359	27,200	175 - 52,300	20	06/15/77-06/19/82
pH (Lab), standard units	8	7.9	7.7	8.3	7.4 - 9.0	57	11/18/80-09/18/91
Dissolved Fluoride, mg/l	1*	1.2	0.8	1.4	0.4 - 2.6	92	10/01/75-09/18/91
Instantaneous Flow, cfs	775	7.5	0.8	840	0.01 - 18,400	115	10/01/75-09/18/91

* Indicates the value is a flow-weighted average.

Source: U.S. Environmental Protection Agency STORET computer data files.

and hardness from specific conductance (personal communication with Wanda Shelby, USGS, 1991). The USGS then calculates average monthly concentrations for those parameters based on the regression models and daily measurements of specific conductance.

The monthly flow, specific conductance, TDS, chloride, sulfate, and hardness recorded by the USGS at the Justiceburg gage from 1975 to 1990 were analyzed for the presence of trends using the statistical approach described by Hirsch et al. (1982) and Gilbert (1987). No statistically significant trends in the data were detected for flow, TDS, chloride, or hardness. Sulfate concentrations indicated a statistically significant (alpha equal to 0.01) decreasing trend. The estimated decrease in sulfate concentrations over the 16 year period was 3.87 mg/l per year. The monthly flow-weighted average concentrations are summarized in Table 3.2. The average monthly flow-weighted concentrations were similar to the average levels of periodic samples reported in Table 3.1, except for the mean monthly flow-weighted chloride level, which was 342 mg/l. The periodic sampling results for TDS, sulfates and hardness apparently were more representative of the true flow-weighted average concentrations than the periodic sampling results for chlorides at the site.

3.1.2 Groundwater in the Lake Alan Henry Reservoir Area

The reservoir site lies outside the limits of any designated major or minor aquifer zones (Texas Water Commission, 1990). The primary water-bearing strata in the reservoir vicinity include the alluvial and terrace deposits along the Double Mountain Fork and its larger tributaries, although these deposits probably

Table 3.2

Summary of Monthly Flow-Weighted Average Dissolved Mineral Concentrations in the Double Mountain Fork of the Brazos River at Justiceburg, Texas between October 1975 and September 1990

	Flow (cfs)	Total Dissolved Solids (mg/l)	Chloride (mg/l)	SO_4 (mg/l)	Hardness (mg/l)
Flow-Weighted Average	764	553	342	49	61
Median	82	1,130	690	93	85
Minimum	0	261	30	11	23
Maximum	8,555	16,600	8,800	1,200	1,581
No. of Months	156	156	156	156	114

do not contain large quantities of groundwater because of their limited extent in the immediate area. Rocks of the Dockum group are known to yield only small amounts of water for domestic and livestock purposes (Cronin, 1972). Groundwater recharge in the alluvial and terrace deposits occurs primarily by precipitation on the outcrop zones, while streamflow provides some recharge to these aquifers during periods of high runoff (Cronin, 1972). The Dockum group in the Southern High Plains has no independent recharge source other than the Ogallala aquifer (Nativ, 1988). Natural discharge from the aquifers occurs through seeps and springs, evapotranspiration, and by discharge into the streams when the water table is above the stream bed elevation. Artificial discharge occurs through pumping from wells.

Chemical quality of groundwater in alluvial and terrace deposits and in the

Dockum group in Dickens and Kent Counties has been characterized (Cronin, 1972), but apparently little attention has been given to these aquifers in Garza County near the proposed reservoir site. Groundwater in the vicinity of the proposed reservoir is probably similar to the quality of groundwater in comparable strata in Dickens and Kent Counties.

The groundwater quality in the alluvium deposits in Dickens and Kent Counties is highly variable. The TDS concentration was less than 500 mg/l in about 11 percent of 114 samples, between 500 and 1,000 mg/l in approximately 16 percent of the samples, and more than 1,000 mg/l in the remaining 73 percent of the samples. Chloride concentrations exceeded 250 mg/l in approximately 72 percent of the samples tested, while about 44 percent of the samples exceeded 250 mg/l of sulfate (Cronin, 1972).

Total dissolved solids in 17 samples of groundwater from the Dockum group ranged from less than 300 mg/l to over 1,000 mg/l, with over half of the samples containing less than 500 mg/l (Cronin, 1972). Rawson (1967) indicated that dissolved solids in water derived from the Dockum Group varied locally, with concentrations exceeding 5,000 mg/l in some shallow wells. Sulfate and chloride were less than 250 mg/l in all but two of the samples.

3.2 Summary of Recent Water Quality Sampling

3.2.1 Sampling Network

The objectives of the pre-impoundment water quality sampling program were to establish baseline water quality conditions and identify the source area of contaminants, if present. A water quality monitoring network consisting of seven sampling sites was established to accomplish these objectives. Sampling was conducted during both baseflow and high flow periods.

Six of the seven sampling stations were on the Double Mountain Fork of the Brazos River and one was on Grape Creek (Figure 3.1). The sites were selected for their accessibility and because they offered the opportunity to isolate runoff from oil production areas. Oil field activities are the most visible of the potential pollution sources in the drainage basin.

Sampling station BR-1 was located near the dam to characterize the composite water quality from the watershed of Lake Alan Henry, excluding the Grape Creek drainage. The total contributing drainage area above BR-1 is 352 square miles. Site BR-1 has a sub-drainage area of 17 square miles below site BR-2.

Sampling site BR-2 was located approximately 4.1 river miles upstream from BR-1. This site allowed analysis of runoff from the Dorward and Justiceburg Oil Fields, which cover a three-mile-wide band extending from the north to the south drainage divides. The total contributing drainage area above site BR-2 is 335 square miles. The sub-drainage area between sites BR-2 and BR-3 is 43 square miles.

Sampling site BR-3 was located approximately 6.6 river miles upstream from BR-2, near the upstream boundary of the Dorward and Justiceburg Oil Fields. The contributing drainage area above site BR-3 is 292 square miles, and the sampling point has a sub-drainage area of 45 square miles.

Sampling site BR-4 was located at U.S. Highway 84 near Justiceburg. The USGS, in cooperation with the City of Lubbock, operates a streamflow gage and quality sampling station at this site. Site BR-4 is approximately 5.2 river miles above site BR-3 and has a contributing drainage area of 247 square miles. The sub-drainage area between BR-4 and BR-5 is approximately 96 square miles.

Sampling site BR-5 is located approximately 10.9 river miles upstream from BR-4. The site is just upstream of a low water crossing used by oil companies and local ranchers to access land north of the river. The total contributing drainage area above this site is 151 square miles, and the sub-drainage area between sites BR-5 and BR-6 is 51 square miles.

Sampling site BR-6 is located at the F.M. 669 bridge approximately 7.7 miles upstream from site BR-5. The contributing drainage area above this site is 100 square miles.

Grape Creek enters the Double Mountain Fork Brazos River near the Lake Alan Henry dam site just downstream of site BR-1. Sampling site GC-1 was located on Grape Creek approximately 1.3 river miles upstream of the confluence. This site covers a significant portion of the runoff which enters the Double Mountain Fork in the intervening area between BR-1 and the dam. The drainage area of site GC-1 is 41 square miles, which is approximately 10 percent of the reservoir's total drainage area.

3.2.2 Sampling Parameters and Frequency

Samples were collected during baseflow and storm runoff events between July 1990 and August 1991. Baseflow was considered to be the normal flow in the river after surface runoff from precipitation passed. The samples were analyzed by the City of Lubbock water and wastewater treatment laboratories for thirty screening parameters, including dissolved minerals, nutrients, priority metals, pesticides, and microbiological constituents. The City of Lubbock laboratories provided a number of additional analyses, including several metals, organics, and a detailed hydrocarbon scan. Two runoff samples from BR-1 were analyzed for priority pollutants. The sampling parameters and the EPA-approved analysis methods are presented in Table 3.3.

In addition to laboratory analyses, several measurements were made in the field at the time of sample collection. Field observations included pH, dissolved oxygen, specific conductance, and temperature. Estimates of instantaneous discharge also were made at each sampling site, using a current meter or the float method. An intensive low flow water quality survey was performed in April 1992 by measuring specific conductance at approximately 100 points between sampling sites BR-2 and BR-4.

The water quality parameters used in this study were selected as indicators of potential pollutant sources in the watershed. For example, high concentrations of total petroleum hydrocarbons (TPH) might indicate contamination due to oil field activity or roadway runoff. High nutrient levels might signal problems due to agricultural activities, soil erosion, or inadequately treated sewage. Elevated concentrations of dissolved minerals might reflect contamination due to natural phenomena such as geologic formations or to human activities such as oil production.

Table 3.3

Analytical Methods Employed by the City of Lubbock Water and Wastewater Laboratories

	EPA METHOD
METALS	
Arsenic	206.2
Cadmium	213.1/213.2
Chromium	218.1/218.2
Copper	220.1
Lead	239.2
Mercury	245.1
Nickel	249.1/249.2
Selenium	270.2
Silver	272.1/272.2
Zinc	289.1
INORGANIC	
pH	150.1
Temp C	170.1
Turbidity	180.1
Conductivity	120.1
Fluoride	340.2
Chloride	300.0
Sulfate	300.0
Dissolved Solids	160.3
Suspended Solids	160.1
NUTRIENTS	
Nitrate	300.0
Ammonia	350.2
TKN	351.3
Phosphate	300.0
BOD	405.1
HERBICIDES	
2,4-D	515.1
2,4,5-T	515.1
2,4,5-TP	515.1
Dioxin	613

Table 3.3, Continued

	EPA METHOD
PESTICIDES	
Endrin	505
Lindane	505
Methoxychlor	505
Dieldrin	505
Heptachlor	505
Toxaphene	505
Chlordane	505
Malathion	505
Parathion	505
PCB (Total)	505
HYDROCARBONS	
Oil & Grease	413.2
TPH	418.1
PHENOLS	
2-Chlorophenol	604
2,4-Dichlorophenol	604
2,4-Dimethyphenol	604
2-Nitrophenol	604
4-Nitrophenol	604
2,4-Dintrophenol	604
4,6-Dinitro-o-Cresol	604
Pentachlorophenol	604
Phenol	604
2-Methylphenol	604
4-Methylphenol	604
2,4.5-Trichlorophenol	604
Acrolein	603
Acrylonitrile	603
PHTHALATES	
Bis (2-Ethylhexyl) Phthalate	606
Butyl Benzyl Phthalate	606
Di-n-Butyl Phthalate	606
Di-n-Octyl Phthalate	606
Diethyl Phthalate	606

Table 3.3, Continued

	EPA METHOD
Dimethyl Phthalate	606
Di (2-ethylhexyl) Adipate	606
BASE NEUTRALS	
Azobenzene	610
Hexachlorobenzene	612
Hexachlorobutadiene	612
Hexachlorocyclopentadiene	612
Hexachloroethane	612
Isophrone	609
Nitrobenzene	609
N-Nitrosodimethylamine	607
N-Nitrosodiphenylamine	607

3.2.3 Results of Sampling

Twenty-six samples during five runoff events and 28 samples during seven baseflow sampling trips, yielding a total of 54 samples, were collected between July 1990 and August 1991. The arithmetic average values of the screening parameters for baseflow and high-flow sampling trips are presented in Tables 3.4 and 3.5, respectively.

Sampling sites BR-5, BR-6, and GC-1 were located in intermittent reaches that had no streamflow during baseflow periods. The results of laboratory and field measurements are listed in Appendix A, and the water quality sampling results for each of the screening parameters are discussed below.

Nitrate-Nitrogen. Nitrogen (N) is an essential plant nutrient that occurs in several different forms in the environment, including elemental nitrogen, organic nitrogen, ammonia, nitrite, and nitrate. Nitrate is the most highly oxidized form of nitrogen and is the form that is most readily utilized by rooted and floating plants and algae. Although nitrogen is essential to plant growth, elevated levels of nitrate-N can contribute to eutrophication of reservoirs if other essential plant nutrients are not limiting to algal populations (Manahan, 1984). Potential sources of nitrate-N are natural, such as the decay of organic matter and nitrate in soil, and manmade, such as runoff from fertilized fields, feedlots, and wastewater treatment plant effluent (Lehr et al., 1980).

The average nitrate-N concentrations in the baseflow samples from the Double Mountain Fork ranged from 0.1 mg/l at BR-3 to 1.2 mg/l at BR-2. The range of nitrate-N in high-flow samples along the river was from 1.5 mg/l at BR-3 to 3.0 mg/l at BR-5. While no apparent trends in concentrations were found in

Table 3.4

Average Concentrations* of the Water Quality Screening Parameters Collected during Baseflow in the Double Mountain Fork of the Brazos River between July 1990 and August 1991

	Sampling Site						
	BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
Nitrate-N	--	--	0.6	0.1	1.2	1.1	--
Ammonia-N	--	--	0.1	0.4	0.1	0.1	--
Total Kjeldahl N	--	--	1.0	0.8	1.3	1.9	--
Total Phosphorus	--	--	0.12	0.15	0.57	0.27	--
Suspended Solids	--	--	292	183	641	1,224	--
Biochemical Oxygen Demand (BOD_5)	--	--	1.1	1.1	1.2	1.2	--
Turbidity	--	--	10	24	38	35	--
Total Diss. Solids	--	--	7,213	10,966	4,316	3,172	--
Chloride	--	--	707	598	587	525	--
Sulfate	--	--	524	468	388	275	--
Fluoride	--	--	1.2	0.7	0.7	0.7	--
Conductivity	--	--	11,674	16,626	7,066	5,406	--
Fecal Coliform	--	--	1,102	582	600	708	--
Fecal Streptococcus	--	--	322	499	821	573	--
Oil and Grease	--	--	0.2	1.3	ND	1.6	--
Total Petroleum Hydrocarbons	--	--	0.60	0.34	0.31	0.11	--
Total PCBs	--	--	ND	ND	ND	ND	--
Diss. Arsenic	--	--	0.008	0.004	0.001	0.007	--
Diss. Cadmium	--	--	0.015	0.016	0.011	0.011	--
Diss. Chromium	--	--	0.008	0.016	0.007	0.003	--
Diss. Copper	--	--	0.018	0.023	0.015	0.11	--
Diss. Lead	--	--	0.003	ND	ND	ND	--
Diss. Mercury	--	--	ND	ND	ND	ND	--
Diss. Nickel	--	--	0.075	0.090	0.047	0.044	--
Diss. Selenium	--	--	ND	ND	ND	ND	--
Diss. Silver	--	--	0.014	0.027	0.010	0.029	--
Diss. Zinc	--	--	0.009	0.008	0.008	0.009	--
pH	--	--	7.9	7.9	8.0	8.0	--
Diss. Oxygen	--	--	8.8	9.6	9.1	9.5	--

NOTES:

* All values are in milligrams per liter, except: fecal bacteria, which are reported in number of colonies per 100 milliliters of sample; pH in s.u.; turbidity in TU; and conductivity in umhos/cm.

-- Indicates no sample was collected due to lack of flow.

ND Indicates constituent was not detected.

Table 3.5

Average Concentrations* of the Water Quality Screening Parameters Collected during High Flow in the Double Mountain Fork of the Brazos River between July 1990 and August 1991

	Sampling Site						
	BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
Nitrate-N	2.3	3.0	1.6	1.5	2.0	1.8	5.5
Ammonia-N	0.1	0.3	0.2	0.2	0.3	0.4	0.1
Total Kjeldahl N	6.5	10.7	10.7	11.2	14.0	10.1	1.9
Total Phosphorus	0.55	0.32	0.71	0.47	0.88	0.32	1.18
Suspended Solids	5,116	9,015	17,707	15,507	20,492	19,704	1,403
Biochemical Oxygen Demand (BOD$_5$)	3.0	4.5	5.3	6.2	6.0	7.8	4.0
Turbidity	135	159	162	180	161	128	146
Total Diss. Solids	1,261	719	686	736	814	1,126	443
Chloride	349	228	129	216	203	410	111
Sulfate	251	213	171	108	133	241	128
Fluoride	2.3	1.1	0.9	0.9	0.8	0.7	0.3
Conductivity	2,033	1,143	1,089	1,054	1,246	1,798	690
Fecal Coliform	2,183	4,483	2,905	3,345	4,701	4,013	5,075
Fecal Streptococcus	1,327	2,860	2,949	2,345	3,534	1,958	7,500
Oil and Grease	14.7	13.3	14.0	15.5	22.0	11.5	ND
Total Petroleum Hydrocarbons	0.3	0.13	ND	0.26	0.11	0.44	ND
Total PCBs	ND	ND	ND	ND	ND	ND	ND
Diss. Arsenic	ND	0.001	0.004	0.013	0.012	0.006	0.001
Diss. Cadmium	0.004	0.022	0.016	0.010	0.012	0.010	0.002
Diss. Chromium	0.008	0.005	0.005	0.014	0.004	0.006	0.004
Diss. Copper	0.045	0.014	0.032	0.040	0.011	0.029	0.018
Diss. Lead	ND	0.001	ND	ND	ND	0.001	0.003
Diss. Mercury	ND	ND	ND	ND	ND	ND	ND
Diss. Nickel	0.075	0.013	0.046	0.055	0.046	0.015	0.015
Diss. Selenium	0.068	0.043	0.022	0.078	0.103	0.028	0.007
Diss. Silver	0.010	0.009	0.005	0.004	0.004	0.013	0.015
Diss. Zinc	0.029	0.013	0.030	0.030	0.007	0.058	0.022
pH	8.6	8.5	8.8	8.9	8.8	8.7	8.1
Diss. Oxygen	12.6	--	12.1	10.6	11.8	10.8	--

NOTES:

*	All values are in milligrams per liter, except: fecal bacteria, which are reported in number of colonies per 100 milliliters of sample; pH in s.u.; turbidity in TU; and conductivity in umhos/cm.
--	Indicates no sample was collected.
ND	Indicates constituent was not detected.

either the upstream or downstream direction, the nitrate-N concentrations generally were greater during high flows.

Grape Creek tended to have flow only after rains, and only two samples were collected from site GC-1 due to lack of rain and inaccessibility during some runoff events. The average nitrate-N concentration at site GC-1 was 5.5 mg/l, with levels ranging from 8.5 mg/l in May 1991 to 2.5 mg/l in June 1991.

Ammonia-Nitrogen. Ammonia is an intermediate form of nitrogen that is derived during the oxidation of elemental and organic nitrogen or from the reduction of nitrate or nitrite. Ammonia presumably has the same sources as nitrate (Lehr et al., 1980). The rate of oxidation to convert ammonia to nitrate is controlled by biochemical processes (Hem, 1970).

The average ammonia-N concentrations in baseflow samples from the Double Mountain Fork ranged from 0.1 mg/l at BR-1, BR-2, and BR-4 to 0.4 mg/l at BR-3. The average concentrations during high flow on the mainstem ranged from 0.1 mg/l at BR-6 to 0.4 mg/l at BR-1. The two high-flow samples collected at site GC-1 averaged 0.1 mg/l.

Total Kjeldahl Nitrogen. Total Kjeldahl nitrogen (TKN) is the sum of organic nitrogen and ammonia nitrogen. Organic matter such as decaying vegetation, human and animal wastes, and other sources similar to those for nitrate and ammonia would contribute to TKN.

The average TKN concentrations for baseflow samples on the Double Mountain Fork ranged from 0.8 mg/l at BR-3 to 1.9 mg/l at BR-1. The high-flow samples from the mainstem averaged from 6.5 mg/l at BR-6 to 14.0 at BR-2. High flows appeared to have significantly higher average concentrations of TKN than baseflows, which probably reflects the influx of organic materials from the watershed during storm events.

The two high-flow samples collected at site GC-1 averaged 1.9 mg/l. This concentration is comparable to those observed at the mainstem sites during low flows and may be due to the time of sampling. By the time site GC-1 could be reached following a rain event, the flood peak had passed and the water level was receding.

Total phosphorous. Phosphorous, like nitrogen, is an essential plant nutrient which can contribute to eutrophication if concentrations are elevated. Sources of phosphorous include detergents, fertilizers, wastewater treatment plant effluent, phosphorous bound on clay minerals, and the mineral apatite, which is found in igneous rock and marine sediment (Hem, 1970).

The average concentrations of total phosphorus in the baseflow samples along the Double Mountain Fork ranged from 0.12 mg/l at BR-4 to 0.57 mg/l at BR-2. The average concentrations in high-flow samples ranged from a minimum of 0.32 mg/l at BR-1 and BR-5 to a maximum of 0.88 mg/l at BR-2. The average concentrations for the two high-flow samples collected at site GC-1 measured 1.18 mg/l and varied from 2.33 mg/l on May 8, 1991, to 0.03 mg/l on June 3, 1991. These levels were comparable to the concentrations measured at the mainstem sites on these two dates.

Biochemical Oxygen Demand. The biochemical oxygen demand (BOD_5) is a measure of the oxygen used by microorganisms in the aerobic oxidation of organic matter (Manahan, 1984). The standard time period for the laboratory measurement is five days. Processes which contribute significantly to oxygen demand include decay of organic matter in the water column and bottom sediments, and nitrification of ammonia.

The average BOD_5 concentrations in the river during baseflow were 1.1 mg/l at BR-3 and BR-4 and 1.2 mg/l at both BR-1 and BR-2. The high-flow concentrations ranged from 3.0 mg/l at BR-6 to 7.8 mg/l at BR-1. High flows had higher BOD_5 concentrations than the low flows, which would be expected due to the input of organic materials during runoff events. Concentrations increased in a downstream direction during both high flows and baseflows. The concentrations for the high-flow samples collected at GC-1 were comparable to those collected at the mainstem sites and ranged from none detectable in May 1991 to 8.0 mg/l in June 1991.

Total Suspended Solids. Suspended solids (TSS) in water are the materials which will be retained on a filter with pores ranging in size from 40 microns to 60 microns and include microorganisms, organic matter, clay, silt, sand, and gravel. The quantity of suspended solids is generally directly related to the flow volume and velocity.

The average concentrations of suspended solids in baseflow samples along the river ranged from 183 mg/l at BR-4 to 1,224 mg/l at BR-1. The average concentrations in high-flow samples greatly exceeded the low flow concentrations, ranging from 5,116 mg/l at BR-6 to 20,492 mg/l at BR-2. As expected, the TSS concentrations are higher in the downstream portion of the study area. The suspended solids concentrations in two samples collected at GC-1 were lower than those observed on the mainstem and ranged from 420 mg/l in May 1991 to 2,385 mg/l in June 1991.

Turbidity. The interference of light transmission through water by insoluble particles, including soil, organic matter, microorganisms, and other materials, is referred to as turbidity. Turbidity is determined by measuring the scatter of light caused by suspended matter. Turbidity in a typical clear lake is 25 turbidity units (TU), and in muddy water it may exceed 100 TU (Hammer, 1986).

The average turbidity in baseflow samples along the Double Mountain Fork of the Brazos River ranged from 10 TU at BR-4 to 38 TU at BR-2. The high-flow samples were significantly more turbid, with average turbidities ranging from 128 TU at BR-1 to 180 TU at BR-3. The turbidities in the two high-flow samples collected at GC-1 were comparable to the levels found at the upper sites along the mainstem. The concentrations at GC-1 ranged from 195 mg/l in May 1991 to 96 mg/l in June 1991.

Total Dissolved Solids. The total dissolved solids (TDS) parameter is a measure of the concentration of dissolved minerals in water. These minerals consist primarily of chlorides, sulfates, carbonates, bicarbonates, nitrates, and phosphates of calcium, magnesium, sodium, potassium and occasionally iron and manganese. Some potential sources contributing to total dissolved solids concentrations include natural geological formations (particularly gypsum and limestone), runoff from oil field production areas and cropland, and effluent from wastewater treatment plants (Lehr et al., 1980).

The average concentrations of TDS at the mainstem sites during baseflow periods were elevated and varied widely, ranging from 3,172 mg/l at BR-1 to 10,966 mg/l at BR-3. The average concentrations during high-flows were significantly lower, ranging from 686 mg/l at BR-4 to 1,261 mg/l at BR-6; site BR-1 averaged 1,126 mg/l TDS. The TDS concentrations at GC-1 were lower than at any of the mainstem sites on the May and June 1991 sampling dates, with TDS levels of 688 mg/l and 178 mg/l.

The TDS concentrations in samples collected at BR-1 and BR-4 were within the range of values reported in previous studies. In general, TDS concentrations tended to decrease with increased flow. The concentrations decreased from BR-4 to BR-1 during baseflow conditions. However, the values observed at BR-1 during high flow were greater than those at BR-4. This pattern was also noted in previous water quality sampling (Freese and Nichols, 1978).

Chloride. The most common sources of chloride are evaporite minerals such as halite (sodium chloride). Evaporites are minerals that have precipitated from bodies of water subjected to intense evaporation (Levin, 1986). Other sources of chloride include oil field brine, wastewater treatment plant effluent, and industrial wastes (Lehr, et al., 1980).

The average concentrations of chloride in baseflow samples on the mainstem decreased slightly in a downstream direction and ranged from 525 mg/l at BR-1 to 707 mg/l at BR-4. The average chloride levels during high-flows were significantly lower than the baseflow levels at all of the sites, with averages ranging from 129 mg/l at BR-4 to 410 mg/l at BR-1. The concentrations of chloride in the two high-flow samples collected at GC-1 were 178 mg/l and 45 mg/l in May and June 1991, respectively. These values were comparable to, and in some cases lower than, the levels found at the mainstem sites on these sampling dates.

The chloride concentrations observed at BR-4 were within the range of values reported by the USGS and Freese and Nichols (1978) for the same site. The chloride concentrations for samples collected at BR-1 were also within the range of concentrations reported in previous water quality sampling (Freese and Nichols, 1978).

Sulfate. Many sulfate compounds are readily soluble in water. Sulfate compounds originate commonly from the oxidation of sulfite ores, the solution of gypsum and anhydrite minerals, the presence of shales, and some industrial wastes (Lehr et al., 1980).

The average concentrations of sulfate at the Double Mountain Fork sites varied from 275 mg/l at BR-1 to 524 mg/l at BR-4. The high-flow averages ranged from 108 mg/l at BR-3 to 251 mg/l at BR-6. The concentrations of sulfate in two high-flow samples from GC-1 were lower than most of the mainstem sites, with concentrations of 216 mg/l in May 1991 and 40 mg/l in June 1991.

The sulfate concentrations in the low-flow samples exhibited similar patterns to sulfate concentrations in previous studies, as well as the chloride concentrations in this study. The average sulfate concentrations were significantly less at sites BR-2, BR-3, and BR-4 during high flow, while the concentrations at BR-1 were comparable during low and high flow. Sulfate levels decreased in a downstream direction during baseflow; however, in high-flow samples the average sulfate concentration at BR-1 was higher than at BR-4.

Fluoride. Fluoride occurs naturally in some geologic formations and is only slightly soluble in water. Other sources of fluoride include certain insecticides, chemical wastes, and airborne particles and gases from aluminum smelting plants (Lehr et al., 1980). Fluoride is used in the structure of bones and teeth in animals and humans (Manahan, 1984).

The average concentrations of fluoride in baseflow samples were 0.7 mg/l at BR-1, BR-2, and BR-3, and 1.2 mg/l at BR-4. The average concentrations during high flow ranged from 0.7 mg/l at BR-1 to 2.3 mg/l at BR-6. The fluoride concentrations in the two high-flow samples collected at GC-1 were 0.23 mg/l and 0.31 mg/l in May and June 1991, respectively. Concentrations of fluoride tended to decrease in a downstream direction through the study area.

Conductivity. Conductivity, or specific conductance, is a measure of the ability of water to conduct an electric current and is the reciprocal of electrical resistivity (Lind, 1974). The conductivity of water is directly related to the amount of dissolved ionic matter present. Therefore, conductivity measurements provide a convenient and frequently employed method for estimating the total dissolved solids concentration of water. In most natural waters, the TDS may be estimated from conductivity measurements by multiplying the reading by a factor, usually between 0.5 and 1.0, that is determined empirically for a specific water body. The Texas Water Comssission, for example, routinely applies a multiplier of 0.5 to conductivity readings to get a rough estimate the dissolved solids concentrations of surface waters in the state (TWC, 1990).

In the present study, conductivity measurements were found to be highly correlated with TDS concentrations. Comparison of the mean values of conductivity and TDS in Tables 3.4 and 3.5 demonstrates this strong relationship. Using regression analysis on samples collected in the study area, it was determined that a factor of 0.62 times conductivity would provide a reasonable estimate of TDS concentration.

Conductivity measurements were used as a quality control check on laboratory analyses for TDS. They also can be used to estimate TDS concentrations on days when no analysis results for TDS were available and when quality control reviews indicated that reported TDS values were outliers. Estimates of TDS concentrations were made for two sampling dates and sites based on conductivity measurements. These dates and sites included July 25, 1990, at BR-4 and December 18, 1990, at BR-1, when quality control checks revealed that the laboratory-reported TDS values appeared to be low relative to conductivity and other dissolved mineral levels.

Fecal Coliform and Fecal Streptococcus Bacteria. The bacteria that comprise these two groups are found in the intestines of warm-blooded animals and humans. Therefore, testing for these bacteria provides an indication of fecal contamination of water. In addition to raw domestic wastewater, fecal bacteria are normally present in runoff which has come into contact with domestic livestock and wildlife wastes.

In the past, the ratio of fecal coliform (FC) and fecal streptococcus (FS) bacteria counts was recommended to determine whether fecal pollution originated from human or animal sources and even to identify the type of animal source (American Public Health Association (APHA), 1985). A ratio of FC to FS less than 0.7 indicated that the pollution derived from animal wastes; a ratio greater than 4.0 suggested that the pollution source was human; and ratios falling between these two values would reflect mixed sources. However, the APHA no longer recommends using the ratio to distinguish between human and animal sources due to potential problems related to sensitivity of different analytical tests to bacterial subspecies, bacterial die-off rates, and pH of the water (APHA, 1989; Gilliland and Baxter-Potter, 1987).

The average fecal coliform counts during baseflow ranged from 582 colonies per 100 ml (col/100 ml) at BR-3 to 1,102 col/100 ml at BR-4. The baseflow average fecal streptococcus counts ranged from 322 col/100 ml at BR-4 to 821 col/100 ml at BR-2.

As expected, the bacterial counts during high flow were significantly greater than the levels observed during low-flow conditions. The high-flow average fecal coliform counts form the Double Mountain Fork of the Brazos River ranged from 2,183 col/100 ml at BR-6 to 4,701 col/100 ml at BR-2. The average fecal streptococcus counts in the river ranged from 1,327 col/100 ml at BR-6 to 3,534 col/100 ml at BR-2. The two high-flow samples collected at GC-1 had an average fecal coliform count of 5,075 col/100 ml and an average fecal streptococcus count of 7,500 col/100 ml.

Oil and Grease. The oil and grease test is used to detect the presence of biodegradable animal greases and vegetable oils, and it also includes the relatively non-biodegradable mineral oils (U.S. Environmental Protection Agency, 1979). The analytical procedure determines the presence of several groups of substances, rather than specific chemicals, that are soluble in trichlorotrifluoroethane. These compounds include chlorophyll, certain organic dyes, sulfur compounds, biological lipids, and mineral hydrocarbons (APHA,1989).

The average oil and grease concentrations in the Double Mountain Fork during baseflow ranged from not detectable at BR-2 to 1.6 mg/l at BR-1. The high-flow average concentrations were higher in the river, ranging from 11.5 mg/l at BR-1 to 22.0 mg/l at BR-2. Neither of the high-flow samples collected at GC-1 had detectable concentrations of oil and grease.

Total Petroleum Hydrocarbons (TPH). The TPH analysis is a generalized scan for the presence of hydrocarbons that originated from petroleum (APHA, 1989). The results of the TPH analysis are supplemental to the oil and grease test (U.S. EPA, 1979).

The average concentrations of TPH in baseflow samples from the Double Mountain Fork ranged from 0.11 mg/l at BR-1 to 0.60 mg/l at BR-4. Concentrations in the high-flow samples along the river averaged from below detectable concentrations at BR-4 to 0.44 mg/l at BR-1. The high-flow samples collected at GC-1 did not contain detectable concentrations of petroleum hydrocarbons.

Total Polychlorinated Biphenyls (PCB). The manufacture of PCB was discontinued in 1977. Prior to 1977, PCBs were used as coolant-insulation fluids in transformers and capacitors; as plasticizers; for the impregnation of cotton and asbestos; and in some epoxy paints (Manahan, 1984). No PCBs were detected in baseflow or high-flow samples at any of the sites.

Dissolved Arsenic. Arsenic is an element which occurs naturally in many rocks, minerals, and soils. Several industries, including ceramics, tanneries, and metal preparation facilities, use arsenic. However, its primary use is in the production of insecticides and herbicides (Lehr et al., 1980).

Average dissolved arsenic concentrations in the baseflow samples at the river sites ranged from 0.001 mg/l at BR-2 to 0.008 mg/l at BR-4. The high-flow average concentrations ranged from below detection level at BR-6 to 0.013 mg/l at BR-3. The concentration of arsenic in the high-flow sample collected from

Grape Creek was 0.002 mg/l in May 1991, and none was detected at the site in June 1991.

<u>Dissolved Cadmium</u>. Cadmium is a heavy metal which is not normally found in surface waters. The sources of cadmium include industrial discharges from electroplating and chemical facilities and from milling and mining wastes at lead and zinc mines (Manahan, 1984). None of these sources are known to exist in the Lake Alan Henry watershed. Cadmium is occasionally found as a component of oil well drilling muds; however, discussions with the Texas Railroad Commission staff and local oil field operators indicated that the muds used in the Lake Alan Henry watershed were not believed to contain cadmium.

The average cadmium concentrations in the Double Mountain Fork during baseflow ranged from 0.011 mg/l at BR-1 and BR-2 to 0.016 mg/l at BR-3. The high-flow average concentrations were slightly lower, ranging from 0.004 mg/l at BR-6 to 0.022 mg/l at BR-5. Only one of the two runoff samples collected from Grape Creek had a detectable level of cadmium. The sample collected at GC-1 in May 1991 had a dissolved cadmium level of 0.004 mg/l.

<u>Total Chromium</u>. Chromium is a heavy metal used in electroplating processes, aluminum anodizing operations, paints, dyes, explosives, ceramics, and paper production (Lehr et al., 1980). The baseflow average chromium concentrations along the Double Mountain Fork ranged from 0.003 mg/l at BR-1 to 0.016 mg/l at BR-3. The high-flow averages ranged from 0.004 mg/l at BR-2 to 0.014 mg/l at BR-3. The chromium concentrations in the high-flow samples from Grape Creek were 0.007 mg/l in May 1991 and 0.001 mg/l in June 1991.

<u>Dissolved Copper</u>. Copper is a naturally occurring element. In addition

to natural sources, copper can leach from the pipes, valves, and pumping equipment used in water distribution systems. Other sources include metal plating, industrial, and mining wastes. Copper compounds also are occasionally used in water supply reservoirs to inhibit algal growth (Manahan, 1984).

The average copper concentrations during baseflow at the Double Mountain Fork of the Brazos River sites ranged from 0.015 mg/l at BR-2 to 0.030 mg/l at BR-1. The high-flow average concentrations ranged from 0.011 mg/l at BR-2 to 0.045 mg/l at BR-6. The copper concentrations in Grape Creek during the two high flows sampled in May and June 1991 were 0.021 and 0.014 mg/l, respectively.

Dissolved Lead. Lead is a heavy metal that accumulates in the body. Natural sources of lead include lead-bearing limestone and the mineral galena. Man-made sources include leaded gasolines, lead solder in pipes, inks, and dyes (Manahan, 1984).

The baseflow concentrations in samples at sites BR-1, BR-2, and BR-3 were below detection levels. The only baseflow samples in which lead was detected were from BR-4, where concentrations of 0.010 mg/l and 0.009 mg/l were found on July 25 and September 24, 1990, respectively.

The high-flow samples collected at sites BR-2, BR-3, BR-4, and BR-6 did not contain detectable concentrations of lead. Small quantities of lead were detected in only one runoff sample each from sites BR-1, BR-5 and GC-1. On May 8, 1991, dissolved lead concentrations of 0.003 and 0.005 mg/l were found at sites BR-1 and GC-1, and a concentration of 0.002 mg/l was recovered from site BR-5 on June 3, 1991.

Dissolved Mercury. Mercury is a heavy metal which is found as a trace component of many minerals. Cinnabar (red mercuric sulfide) is the chief commercial mercury ore. Mercury is used in laboratory vacuum equipment, as an electrode in the electrolytic generation of chlorine gas, in pesticides, and in amalgam tooth fillings (Manahan, 1984). No mercury was detected in any of the baseflow or high-flow samples at any of the sites.

Dissolved Nickel. Nickel is a naturally occurring metal that is found in the earth's crust. It is used by various industries in the production of ceramics, magnet materials, and nickel-cadmium batteries (U.S. Public Health Service, 1987).

The average concentrations of dissolved nickel in the Double Mountain Fork during baseflow sampling ranged from 0.044 mg/l at BR-1 to 0.090 mg/l at BR-3. The high-flow averages varied from 0.013 mg/l at BR-5 to 0.075 mg/l at BR-6. The high-flow sample collected from Grape Creek in May 1991 had a concentration of 0.029 mg/l, while none was found in the runoff sample collected in June 1991.

Dissolved Selenium. The most common sources of selenium are soil and vegetation. Some plants, such as members of the genus Astragalus (milk vetch), take up selenium in large amounts. Drainage water from seleniferous irrigated soil has also been found to contribute to elevated selenium levels in some streams (Hem, 1970).

Selenium was below detectable concentrations in all of the baseflow samples and in most of the high-flow samples. The high flows that were sampled on June 2-3, 1991, revealed the presence of selenium at each of the seven sites on at least one of the dates. The average concentrations at the Double Mountain Fork sites ranged from 0.022 mg/l at BR-4 to 0.103 mg/l at BR-2. The only other detection of selenium at the mainstem sites was at BR-2 on November 9, 1990, when a level of 0.007 mg/l was found in a high-flow sample. The high-flow sample collected at site GC-1 on June 3, 1991, had a selenium concentration of 0.013 mg/l, while the sample collected in May 1991, had no detectable selenium.

Dissolved Silver. Silver is a naturally occurring precious metal. It is commonly found in electroplating, mining, and film processing wastes, and its compounds are occasionally used as a disinfectant in water (Hem, 1970).

The average concentrations of silver in the baseflow samples on the Double Mountain Fork ranged from 0.010 mg/l at BR-2 to 0.029 mg/l at BR-1. The high-flow average concentrations in the river varied from 0.004 mg/l at BR-2 and BR-3 to 0.010 mg/l at BR-6. The concentration of silver in the Grape Creek samples was 0.015 mg/l.

Dissolved Zinc. Zinc is found in sulfide sphalerite, the most important zinc ore. It also is commonly found in carbonate rocks. Zinc is used in galvanizing metals and in manufacturing paint pigments, cosmetics, pharmaceuticals, and insecticides (Hem, 1970).

The average zinc concentrations in baseflow samples from the Double Mountain Fork were fairly uniform at the four downstream sites, ranging from 0.008 mg/l to 0.009 mg/l. The high-flow average concentrations ranged from 0.007 mg/l at BR-2 to 0.058 mg/l at BR-1. The concentrations of zinc in the samples collected at GC-1 during high flow were 0.034 mg/l in May 1991 and 0.010 mg/l in June 1991.

pH. pH is a measure of the hydrogen ion activity in a solution and indicates whether the solution is acidic or basic (alkaline). If the pH is less than 7.0, the solution is acidic, and if the pH is greater than 7.0, the solution is alkaline. A pH equal to 7.0 is neutral.

The baseflow samples indicated that the pH of the river averaged approximately 8. During high flow, the Double Mountain Fork sites had a slightly higher pH, ranging between 8.5 and 8.9. The average pH value at GC-1 during high flow was 8.1.

Dissolved Oxygen. Dissolved oxygen is important in sustaining aquatic life and preventing the formation of anaerobic compounds, such as hydrogen sulfide, which generally impart a foul taste and/or odor to water (Hem, 1970).

The baseflow and high-flow samples from the mainstem sites had dissolved oxygen concentrations in excess of 6.7 mg/l on all occasions. Dissolved oxygen was not measured at BR-5 or GC-1.

Organics. The organics analyses included chlorinated pesticides, organophosphorous pesticides, phenoxy herbicides, and numerous volatile and semivolatile organics. A detailed hydrocarbon scan was also performed. No pesticides were detected in any of the baseflow or high-flow samples. Only a limited number of hydrocarbons and other organics were detected. Table 3.6 presents the average of the detected concentrations and the number of detections by site.

Table 3.6
Summary of Organic Analyses in Samples Collected from the Double Mountain Fork of the Brazos River from July 1990 through August 1991

Compound	Detection Level (µg/l)	No. Samples/ No. Detections	Detected Concentrations Min. (µg/l)	Detected Concentrations Max. (µg/l)	Average of Detected Concentrations (µg/l)	No. of Detections by Site BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
VOLATILE ORGANICS:												
Chloroform	1.0	44/0	ND*	ND	ND	0	0	0	0	0	0	0
Bromodichloromethane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Dibromodichloromethane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Bromoform	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Trichloroethylene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Carbon Tetrachloride	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,2-Dichloroethane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Vinyl Chloride	0.4	44/0	ND	ND	ND	0	0	0	0	0	0	0
Benzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
p-Dichlorobenzene	1.0	44/1	2.0	2.0	2.0	0	0	0	1	0	0	0
1,1-Dichlorobenzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,1,1-Trichlorobenzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Chlorobenzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
m-Dichlorobenzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
o-Dichlorobenzene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
trans-1,2-Dichloroethylene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
cis-1,2-Dichloroethylene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,1-Dichloroethane	1.0	44/1	2.0	2.0	2.0	0	0	0	1	0	0	0
1,1-Dichloropropene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,3-Dichloropropene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,2-Dichloropropene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,2-Dichloropropane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
1,3-Dichloropropane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
2,2-Dichloropropane	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Ethylbenzene	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Styrene	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0

*ND means not detected.

Table 3.6, continued

Compound	Detection Level (µg/l)	No. Samples/ No. Detections	Detected Concentrations Min. (µg/l)	Detected Concentrations Max. (µg/l)	Average of Detected Concentrations (µg/l)	No. of Detections by Site BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
VOLATILE ORGANICS, continued:												
Tetrachloroethylene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Toluene	1.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
p-Xylene	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
o-Xylene	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
m-Xylene	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Methyl ethyl ketone	4.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Tetrahydrofuran	10.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
PESTICIDES:												
Endrin	0.2	44/0	ND	ND	ND	0	0	0	0	0	0	0
Lindane	0.2	44/0	ND	ND	ND	0	0	0	0	0	0	0
Methoxychlor	0.5	44/0	ND	ND	ND	0	0	0	0	0	0	0
Dieldrin	0.2	44/0	ND	ND	ND	0	0	0	0	0	0	0
Heptachlor	0.2	44/0	ND	ND	ND	0	0	0	0	0	0	0
Toxaphene	5.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Chlordane	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
2,4-D	20.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
2,4,5-T	5.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
2,4,5-TP	5.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
PCB (Total)	0.001	44/0	ND	ND	ND	0	0	0	0	0	0	0
Dioxin	0.5	44/0	ND	ND	ND	0	0	0	0	0	0	0
Malathion	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
Parathion	2.0	44/0	ND	ND	ND	0	0	0	0	0	0	0
HYDROCARBONS:												
n-Hexane	0.01	36/1	0.01	0.01	0.01	1	0	0	0	0	0	0
2,4-Dimethylpentane	0.01	36/2	0.5	0.5	0.5	0	0	0	1	1	0	0
n-Heptane	0.01	37/5	0.01	0.1	0.04	0	0	3	1	0	1	0

Table 3.6, continued

Compound	Detection Level (μg/l)	No. Samples/ No. Detections	Detected Concentrations Min. (μg/l)	Detected Concentrations Max. (μg/l)	Average of Detected Concentrations (μg/l)	No. of Detections by Site BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
HYDROCARBONS, continued:												
n-Octane	0.01	36/4	0.01	1.0	0.29	0	0	2	2	0	0	0
Xylenes (Total)	0.01	36/2	0.02	6.0	3.1	0	0	0	2	0	0	0
n-Decane	0.01	36/2	0.01	0.8	0.4	0	0	0	2	0	0	0
n-Butylbenzene	0.01	36/2	0.01	0.01	0.01	1	0	1	0	0	0	0
n-Dodecane	0.01	36/2	0.04	1.0	0.52	1	0	0	1	0	0	0
Naphthalene	0.01	36/1	0.01	0.01	0.01	0	0	1	0	0	0	0
2-Methylnaphthalene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
1-Methylnaphthalene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
Acenaphthalene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
Acenaphthene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
Fluorene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
Phananthrene	0.01	36/0	ND	ND	ND	0	0	0	0	0	0	0
Anthracene	0.01	36/1	0.02	0.02	0.02	1	0	0	0	0	0	0
Pyrene	0.01	34/2	0.01	0.01	0.01	1	0	1	0	0	0	0
Priority Pollutants												
PHENOLS:												
2-Chlorophenol	0.5	2/0	ND	ND	ND	0	0	0	0	0	0	0
2,4-Dichlorophenol	0.6	2/0	ND	ND	ND	0	0	0	0	0	0	0
2,4-Dimethylphenol	0.6	2/0	ND	ND	ND	0	0	0	0	0	0	0
2-Nitrophenol	0.7	2/0	ND	ND	ND	0	0	0	0	0	0	0
4-Nitrophenol	2.0	2/0	ND	ND	ND	0	0	0	0	0	0	0
2,4-Dinitrophenol	0.6	2/0	ND	ND	ND	0	0	0	0	0	0	0
4,6-Dinitro-o-Cresol	0.5	2/0	ND	ND	ND	0	0	0	0	0	0	0
Pentachlorophenol	0.6	2/0	ND	ND	ND	0	0	0	0	0	0	0
Phenol	2.0	2/0	ND	ND	ND	0	0	0	0	0	0	0
2-Methylphenol	0.5	2/0	ND	ND	ND	0	0	0	0	0	0	0

Table 3.6, continued

Compound	Detection Level (µg/l)	No. Samples/ No. Detections	Detected Concentrations Min. (µg/l)	Detected Concentrations Max. (µg/l)	Average of Detected Concentrations (µg/l)	No. of Detections by Site BR-6	BR-5	BR-4	BR-3	BR-2	BR-1	GC-1
PHENOLS, continued:												
4-Methylphenol	0.5	2/0	ND	ND	ND	0	0	0	0	0	0	0
2,4,5-Trichlorophenol	0.5	2/0	ND	ND	ND	0	0	0	0	0	0	0
Acrolein	1.0	2/0	ND	ND	ND	0	0	0	0	0	0	0
Acrylonitrile	1.0	2/0	ND	ND	ND	0	0	0	0	0	0	0
PHTHALATES:												
Bis(2-Ethylhexyl)Phthalate	5.0	2/0	ND	ND	ND	0	0	0	0	0	0	0
Butyl Benzyl Phthalate	2.5	12/11	2.8	4.8	3.5	1	1	1	3	1	3	1
Di-n-Butyl Phthalate	2.0	12/12	2.0	12.3	4.4	1	1	1	3	1	4	1
Di-n-Octyl Phthalate	0.5	9/7	0.7	1.3	0.9	1	0	1	1	1	2	1
Diethyl Phthalate	0.9	12/11	0.9	1.6	1.2	1	1	1	3	1	3	1
Dimethyl Phthalate	0.2	2/1	0.2	0.2	0.2	0	0	0	0	0	1	0
Di(2-Ethylhexyl) Adipate	1.0	2/1	1.0	1.0	1.0	0	0	0	0	0	1	0
BASE NEUTRALS:												
Azobenzene	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Hexachlorobenzene	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Hexachlorobutadiene	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Hexachlorocyclopentadiene	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Hexachloroethane	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Isophrone	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
Nitrobenzene	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
N-Nitrosodimethylamine	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0
N-Nitrosodiphenylamine	0.2	2/0	ND	ND	ND	0	0	0	0	0	0	0

4. ASSESSMENT OF WATER QUALITY DATA

The water quality sampling data collected during this study were screened by comparison to applicable drinking water and surface water quality criteria. The parameters that exceeded the criteria during stream sampling were evaluated further by assessing their probable ranges under lake conditions. The criteria that were used included state and federal drinking water standards and surface water standards for toxics and human health protection.

From the standpoint of predicting reservoir quality based on stream samples, it would be desirable to use flow-weighted average concentrations from a long-term database. In general, a long period of record should yield a more representative flow-weighted average than a short-term record because the long-term data base will include the variation in water quality due to flow, seasonal cycles, and other factors. The sampling data published by the USGS for the Justiceburg site (BR-4) provided an acceptable long-term database for developing flow-weighted averages of dissolved minerals. Arithmetic averages of other constituents sampled during the present short-term study were also used to evaluate possible pollution problems and assess future lake quality.

4.1 Water Quality Criteria

Drinking water standards have been adopted by both the state and federal governments to protect public health and welfare. Texas Surface Water Quality Standards were established to maintain the quality of the surface waters of the state and prevent their degradation due to the activities of man. The water quality criteria applicable to the parameters tested in this study are presented in Table 4.1.

The National Primary and Secondary Drinking Water Regulations (Code of Federal Regulations (CFR), Title 40, Parts 141 and 143) and the Texas Drinking Water Standards (Texas Administrative Code, Title 25, Chapter 337) establish maximum permissible and recommended maximum contaminant levels. Maximum contaminant levels (mcl) are the maximum allowable limits of specific chemical constituents in a public water supply system. Secondary maximum contaminant levels (smcl) are recommended goals, not enforceable limits, for certain constituents in public drinking water supplies. Secondary levels are established for parameters which are not necessarily health-related but may affect aesthetics, such as taste and odor, and other uses of water. If local conditions such as lack of an alternate supply source or some other factors dictate, a water supply system may be approved for use even though one or more constituents exceed an smcl. All public water suppliers must receive a variance or exemption from the State for any constituent which is not expected to be within the drinking water standards.

It should be noted that the drinking water standards contain criteria that have been established for treated water. Samples collected during this study from the Double Mountain Fork of the Brazos River and Grape Creek were not treated prior to laboratory analysis. If raw, untreated water meets the drinking water standards, it can be assumed that treated water will be within the standard limits. Even though some of the raw water samples from the streams exceeded some

Table 4.1

Water Quality Criteria for the Constituents Tested during the Lake Alan Henry Water Quality Protection Study

	DRINKING WATER STANDARDS				TEXAS SURFACE WATER QUALITY STANDARDS			
	FEDERAL		STATE		TOXICS		HUMAN HEALTH PROTECTION	
Constituent	MCL (mg/l)	SMCL (mg/l)	MCL (mg/l)	SMCL (mg/l)	ACUTE (ug/l)	CHRONIC (ug/l)	WATER & FISH (ug/l)	FW FISH ONLY (ug/l)
1,1,1-Trichlorobenzene	--	--	--	--	--	--	--	--
1,1-Dichlorobenzene	--	--	--	--	--	--	--	--
1,1-Dichloroethane	--	--	--	--	--	--	--	--
1,1-Dichloropropene	--	--	--	--	--	--	--	--
1,2-Dichloroethane	0.005	--	0.005	--	--	--	5	1794
1,3-Dichloropropene	--	--	--	--	--	--	--	--
2,2-Dichloropropane	--	--	--	--	--	--	--	--
2,4,5-T	--	--	--	--	--	--	2767	4021
2,4,5-TP	0.01	--	0.01	--	--	--	10	--
2,4-D	0.1	--	0.1	--	--	--	100	--
2,4-Dimethylpentane	--	--	--	--	--	--	--	--
2-Methylnaphthalene	--	--	--	--	--	--	--	--
Acenaphthalene	--	--	--	--	--	--	--	--
Acenapththene	--	--	--	--	--	--	--	--
Aluminum	--	0.05 to 0.2	--	--	991	--	--	--
Ammonia	--	--	--	--	--	--	--	--
Anthracene	--	--	--	--	--	--	--	--
Arsenic	0.05	--	0.05	--	360	190	50	--
Barium	1.0	--	1.0	--	--	--	1000	--
Benzene	0.005	--	0.005	--	--	--	5	312

Table 4.1, Continued

	DRINKING WATER STANDARDS				TEXAS SURFACE WATER QUALITY STANDARDS			
	FEDERAL		STATE		TOXICS		HUMAN HEALTH PROTECTION	
Constituent	MCL (mg/l)	SMCL (mg/l)	MCL (mg/l)	SMCL (mg/l)	ACUTE (ug/l)	CHRONIC (ug/l)	WATER & FISH (ug/l)	FW FISH ONLY (ug/l)
BOD	--	--	--	--	--	--	--	--
Bromide	--	--	--	--	--	--	--	--
Bromodichloromethane	--	--	--	--	--	--	--	--
Bromoform	--	--	--	--	--	--	--	--
Cadmium	0.005	--	0.01	--	53.229	1.55	10	
Calcium	--	--	--	--	--	--	--	--
Carbon tetrachloride	0.005	--	0.005	--	--	--	5	182
Chlordane	0.002	--	--	--	2.4	0.004	0.021	0.0213
Chloride	--	250	--	300	--	--	--	--
Chlorobenzene	--	--	--	--	--	--	1350	4947
Chloroform	--	--	--	--	--	--	100	12130
Chromium (Hexavalent)	0.1	--	0.05	--	16	11	50	--
cis-1,2-Dichloroethylene	0.07	--	--	--	--	--	--	--
Conductivity	--	--	--	--	--	--	--	--
Copper	--	1.0	--	1.0	28.12	18.09	--	--
Cyanide	0.2	--	--	--	45.78	10.69	--	--
Dieldrin	--	--	--	--	2.5	0.002	0.0012	0.0012
Di(2-ethylhexyl) adipate	0.4	--	--	--	--	--	--	--
Dibromochloromethane	--	--	--	--	--	--	1590	15354
Dioxin	0.0000003	--	--	--	--	--	0.000001	0.000001
Dissolved Solids	--	500	--	1000	--	--	--	--
Endrin	0.002	--	0.0002	--	0.18	0.002	0.2	--
Ethylbenzene	0.7	--	--	--	--	--	--	--
Fecal Coliform	--	--	--	--	--	--	--	--
Fecal Streptococcus	--	--	--	--	--	--	--	--

Table 4.1, Continued

	DRINKING WATER STANDARDS				TEXAS SURFACE WATER QUALITY STANDARDS			
	FEDERAL		STATE		TOXICS		HUMAN HEALTH PROTECTION	
Constituent	MCL (mg/l)	SMCL (mg/l)	MCL (mg/l)	SMCL (mg/l)	ACUTE (ug/l)	CHRONIC (ug/l)	WATER & FISH (ug/l)	FW FISH ONLY (ug/l)
Fluorene	--	--	--	--	--	--	--	--
Fluoride	4.0	2.0	4.0	2.0	--	--	4000	--
Hardness (CaCO3)	--	--	--	--	--	--	--	--
Heptachlor	0.0004	--	--	--	0.520	0.004	0.0177	0.0181
Iron	--	0.3	--	0.3	--	--	--	--
Lead	--	--	0.05	--	136.8	5.331	5	25
Lindane	0.004	--	0.004	--	2.0	0.080	4	16
Magnesium	--	--	--	--	--	--	--	--
Malathion	--	--	--	--	--	0.010	--	--
Manganese	--	0.05	--	0.05	--	--	--	--
Mercury	0.002	--	0.002	--	2.4	1.3	0.0122	0.0122
Methoxychlor	0.1	--	0.1	--	--	0.030	100	--
Methyl Ethyl Ketone	--	--	--	--	--	--	4411	88667
m-Dichlorobenzene	--	--	--	--	--	--	--	--
m-Xylene	--	--	--	--	--	--	--	--
Naphthalene	--	--	--	--	--	--	--	--
Nickel	--	--	--	--	1998.59	222.18	--	--
Nitrate (as N)	10.0	--	10.0	--	--	--	10000.0	--
Nitrite (as N)	1.0	--	--	--	--	--	--	--
n-Butylbenzene	--	--	--	--	--	--	--	--
n-Decane	--	--	--	--	--	--	--	--
n-Dodecane	--	--	--	--	--	--	--	--
n-Heptane	--	--	--	--	--	--	--	--
n-Hexane	--	--	--	--	--	--	--	--
n-Nitroso-di-n-butylamine	--	--	--	--	--	--	1.84	13.5

Table 4.1, Continued

Constituent	DRINKING WATER STANDARDS				TEXAS SURFACE WATER QUALITY STANDARDS			
	FEDERAL		STATE		TOXICS		HUMAN HEALTH PROTECTION	
	MCL (mg/l)	SMCL (mg/l)	MCL (mg/l)	SMCL (mg/l)	ACUTE (ug/l)	CHRONIC (ug/l)	WATER & FISH (ug/l)	FW FISH ONLY (ug/l)
n-Nitrosodiethylamine	--	--	--	--	--	--	0.0382	7.68
n-Octane	--	--	--	--	--	--	--	--
Oil and Grease	--	--	--	--	--	--	--	--
Ortho-phosphate	--	--	--	--	--	--	--	--
o-Dichlorobenzene	0.6	--	--	--	--	--	--	--
o-Xylene	--	--	--	--	--	--	--	--
Parathion	--	--	--	--	0.065	0.013	--	--
PCB (total)	0.0005	--	--	--	2.0	0.014	0.0013	0.0013
pH	--	6.5-8.5	--	>7.0	--	--	--	--
Phenanthrene	--	--	--	--	30.0	30.0	--	--
Phosphate	--	--	--	--	--	--	--	--
Potassium	--	--	--	--	--	--	--	--
Pyrene	--	--	--	--	--	--	--	--
p-Dichlorobenzene	0.075	--	0.075	--	--	--	75.0	--
p-Xylene	--	--	--	--	--	--	--	--
P. Alkalinity	--	--	--	--	--	--	--	--
Selenium	0.05	--	0.01	--	20.0	5.0	10.0	--
Silica	--	--	--	--	--	--	--	--
Silver	0.05	0.10	0.05	--	0.92	0.49	50.0	--
Sodium	--	--	--	--	--	--	--	--
Styrene	0.005	--	--	--	--	--	--	--
Sulfate	--	250	--	300	--	--	--	--
Suspended Solids	--	--	--	--	--	--	--	--
Temperature	--	--	--	--	--	--	--	--
Tetrachloroethylene	0.005	--	--	--	--	--	597	1832

Table 4.1, Continued

Constituent	DRINKING WATER STANDARDS				TEXAS SURFACE WATER QUALITY STANDARDS			
	FEDERAL		STATE		TOXICS		HUMAN HEALTH PROTECTION	
	MCL (mg/l)	SMCL (mg/l)	MCL (mg/l)	SMCL (mg/l)	ACUTE (ug/l)	CHRONIC (ug/l)	WATER & FISH (ug/l)	FW FISH ONLY (ug/l)
Tetrahydrofuran	--	--	--	--	--	--	--	--
Total Kjeldahl Nitrogen	--	--	--	--	--	--	--	--
Toluene	2	--	--	--	--	--	--	--
Toxaphene	0.005	--	0.005	--	0.78	0.0002	0.044	0.0445
Total Petroleum Hydrocarbons	--	--	--	--	--	--	--	--
trans-1,2-Dichloroethylene	0.7	--	--	--	--	--	--	--
Trichloroethylene	0.005	--	0.005	--	--	--	5	--
Turbidity	--	--	--	--	--	--	--	--
T. Alkalinity	--	--	--	--	--	--	--	--
Vinyl Chloride	0.002	--	0.002	--	--	--	2	94.5
Xylenes (total)	10.0	--	--	--	--	--	--	--
Zinc	--	5	--	5.0	164.99	149.4	--	--

of the drinking water standards, in most cases the treated water from the reservoir will meet the criteria.

The water quality data were also compared to the Texas Surface Water Quality Standards (Texas Administrative Code, Title 31, Chapter 307). The Texas Water Commission (TWC) classifies surface water segments according to attainable uses and establishes segment-specific numerical criteria to protect those uses. The numerical criteria for designated segments pertain to TDS, chloride, sulfate, dissolved oxygen, pH, temperature, and fecal coliform bacteria. The uses deemed desirable for fresh surface water segments may include domestic water supply (surface supply or aquifer protection), recreation (contact or non-contact), and aquatic life (low, intermediate, high, or exceptional quality habitat). In addition, the surface water standards contain numerical criteria for toxics and human health protection.

The Double Mountain Fork of the Brazos River is not a classified stream segment. Nevertheless, the surface water quality standards contain general criteria and criteria for toxics and human health that are applicable to the stream. The general criteria include limits for dissolved oxygen of not less than 2.0 mg/l on a 24-hour average basis and an absolute minimum of 1.5 mg/l. In addition, fecal coliform counts may not exceed 200 colonies per 100 ml in contact recreation waters, based on a geometric mean of five or more samples collected within a 30 day period. There are no numerical limits for TDS, chloride, or sulfate in the general criteria.

Toxics criteria are divided into freshwater and marine categories. These are further divided into acute and chronic criteria. Acute toxicity exerts short-term, lethal impacts on aquatic organisms. Chronic toxicity exerts sublethal, negative effects on organisms such as growth impairment and reduced reproduction or is lethal after long-term exposure. The acute toxicity limits are applied as 24-hour averages, while the chronic toxicity limits are applied as average concentrations over a 7-day period.

Human health criteria are designed to prevent contamination of water and fish, to ensure that they are safe for human consumption. These criteria are applied as the average of four or more samples collected over a period of at least one year.

4.2 Projected Reservoir Quality

The results of this study verified previous indications that dissolved solids would be the primary water quality concern in Lake Alan Henry. However, a few other parameters were found in the stream samples, including turbidity, some metals, nutrients, and fecal coliform, that exceeded either drinking water or surface water quality criteria. These parameters were investigated further to evaluate their probable concentrations in Lake Alan Henry, as described in Section 4.2.2. After additional evaluation, none of these constituents was believed to pose a significant threat to reservoir quality.

Although oil field activity, because of its high visibility in the watershed, was initially feared to be a significant source of contamination, the sampling data did not indicate that this was the case. Of the numerous samples tested for petroleum hydrocarbons, very few were detected (Table 3.6). Even though site-specific, localized soil contamination was observed at some oil wells, the results of recent sampling did not indicate a measurable impact on water quality in the watershed.

4.2.1 Dissolved Solids

The drinking water standards for TDS are secondary maximum contaminant levels (smcl) which are set for aesthetic reasons such as taste and odor rather than for health effects. The federal limit for TDS is 500 mg/l, and the state limit is 1,000 mg/l. The average concentrations of all of the baseflow samples exceeded both the federal and state secondary limits. The high-flow average concentrations in the samples collected at all sites exceeded the federal limit, but only the average concentrations at BR-6 and BR-1 exceeded the state limit. The baseflow concentrations decreased in a downstream direction, while the high-flow TDS concentrations increased between BR-4 and BR-1. The total dissolved solids concentrations in the high-flow samples were significantly less than those of the baseflow samples.

To investigate the possibility that the oil fields located downstream of BR-4 were contributing to the elevated TDS concentrations, average ion ratios of the baseflow samples collected at sites BR-1 through BR-4 were compared to ion ratios of 103 brine samples taken from the San Andres Formation, the predominant oil-bearing formation in the Lake Alan Henry watershed (Nativ, 1988). The baseflow average concentrations were used since brine contamination would be more readily detectable during low-flow periods. The ion ratios in samples collected from the Double Mountain Fork of the Brazos River were substantially different from the brine samples in the San Andres Formation. The ion ratios are compared in Table 4.2.

Table 4.2

Comparison of Ion Ratios in Brine from the San Andres Formation and Baseflow Samples from the Double Mountain Fork of the Brazos River

Site	HCO_3/Cl	Na/Cl	$Ca/(SO_4+HCO_3)$	SO_4/Cl
San Andres	0.02	0.845	9.32	0.008
BR-1	0.28	8.45	0.82	0.46
BR-2	0.19	4.15	0.65	0.46
BR-3	0.20	4.77	0.68	0.74
BR-4	0.19	3.18	0.58	0.67

Notes:

HCO_3 = Bicarbonate
Cl = Chloride
Na = Sodium
Ca = Calcium
SO_4 = Sulfate

An intensive water quality survey was performed in March 1992 to identify the reason for the elevated dissolved solids concentrations at site BR-3 during baseflow periods. The survey consisted of measuring specific conductance at numerous points between sampling sites BR-2 and BR-4. Figure 4.1 shows that the specific conductance steadily increased from about 7,500 umhos/cm at BR-4 to approximately 12,000 umhos/cm at BR-3. The specific conductance gradually decreased from BR-3 to BR-2. No readily identifiable source for the high conductivity readings was observed. As shown in Table 3.5, high flows apparently dilute the source of the dissolved minerals along this reach.

The major source of dissolved minerals in the Lake Alan Henry watershed is most likely natural. Rawson (1967) noted previously that seepage of groundwater from outcrop areas of the Dockum group results in elevated levels of dissolved solids. It is well known that soils and geologic formations in semi-arid regions typically yield higher levels of dissolved minerals to baseflow because they have not been leached as thoroughly as in regions with greater rainfall. While some of the dissolved mineral loadings might be attributable to historical oil production activities, the results of this study indicate no apparent correlations to the distribution of oil wells in the watershed.

Freese and Nichols (1978) previously developed a computer model to simulate average TDS, chloride, and sulfate concentrations in Lake Alan Henry. Using the previously developed methodology and the current sampling results, the computer model was updated to estimate the dissolved solids concentrations in the reservoir and also to predict chloride and sulfate levels. A detailed discussion of the methodology is presented in Appendix B, and alternative reservoir operating strategies are evaluated using the model in chapter 5.

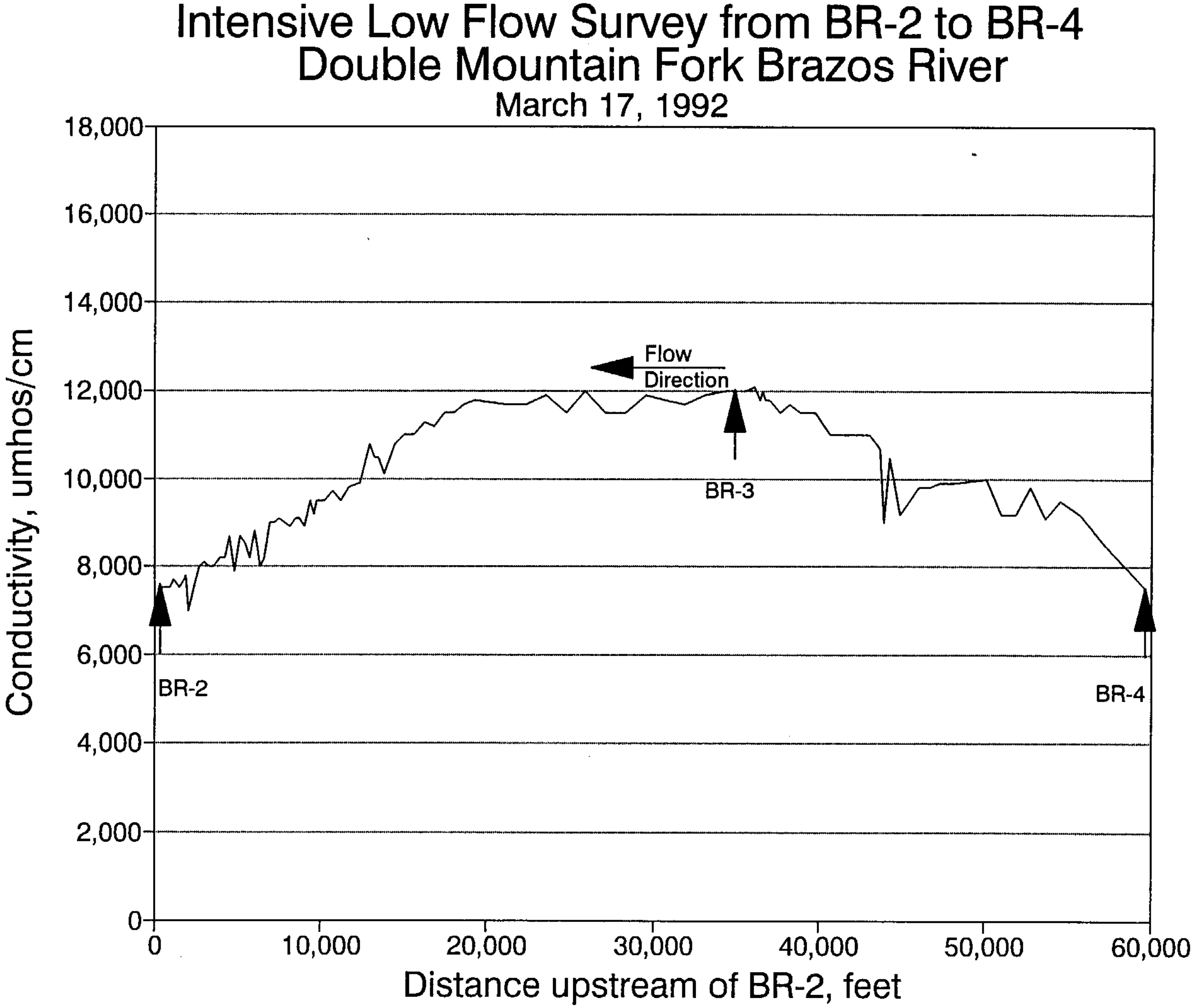

Intensive Low Flow Survey from BR-2 to BR-4
Double Mountain Fork Brazos River
March 17, 1992
Conductivity, umhos/cm
18,000
16,000
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
Flow
Direction
BR-2
BR-3
BR-4
0
10,000
20,000
30,000
40,000
50,000
60,000
Distance upstream of BR-2, feet

FIGURE 4.1

The projected concentrations of TDS, chloride and sulfate in Lake Alan Henry under the variable demand operating condition are summarized in Table 4.3. For comparison, the long-term statistics on TDS, chloride, and sulfate in Lake Meredith, Lubbock's current surface water supply source, are presented in Table 4.4. Based on comparison of these dissolved mineral concentrations, the water from Lake Alan Henry should be comparable to or better than the quality of Lake Meredith water.

The simulation results indicated that the TDS concentrations in the reservoir would be less than 1,000 mg/l approximately 75 percent of the time. The median TDS concentration in Lake Alan Henry would be 910 mg/l, and the projected maximum concentration would be 1,405 mg/l. These predicted TDS levels are slightly lower than the historical median and maximum concentrations from Lake Meredith, which were 1,160 mg/l and 1,670 mg/l, respectively.

Simulated chloride concentrations in Lake Alan Henry were at or below the state drinking water limit of 300 mg/l only about 10 percent of the time. The computer model showed the reservoir to have a median chloride concentration of 355 mg/l and a maximum concentration of 548 mg/l. The historical chloride concentrations in Lake Meredith were slightly less than the modeled values in Lake Alan Henry, with a median of 305 mg/l and a maximum of 510 mg/l.

The maximum sulfate concentration predicted in Lake Alan Henry was shown as 126 mg/l, which is well below the federal and state drinking water limits of 250 mg/l and 300 mg/l. The sulfate concentrations were also significantly lower than the historical sulfate levels found in Lake Meredith, which ranged from 236 mg/l to 431 mg/l, with a median of 282 mg/l.

Table 4.3

Summary of Simulated TDS, Chloride, and Sulfate Levels in Lake Alan Henry with Variable Demand Operation

Percent of Time Concentrations Less than or Equal to Indicated Values	Key Constituents		
	TDS (mg/l)	Chloride (mg/l)	Sulfate (mg/l)
0%	678	264	61
5%	751	293	67
10%	780	304	70
15%	801	313	72
20%	817	319	74
25%	832	324	75
30%	845	330	76
35%	858	335	77
40%	873	340	79
45%	890	347	80
50%	910	355	82
55%	925	361	83
60%	941	367	85
65%	960	374	86
70%	979	382	88
75%	1,002	391	90
80%	1,021	398	92
85%	1,043	407	94
90%	1,096	428	99
95%	1,171	457	105
100%	1,405	548	126

Table 4.4

Summary of Lake Meredith Raw Water Quality from 1965 through 1991

	TDS	Chloride	Sulfate
Mean	1,165	307	286
Median	1,165	305	282
Minimum	1,010	244	236
Maximum	1,670	510	431

Source: City of Lubbock Water Treatment Laboratory.

4.2.2 Evaluation of Other Parameters

Turbidity. The turbidity levels in all of the raw water samples exceeded the drinking water standards. In general, the higher the flow, the higher the concentration of suspended solids and turbidity. In the reservoir, the heavier suspended solids will settle out in the headwaters of the reservoir as the flow velocity decreases. Since the reservoir will be long and deep, and there will be extended periods of low inflow, much of the finer sediment is also expected to settle to the bottom. Therefore, the turbidity should be noticeably lower in the reservoir than in the stream, although (as with nearly all Texas lakes) the lake may not actually be clear. The raw water pumped from Lake Alan Henry will be filtered during treatment to remove the remaining suspended solids. The turbidity in Lake Alan Henry is not expected to cause adverse drinking water quality problems.

Metals. Cadmium and selenium were the only parameters tested in this study that exceeded primary drinking water standards. Chromium, copper and silver were found in concentrations which were greater than the Texas Surface Water Quality Standards chronic criteria for toxics. Silver and copper concentrations also exceeded the acute criteria. Neither chromium, copper, or silver concentrations exceeded drinking water standards.

The USGS has analyzed 47 samples for dissolved cadmium and 16 for total cadmium at its gaging site near Aspermont, Texas, approximately 93 river miles downstream from the Lake Alan Henry dam. None of the 63 samples had cadmium concentrations greater than 0.003 mg/l (personal communication with Frank Wells, USGS, 1992).

Cadmium does not normally occur in natural waters. Although it is occasionally found as a contaminant in low-grade, barite drilling mud, the Texas Railroad Commission (RRC) staff indicated that this type of drilling mud has not been used recently, if at all, in the oil fields in the Lake Alan Henry watershed (personal communication with Barry Wood, RRC, 1991). No other sources of cadmium were identified in the Lake Alan Henry watershed which would contribute to cadmium concentrations in the amounts observed.

Selenium was detected only in high-flow samples. The detection of selenium only during high flows suggested that the source of this contaminant was primarily eroded soil. The USGS (1984) has documented naturally occurring selenium concentrations in soils in the Lake Alan Henry area ranging from 0.15 to 0.2 parts per million.

Cadmium and selenium are not expected to pose significant water quality problems in the reservoir. Important natural mechanisms for removing cadmium from the water column are precipitation and adsorption on the surface of solids, with adsorption being the most important factor. Selenium also has an affinity for adsorption to fine sediment particles and clays (Schnoor et al., 1987).

Suspended sediment levels are expected to provide an abundant sink for adsorption of cadmium and selenium, and a significant volume of these metals likely will be removed from the water column as the sediment settles to the bottom of the reservoir. Additionally, the raw water from the lake will be filtered during treatment to reduce the concentration of suspended solids prior to distribution. Therefore, these elements are not expected to present a problem in either the reservoir or in the treated drinking water. However, cadmium and selenium should be included in the post-impoundment water quality monitoring program described in Section 6.3.

Since chromium, copper, and silver were not found in any of the samples in concentrations above drinking water standards, they are not expected to pose problems to drinking water quality. Their effect on aquatic life is less evident. These three metals should also be included in the continuing monitoring program.

<u>Nutrients</u>. The only drinking water standard applicable to the nutrients is for nitrate-nitrogen. The federal and state mcl for nitrate-nitrogen is 10 mg/l. None of the average concentrations exceeded the drinking water criterion for nitrate-nitrogen.

No criteria have been set for nitrate-nitrogen, ammonia-nitrogen or phosphorous in the Texas Surface Water Quality Standards. However, the TWC (1990) considers nitrogen levels to be elevated when the sum of nitrate-nitrogen and ammonia-nitrogen concentrations exceed 1.0 mg/l. Similarly, phosphorus levels are considered elevated when concentrations exceed 0.15 mg/l. Phosphorus and nitrogen were present in both the baseflow and high-flow samples in concentrations that exceeded the TWC guidelines. In the Lake Alan Henry watershed, phosphorus and nitrogen contributions are probably associated primarily with soil eroded from the basin. Wastewater treatment plant effluent can contribute to elevated concentrations of these nutrients, but there are no known industrial or municipal wastewater discharges above the dam site.

It is apparent that nutrients will not be a limiting factor to the productivity of Lake Alan Henry, and, as with most reservoirs in Texas, the lake likely will be eutrophic. However, the morphology of the lake should tend to moderate primary productivity. With a conservation storage capacity of 115,937 acre-feet and corresponding surface area of 2,884 acres, the reservoir will be relatively deep with a mean depth of approximately 40 feet. The lake also will be long and narrow with steep canyon walls in many places, and it will lie roughly perpendicular to the prevailing wind direction. This orientation will tend to protect the lake from wind mixing. In general, deeper lakes with limited mixing tend to have lower biological productivity than shallow lakes with complete mixing (Olem and Flock, 1990). Turbidity levels may at times limit light penetration into the water, which will also result in a dampening effect on algal production.

<u>Fecal coliform bacteria</u>. The drinking water standards require that no fecal coliform are to be present in treated water. It is common for fecal coliforms to be present in surface water, especially after periods of runoff. Bacteria are easily removed from water prior to distribution using disinfectants

such as chloramine and ozone. The primary sources of fecal coliform in the Lake Alan Henry watershed are livestock and wildlife. These sources are typical of all Texas lakes and are probably less abundant than in many reservoir basins across the state. The lack of dense population centers in the watershed, and the sparsity of other fecal sources lead to the conclusion that fecal coliforms should not be a problem in Lake Alan Henry.

5. IDENTIFICATION AND EVALUATION OF ALTERNATIVE POLLUTION CONTROL MEASURES

Several categories of pollution control alternatives were examined for applicability to the Lake Alan Henry project. These included source elimination, physical and structural controls, institutional controls, and the alternative of taking no action. Control measures were evaluated based on the water quality problems that were identified by the sampling program.

5.1 Alternative Pollution Control Measures

5.1.1 Source Elimination

One of the more visible potential sources of contaminants in the Lake Alan Henry watershed is oil field related facilities. Activities designed to eliminate some of these sources would include oil well plugging, well inspection and enforcement of regulations, well maintenance, tank battery and gathering line removal or relocation. The Brazos River Authority is undertaking and encouraging these activities within the reservoir pool up to elevation 2245 feet mean sea level, which is five feet above the 100-year flood elevation. The large number of wells and related facilities in the watershed render such source elimination activities cost prohibitive beyond the flood pool. It is anticipated that the purchase and plugging of wells and relocation of pipelines out of the reservoir pool area will significantly reduce the pollution potential from these sources, although quantifying the risk reduction is difficult.

In addition to the Brazos River Authority's purchase and relocation of oil production facilities, the Texas Railroad Commission (RRC) identified six abandoned, improperly plugged oil wells within the conservation pool.

Subsequently, the RRC utilized state funds to plug the wells in accordance with RRC specifications. The state funding program, which is described under the discussion of institutional control measures, is available for plugging wells for which no owner or operator can be identified.

5.1.2 Physical Controls

Pipeline Improvements. Four pipeline companies that operate lines within the Lake Alan Henry watershed monitor the inflow and outflow volumes or pressures within the pipelines from either a control center or pump stations. The U.S. Department of Transportation (DOT) requires patrol of the right-of-way for leakage 26 times a year for high-pressure lines (49 CFR 195). High-pressure lines are those with internal pressures of more than 20 percent of the specified minimum yield strength of the line. AMOCO Pipeline Company and Shell Crude Pipeline Company conduct aerial reconnaissance every other week. Scurlock Permian Pipeline Company visually monitors lines by air once a week. Dunigan Operating Company locates its lines near roads to allow daily visual monitoring from vehicles.

Automatic shutoff valves on pipelines are not common in the oil industry. AMOCO does have some automatic shutoff valves on high-pressure lines that are remote-controlled by the monitoring station in Tulsa, Oklahoma. Manual shutoff valves are located at strategic points along the routes of the lines. Check valves are used at certain locations to prevent backflow. Shell places valves not only at its pump stations, but also at crossings of major rivers and connections to the main line. AMOCO places shutoff valves on both sides of a river or lake on lines greater than 8 inches in diameter. On gathering lines (lines less than 8 inches in diameter) no valves are used unless the line is in a sensitive area as determined by AMOCO.

A possible method of pollution prevention in the Lake Alan Henry watershed is to install manual valves at all crossings of the pipelines with the tributaries that enter the reservoir. The pipeline companies that were surveyed estimated this cost to range from $1,000 to $10,000 for a cut-off valve on either side of a tributary. The major portion of this expense is the cost of cutting the line to install the valve. Revenue also would be lost during installation due to the interruption of flow in the line. Precautions would need to be taken to avoid an oil spill when cutting the line.

Detention Structures. Vehicles transporting toxic substances along roads and railways within the watershed would be potential sources of water pollution at the crossings of tributaries of Lake Alan Henry. Detention structures could be designed to capture spilled substances before they reached the Double Mountain Fork of the Brazos River or its tributaries. Such containment would enhance the opportunity for a more thorough cleanup than if the material is allowed to flow uncontrolled into a stream.

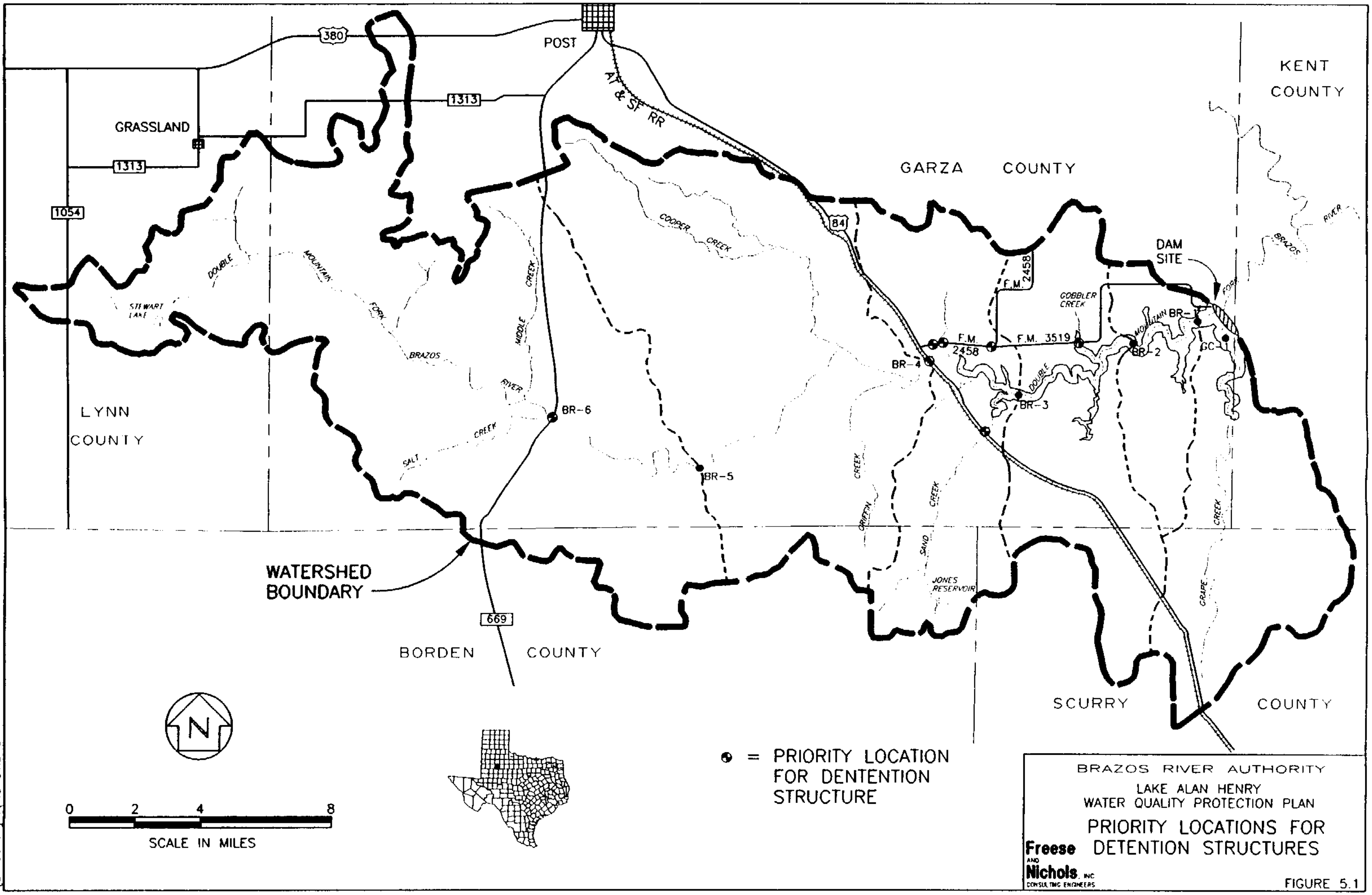
The detention structures would be located on drainage ditches along roads and railways near tributary crossings. However, as discussed in Chapter 2, some crossings pose a higher risk than others, depending on factors such as the variety of materials transported, the speed of travel, and the distance from the reservoir. Therefore, the recommended placement of detention structures can be prioritized on the basis of potential impact from a spill, as described in the following paragraphs.

Priority locations for detention structures in the watershed include the railway and the roadways that are most heavily travelled and that are closest in proximity to the reservoir (Figure 5.1). U.S. Highway 84 and the Atchison, Topeka and Santa Fe (ATSF) Railroad cross the Double Mountain Fork of the Brazos River near sampling site BR-4. These crossings pose the greatest risk of transportation spills because of high traffic volumes and speeds, variety of chemicals transported, and the close proximity to Lake Alan Henry. The crossings of U.S. Highway 84 and the ATSF Railroad at Sandy Creek, southeast of the Double Mountain Fork crossings, also would pose a relatively high risk of lake contamination from a spill.

F.M. 2458 crosses tributaries of the Double Mountain Fork of the Brazos River at three locations. Detention structures at these locations would be given priority because of their proximity to the headwaters of the Double Mountain Fork of the Brazos River at Lake Alan Henry.

F.M. 3519 is the paved access road that continues eastward where F.M. 2458 turns north. Detention structures would be useful on both sides of the bridge where F.M. 3519 crosses Gobbler Creek to control a spill into the road ditches that would lead directly into the reservoir.

F.M. 669 crosses the Double Mountain Fork of the Brazos River near sampling site BR-6. This crossing does not pose as great a threat to water quality in Lake Alan Henry because of its distance upstream and relatively lighter traffic load. However, the road crosses the main source of water for the reservoir; therefore, this site would be a priority location for detention structures.



BRAZOS RIVER AUTHORITY

LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

PRIORITY LOCATIONS FOR DETENTION STRUCTURES

Freese and Nichols, Inc
CONSULTING ENGINEERS

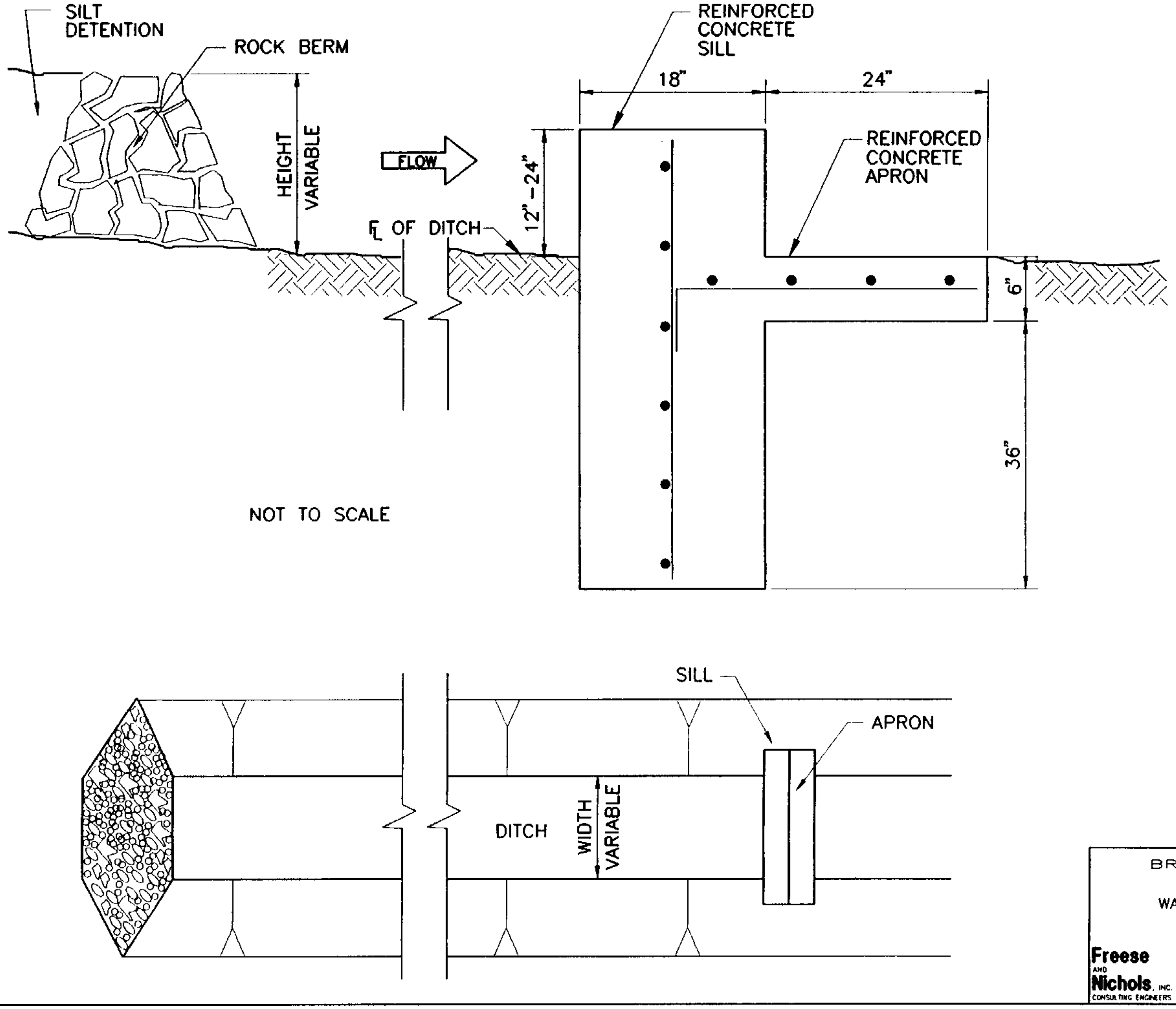
FIGURE 5.1

ACAD\MLP (8-25-92)
[BRA90107]N:\FIG-51.DWG

A detention structure in drainage ditches on each side of a roadway near stream crossings would allow for spill containment on both banks of a stream. The structures should be constructed of concrete with appropriate erosion control on the downstream channel banks. The structure should have a maximum height of approximately two feet. The ditch leading to detention structures may need to be widened or the slope reduced if necessary to allow for containment of the expected volume of released material. A typical detention structure is shown in Figure 5.2.

The design of detention structures must consider the maximum volume that could be released from a truck or railcar in the event of an accident. In addition, the design would have to follow State Highway Department design criteria for obstruction clearances and drainage. According to the U.S. Department of Transportation, the maximum volume of a hazardous substance carried by a tanker on the highway is 8,000 gallons. The actual volume depends on the specific material being transported. Tankers have either compartments or baffles inside to minimize the movement of material within the tanker. Compartments would also serve to reduce the volume of hazardous material released in the event of an accident. According to the Texas Railroad Commission, the standard railway tanker contains 33,000 gallons of material. The maximum volume for a railway tanker is approximately 36,000 gallons, depending on the substance.

Costs involved in this physical control measure include design, construction, and maintenance expenses. The actual dimensions for each detention structure will differ among the crossings depending on the width and slope of the existing drainage ditches and the anticipated risk at each crossing due to amount



BRAZOS RIVER AUTHORITY
LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

TYPICAL DETENTION STRUCTURE

Freese and Nichols, INC.
CONSULTING ENGINEERS

FIGURE 5.2

ACAD\MLP (8-26-92)
[BRA90107]N:\FIG-52.DWG

of travel. Construction costs include the labor and materials required to build the detention structures and modify the ditches as necessary to provide adequate capacity to contain the expected maximum spill volume. The estimated cost of the concrete structure is approximately \$100 per foot of length plus about \$400 for excavation at each site. The costs could be considerably more if extensive ditch modifications and right-of-way purchases are required. Maintenance costs would involve the periodic removal of sediment and debris that accumulates in the ditch. Failure to perform this maintenance task would defeat the purpose of the containment structures. A rock berm or silt fence could be installed upstream of the detention structure to control sediment and reduce maintenance frequency and costs.

Bridge Improvements. Another physical control to protect water quality in Lake Alan Henry is to modify drainage from existing bridges. This control measure would be used in conjunction with detention structures at tributary and reservoir crossings. Priority locations for bridge improvements include roadways that are most heavily travelled and that are closest to the reservoir. Existing bridge drainage would allow spilled material to drain directly into the tributaries of Lake Alan Henry.

One possible modification to bridges would involve the installation of gutter systems to transport water and materials from the bridge. Gutter systems could be retro-fitted to existing bridge drains to convey spilled material and water from the bridge surface into the detention structures described previously. Expenses involved in the installation of gutter systems for bridges include the design of individual systems for each bridge and labor and materials for the construction of the system.

Another alternative would be to plug existing bridge drains and resurface the bridge as necessary so that spilled material would drain to the end of the bridge where it could be diverted into the ditch above a detention structure. A grade of 0.5 percent should be sufficient for surface drainage on the bridge. Plugging the drains and resurfacing the bridge to create a sufficient slope for drainage probably would be less expensive than installing guttering systems. In either case, efforts would have to be coordinated with the State Department of Highways and Public Transportation prior to modifying any public highway bridge.

The priority locations for bridge improvements would be where U.S. 84 crosses the Double Mountain Fork and Sand Creek near Justiceburg and where F.M. 3519 crosses Gobbler Creek. The F.M. 669 bridge over Double Mountain Fork would also be a candidate for modification, although the lower traffic volume and greater distance from the reservoir make improvements at this site a lower priority.

Developing a containment system for spills on the railroad bridges over the Double Mountain Fork of the Brazos River and Sand Creek would be considerably more difficult and costly. The existing open wooden trestle bridges would have to be fitted with a drip pan beneath their entire expanse, which would be somewhat impractical. The most likely cause of a significant spill from a railroad tanker would be due to a train derailment. Such an accident at the bridge would probably result in the tanker falling off the bridge, in which case spill containment on the bridge would be of little or no value.

<u>Reservoir Operation</u>. The operation of Lake Alan Henry is a physical

control alternative which could be used to control water quality in the reservoir. Several operating scenarios were evaluated for their impact on water quality, using the computer model for TDS, chloride, and sulfate. These operations included three constant water demand patterns and one variable demand pattern. The constant demands included zero withdrawal, 12,000 acre-feet per year (ac-ft/yr), and 25,000 ac-ft/yr. The variable demand pattern was as follows: the rate of withdrawal was 35,000 ac-ft/yr when the reservoir contents were greater than 60,000 ac-ft; when the contents were between 30,000 ac-ft and 60,000 ac-ft, the demand decreased to 25,000 ac-ft/yr; and when the contents in the reservoir dropped below 30,000 ac-ft, the demand was reduced to 20,000 ac-ft/yr. Results of the water quality simulations under the varying operating conditions are summarized in Table 5.1.

The simulation indicated that greater annual water demands resulted in lower dissolved mineral concentrations. The maximum simulated TDS concentration for the zero ac-ft/yr scenario was 1,658 mg/l, while the maximum for the 25,000 ac-ft/yr withdrawal rate was 1,445 mg/l. All of the constant water demands resulted in higher concentrations of dissolved solids in the reservoir than with the variable demand. The maximum simulated concentration of dissolved solids under the variable demand condition was 1,405 mg/l, and the concentration was projected to be less than 1,000 mg/l approximately 75 percent of the time. The TDS concentration with a constant withdrawal rate of 25,000 ac-ft/yr is expected to be less than 1,000 mg/l 66 percent of the time.

The results of modeling the dissolved mineral concentrations clearly show that removing water from the reservoir would have a positive effect on the

Table 5.1

Summary of Water Quality Simulations in Lake Alan Henry

Reservoir Demand (ac-ft/yr)	TDS (mg/l) Minimum	Median	Mean	Maximum	% Time < 1,000 mg/l
0	694	1,118	1,155	1,658	31.1
12,000	693	1,074	1,083	1,529	35.0
25,000	671	936	955	1,445	65.8
Variable	678	910	925	1,405	74.8

Reservoir Demand (ac-ft/yr)	Chloride (mg/l) Minimum	Median	Mean	Maximum	% Time < 300 mg/l
0	271	436	450	647	2.5
12,000	270	419	422	596	2.6
25,000	262	365	372	564	5.6
Variable	264	355	361	548	8.1

Reservoir Demand (ac-ft/yr)	Sulfate (mg/l) Minimum	Median	Mean	Maximum	% Time < 300 mg/l
0	62	101	104	149	100
12,000	62	97	97	138	100
25,000	60	84	86	130	100
Variable	61	82	83	126	100

dissolved mineral concentrations. This water could be removed either by withdrawal for public supply or release from the reservoir. As the rate of water removal is lowered, dissolved minerals would be expected to accumulate in the reservoir due to evaporation, resulting in higher concentrations of total dissolved solids.

Water Quality Monitoring. Water quality monitoring in Lake Alan Henry would allow the BRA and the City of Lubbock to detect water quality trends over time. Such a program could provide an early warning that would allow a minor pollution problem to be corrected before it developed into a major problem that might affect human health and cost a significant amount to address. Routine monitoring also could be used to evaluate the effectiveness of source elimination programs or the effects of best management practices implemented within the watershed. Detailed recommendations for a water quality monitoring program are presented in Section 6.3.

5.1.3 Institutional Controls

Public Information and Education. Taking steps to inform and educate the public about the value of water quality in Lake Alan Henry is another control measure that warrants consideration. Because the watershed covers a large area that is sparsely populated, informed citizens can play a valuable role in initiating response to an accidental spill or some other potential water quality problem.

One possible way to encourage public participation is to educate the public in reporting a release. The community can be informed about making the first contact in several ways. Signs displaying the National Response Center's (NRC) emergency phone number may be posted at strategic locations in the watershed. Ideal locations would be those where public highways and roads enter the drainage area. Signs or billboards might display a message such as, "You are entering the Lake Alan Henry watershed. Help protect our water quality. Phone 1-800-424-8802 to report a chemical spill." Additional signs might be posted on public roads within the watershed.

A second method for informing the public entails the use of local newspapers, such as The Lubbock Avalanche Journal, The Post Dispatch, and The Snyder Daily News. Special interest articles, letters to the editor, and advertisements could be written to inform the public about the importance of community assistance. Information should include the need for protecting water quality in Lake Alan Henry, the potential sources of pollution, and the source to contact should a chemical release be discovered.

In addition to newspaper articles, local television and radio stations could air public service announcements that summarize the role of the public in protecting the water quality of Lake Alan Henry. Instructions for reporting spills that occur within the watershed should also be given.

Maps and literature related to Lake Alan Henry could be distributed to citizens that reside within the watershed as well as visitors to the reservoir. The literature should include general water safety information, navigation markings, and information on reporting leaks, spills, or other potential water quality problems. Phone numbers of the NRC, the Texas Water Commission (TWC) and the reservoir manager should be incorporated into the literature.

Zoning. The establishment of a zoning plan for the area surrounding Lake Alan Henry can help preserve and enhance the quality of the reservoir. Garza

County was authorized by the Texas Legislature in April 1991 to adopt zoning and building construction ordinances for "... those parts of the county located within one mile of the high water marks established for Lake Alan Henry." The high water mark for the reservoir is considered to be 2245.0 feet above mean sea level.

The Commissioners Court of Garza County has the authority to regulate items such as the height, number of stories, and size of buildings; the percentage of a lot that may be occupied; the size of yards and other open spaces; population density; the location and use of buildings and land for commercial, industrial, residential, or other purposes; and the placement of water and sewer facilities, parks, and other public areas. Because the vicinity of Lake Alan Henry is dominated by rural land use, most of the items that may be zoned are not relevant to Garza County. Should interest in industrial, commercial, or residential developments become an issue, Garza County could exercise its zoning authority to protect sensitive areas of the watershed.

A zoning ordinance for the placement of water and sewage facilities, parks and other public facilities may be useful to protect water quality in the reservoir. Restricted zones could be created to prohibit placement of such facilities within a specific distance from the reservoir. For example, the TWC has designated restricted zones around several reservoirs in the Brazos River basin between the shoreline of each reservoir and a parallel line 75 feet from the shoreline. Construction of soil absorption systems, septic tanks, holding tanks, sanitary sewer lines, or other sewerage facilities is prohibited within the restricted zone (Section 285.83, Subchapter E, Texas Water Code).

Unless mobile home parks and multi-use residential developments are limited by zoning, sewerage systems could become a potential source of pollution in the watershed. Present Texas Health Department requirements for mobile home parks require that no more than twenty units be connected to a single sewerage system, and discharges to the system may not exceed 5,000 gallons per day (Section 301.11(f)(5) of Construction Standards for On-Site Sewerage Facilities). Zoning ordinances could be adopted to restrict the development of sewerage systems from sensitive areas in the watershed, for example near tributaries and close to the edge of the reservoir. According to the Texas Department of Health standards, Section 301.11(e)(4), the Brazos River Authority may assist in water pollution control enforcement procedures through orders issued by the TWC to control or prevent the use of on-site sewerage systems in designated areas. The TWC could delegate its authority to the Brazos River Authority to inspect systems, issue licenses, and enforce the TWC's orders in a designated area around Lake Alan Henry, as it has for four other reservoirs downstream.

Other public facilities to be zoned would include the local roads. A county zoning ordinance would be useful in limiting the development of roads in sensitive areas of the drainage basin. The development of roads could be a threat to water quality because of increased soil erosion potential.

At present, Kent County does not have zoning authority. Because part of the dam and much of the Grape Creek sub-watershed are located in Kent County, it would be desirable for Kent County to obtain zoning authority to allow some control over potential sources of water pollution.

<u>Federal and State Regulations</u>. Several federal and state regulations have been established to minimize water quality impacts from spills and hazardous substances. These regulations require emergency spill response and cleanup and

establish penalties for failure to respond in a timely and effective manner.

Federal regulations regarding oil spills into the waters of the United States are located in Section 311 of the Federal Clean Water Act (CWA). As part of Section 311, owners and operators of large oil storage facilities must comply with EPA regulations by developing, implementing, and maintaining Spill Prevention, Control, and Countermeasure (SPCC) plans. Elements of the SPCC plan include the installation of containment structures; inspection schedules; implementation of other preventive measures, including employee training programs; and a response plan to be followed in case of an emergency.

Federal requirements for reporting a spill of a hazardous substance are found in the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Emergency Planning and Community Right-to-Know Act, otherwise known as Title III of the Superfund Amendments and Reauthorization Act (SARA). Section 103 of CERCLA requires that "... any person in charge of any facility, as soon as he has knowledge of any release (except a federally permitted release) of a hazardous substance in excess of 'reportable quantities' established under Section 102, must immediately notify the National Response Center (NRC) of the release." Important information necessary for reporting an emergency includes the caller name and phone number, the carrier name and responsible party, the nature, location and time of the incident, the material released, and the container type and railcar or truck number.

The phone number for NRC and an incident response form are provided in Appendix C. Failure to report releases immediately to the NRC may result in civil and/or criminal penalties up to $10,000 and imprisonment up to a year, or both (33 USC Section 1319).

Section 301 of SARA Title III requires each governor to appoint a state emergency response commission (SERC). The SERC designates emergency planning districts within the state and appoints local emergency planning committees (LEPC) statewide. The SERC and the LEPC's are charged with developing emergency response procedures that are to be followed upon detection of a spill or leak. Section 304 of SARA Title III outlines procedures for reporting releases to the SERC and the LEPC.

The Texas Emergency Response Commission (TERC) consists of the Texas Water Commission (TWC), the Texas Railroad Commission (RRC), and the Texas Air Control Board (TACB). Each agency has authority over specific types of spills. In the event of a spill, either the state or local office of the agency with jurisdiction over the type of spill must be contacted. The district offices of these agencies closest to the Lake Alan Henry watershed are located in Lubbock. The name and phone number for each agency, as well as a template form for use by other reservoir managers in Texas, are provided in Appendix C.

The TWC is the primary authority in the state on matters of water quality as established by Section 26.127 of the Texas Water Code. The TWC is the lead state agency for response to spills occurring on land or into water. Furthermore, the TWC has the authority to act independently in response to a spill or discharge of oil or hazardous substances if no action is being taken by a federal agency.

The Texas Spill Response Fund, created under the terms of Section 26.265 of the Texas Water Code, may be used to finance cleanups of oil and hazardous substance spills when action by the responsible party, local, or federal government is inadequate. If unable to identify the responsible party, the TWC may use the fund for the cleanup of the spill or discharge. However, if a responsible party is identified after cleanup, that party must reimburse the state for twice the costs incurred. Further penalties are (1) $100-$10,000 per day fine for not reporting a spill, (2) $100-$10,000 per day for not taking action in response to a spill, and (3) a class A misdemeanor charge for any person who knowingly falsifies records or reports or hinders the cleanup of a discharge or spill.

Section 26.131 of the Texas Water Code designates the RRC as the agency responsible for activities associated with the exploration, development, and production of oil, gas, or geothermal resources. These responsibilities include the control and disposition of wastes and the abatement and prevention of pollution of surface and groundwater.

The TACB is the state agency with authority over the discharge of hazardous substances into the air. The TACB requires facilities to report any "major upset" condition which causes or may cause an excessive emission under the Texas Clean Air Act or the TACB regulations. A "major upset" is an "...unscheduled occurrence ... that results in an emission of air contaminants that contravenes the Texas Clean Air Act and is beyond immediate control ..." (Texas Water Commission, 1988). Many releases regulated under SARA will constitute a "major upset" under TACB rules and will be deemed a spill or discharge under the Texas Water Code.

Another state program designed to reduce impacts from spills and hazardous substances is the State of Texas Oil and Hazardous Substances Spill Contingency Plan (TOHSSCP), which was developed in accordance with the CWA, CERCLA, the federal regional response program, and State of Texas statutes. The federal regional response program creates regional bodies for two purposes: planning and preparedness before response actions are taken, and coordination of agencies during response actions. The purpose of the state contingency plan is "to strengthen and improve the response mechanism for discharges or spills of oil and hazardous substances within the territorial limits of the state." The TOHSSCP encompasses all of Texas and, therefore, does not provide detailed response procedures necessary at the local level.

The Texas Disaster Act of 1975, as amended, requires a spill contingency and response plan at the city and county level. Response to a spill in the absence of a plan may be viewed as inadequate or it may be unnecessarily delayed. This may subject the responsible party to additional penalties from state authorities.

Both federal and state regulations require contingency plans at the county and local levels. Examples of these plans are discussed below.

Emergency Action Plans. Each of the pipeline companies that operates within the Lake Alan Henry watershed has an emergency spill response plan and an emergency response team trained in containment and cleanup procedures. Shell has a response team and containment and cleanup equipment based in Hamlin, Texas. Scurlock Permian owns five mobile response vans strategically located in Texas, the nearest in Abilene. AMOCO has spill response vehicles and teams in Snyder and Sterling City. AMOCO and Scurlock Permian each maintain a list of pre-approved, insured contractors in case additional assistance is necessary. Dunigan's spill prevention plan includes a team of trained employees on site at a field office in Borden County.

The Santa Fe Railroad has a response team in Lubbock at the Assistant

Superintendent's office that is trained and available to respond to emergencies involving the railroad in the drainage area of the reservoir (personal communication with Ron Jackson, Santa Fe Railroad, July 7, 1992). In addition to the response team in Lubbock, Santa Fe's Environmental Office in Topeka, Kansas, is also involved in cleanup of hazardous substances. The Environmental Office is the main contact with federal, state, and local agencies. In the event of a spill, the Santa Fe contingency plan requires that Santa Fe officials will be notified, as well as the TWC, NRC, and other appropriate agencies.

According to Section 303 of the Emergency Planning and Community Right-to-Know Act, the local emergency planning committees (LEPC) are appointed by the state emergency response committee and are required to create contingency plans to address an emergency spill. Applicable government agencies in the region also have emergency response plans. Spill response differs from typical emergency response by fire, law, and medical personnel because the actions of many local and state agencies must be coordinated. The emergency action plans serve to delegate responsibilities of each agency prior to the event of a spill or leak of hazardous substances. The highest elected official, such as the county judge or city mayor or an appointed coordinator, is responsible for the emergency response plan, whether it is for the county or the incorporated city. For example, the City of Snyder and Scurry County have created a joint jurisdiction with a coordinator who developed the Emergency Management Plan, Snyder/Scurry County. The purpose of this plan is to incorporate four phases of emergency management: mitigation, preparedness, response, and recovery. Garza County and Lynn County also have emergency response plans. Borden County and Kent County, however, do not have formal contingency plans. The Brazos River Authority will have an Emergency Action Coordinator on staff at Lake Alan Henry to help coordinate local response efforts and to distribute necessary information.

Proper response to an emergency spill requires prior training, planning, and coordinated efforts. For this reason, the Clean Water Act requires that Spill Prevention, Control, and Countermeasure (SPCC) plans be developed and maintained by owners and operators of facilities that handle oil and hazardous waste and materials. Examples of owners and operators include pipeline companies, railways, and tank trucks. Training, such as Hazardous Waste Operations and Response Training (HAZWOPER Training), for employees involved in the identification, notification, control, and containment of hazardous spills is required by the Occupational Safety and Health Administration (OSHA). HAZWOPER training complies with the OSHA standards for working conditions that involve the handling, storage, and transport of toxic and hazardous substances (29 CFR 1910). Preventive planning for emergency spills should also be a part of an emergency management plan.

The U.S. Department of Transportation's (DOT) <u>1990 Emergency Response Guidebook</u> contains important information, including phone numbers for reporting spills and instructions for identifying hazardous materials. The DOT Guide is provided to emergency response personnel. Many companies involved in the transport of hazardous substances carry the DOT Guide in their vehicles to satisfy the requirement for having emergency response information on board. Developed for first responders to an emergency, the purpose of the DOT Guide is to assist in making initial decisions involving hazardous materials to protect the responders and the general public. Additional information, warnings, and guidelines regarding hazardous materials are provided by the Chemical

Transportation Emergency Center (CHEMTREC). CHEMTREC is a service of the Chemical Manufacturers Association, created to ensure that the chemical industry's capabilities are available in emergency situations. The 24-hour phone number for CHEMTREC is provided in Appendix C.

Water Quality Protection Task Force. A local water quality task force might play a key role in overseeing the implementation of appropriate pollution control measures. Such a task force should be comprised of technical and non-technical members who have an interest in protecting water quality in the Lake Alan Henry watershed. Technical members might include representatives from the BRA, City of Lubbock, Soil Conservation Service, TWC, RRC, Santa Fe Railroad, State Department of Highways and Public Transportation, and oil and pipeline companies. Non-technical members might include representatives of the local ranching and farming community and the nearby county commissioners.

Responsibilities of the Water Quality Protection Task Force might include, but not be limited to, preparing and coordinating media advertisements; soliciting support from cooperating agencies, elected officials, rate payers, special interest groups, etc., for implementation of watershed protection projects; and reviewing proposed development plans near the lake and making recommendations to the Garza County zoning commission. This task force should serve as an extension of the BRA's Upper Basin Subcommittee on regional water quality assessment, which was developed to fulfill the requirements of the Texas Clean Rivers Act.

The task force should meet at least twice annually. Meetings should be advertised locally and be open to the public, which would provide a forum for local landowners and others to make the task force aware of water quality concerns and potential solutions.

5.2 No Action

Adoption of the No Action alternative would increase the risk of contamination in Lake Alan Henry. The benefits of source elimination and physical and institutional control measures would not be realized.

Without the implementation of reservoir releases or withdrawals, the dissolved minerals in the reservoir probably would exceed acceptable levels at times. The reduction in pollution potential due to installation of pipeline check valves and cutoff valves, drainage ditch detention structures, and bridge improvements would not occur under the No Action alternative. Failure to monitor water quality in the reservoir would eliminate the BRA's opportunity to detect subtle adverse changes in reservoir quality and respond to the source of such a change.

The omission of a public information and education campaign and a Water Quality Protection Task Force would preclude the BRA from maximizing public cooperation for water quality protection. By not providing zoning recommendations to Garza County, interests of the BRA and the City of Lubbock, in terms of reservoir quality protection, may be overlooked. If the reservoir manager were not afforded the advantage of receiving HAZWOPER training, he or she may not be equipped to perform as efficiently or safely if called on in an initial response situation.

However, even under the No Action alternative, some pollution control measures would be in place. The federal, state, and local agencies would continue pollution control and abatement activities under their applicable regulations. Appendix C of this report also provides some guidance for initial response to a chemical spill that might threaten the reservoir. In addition, source elimination measures have already begun. The BRA has purchased several oil wells in the reservoir pool and is also negotiating the removal or protection of pipelines from the reservoir pool. The Texas Railroad Commission identified six abandoned wells in the reservoir area and plugged them using State funds.

6. CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

a. The Lake Alan Henry watershed does not appear to have a significant existing pollution problem from oil production activities.

b. The most significant chronic, or long-term, water quality problem anticipated in Lake Alan Henry is dissolved solids concentrations. The source of dissolved solids is believed to be primarily natural.

c. Dissolved mineral concentrations can be reduced somewhat by removing water from the reservoir to avoid accumulation of solids by evaporation. Water could be removed by diversions from the reservoir for municipal supply or, in early years when full demand has not developed, by releasing water downstream.

d. Although several constituents, including turbidity, selenium, cadmium, chromium, copper, silver, nitrogen, phosphorus, and fecal coliforms, were found in the stream at concentrations exceeding water quality standard limits, these are not expected to present significant problems in the reservoir or in the treated drinking water.

e. Numerous federal, state, and local regulations and programs are already established, as discussed in Section 5.1.3, to provide economic assistance and administrative guidance for controlling pollutants from oil production facilities and accidental spills.

f. The oil and pipeline companies operating in the Lake Alan Henry watershed have trained response crews or contractors and containment and cleanup equipment nearby to respond to incidents if needed.

g. Organic pollutants, including hydrocarbons and pesticides, do not appear to be a problem in the Lake Alan Henry watershed.

h. The potential for an acute water quality problem (i.e., a spill of oil or toxic chemical) is lower in the Lake Alan Henry watershed than in many other Texas watersheds due to the lack of industrial development, population centers, and the sparsity of public transportation facilities.

i. The river crossings at Justiceburg would pose the greatest potential for an acute pollution problem due to the variety of chemicals transported along the route by truck, railroad, and pipeline; vehicle speeds; and the proximity of the site to the reservoir. Other potential sites, listed in descending order of risk, include the crossings at Sand Creek south of Justiceburg, the box culverts along F.M. 2458, and the bridge over Gobbler Creek on F.M. 3519.

j. A combination of preventive control measures should be adequate to reduce the risk of contamination from accidental spills and to control the influence of natural factors on water quality.

6.2 <u>Recommendations</u>

a. The BRA should continue its source elimination activities such as oil well purchase and plugging and relocation of pipelines within the reservoir pool.

b. The BRA should consider negotiating with AMOCO to install automatic or manual cutoff valves on the 4-inch AMOCO crude line that crosses Sand Creek and the Double Mountain Fork just upstream of U.S. Highway 84 and Lake Alan Henry.

c. The reservoir should be operated to maximize water removal and control undue accumulation of dissolved minerals. This could be accomplished using a variable demand operation as discussed previously. Water could be removed by a combination of withdrawals for water supply and downstream releases, if necessary.

d. The BRA and the City of Lubbock should urge Garza County to include pollution prevention measures, such as restriction of on-site sewerage systems, in the zoning ordinances for Lake Alan Henry.

e. Kent County should seek zoning authority from the Texas Legislature and coordinate its zoning program with that of Garza County.

f. The Lake Alan Henry reservoir manager should become familiar with the local emergency planning committees in the watershed. The phone numbers and initial response forms contained in Appendix C should be posted in a prominent location near a telephone in the reservoir manager's office.

g. The reservoir manager should receive the 40-hour OSHA HAZWOPER training and annual 8-hour refresher courses. This training would provide the manager a basic knowledge of the standard procedures for responding to an accidental spill.

h. A Water Quality Protection Task Force should be established to assist with the implementation and maintenance of pollution control measures.

i. A public information and education program should be developed to encourage public participation in protecting the quality of Lake Alan Henry. At a minimum, this program should include the posting of signs displaying the National Response Center toll-free emergency phone number where roadways enter the watershed and at the crossings of U.S. Highway 84 over Sand Creek and the Double Mountain Fork of the Brazos River.

j. The City of Lubbock should continue its cooperative flow and water quality monitoring program with the USGS at the U.S. Highway 84 bridge.

k. The BRA should establish a reservoir water quality monitoring program. Specific recommendations for the sampling program are provided in Section 6.3.

6.3 Recommendations for Future Monitoring

Monitoring water quality in Lake Alan Henry will provide an essential water quality management tool. The recommended monitoring program was designed to meet the following objectives:

- Allow detection of long-term trends;
- Allow detection of sudden water quality changes;
- Provide a database for future water quality modeling in the reservoir, if necessary;
- Provide a measure of the effects of changes in land use in the watershed above the dam;

- Provide water quality data useful for fisheries management in the lake;

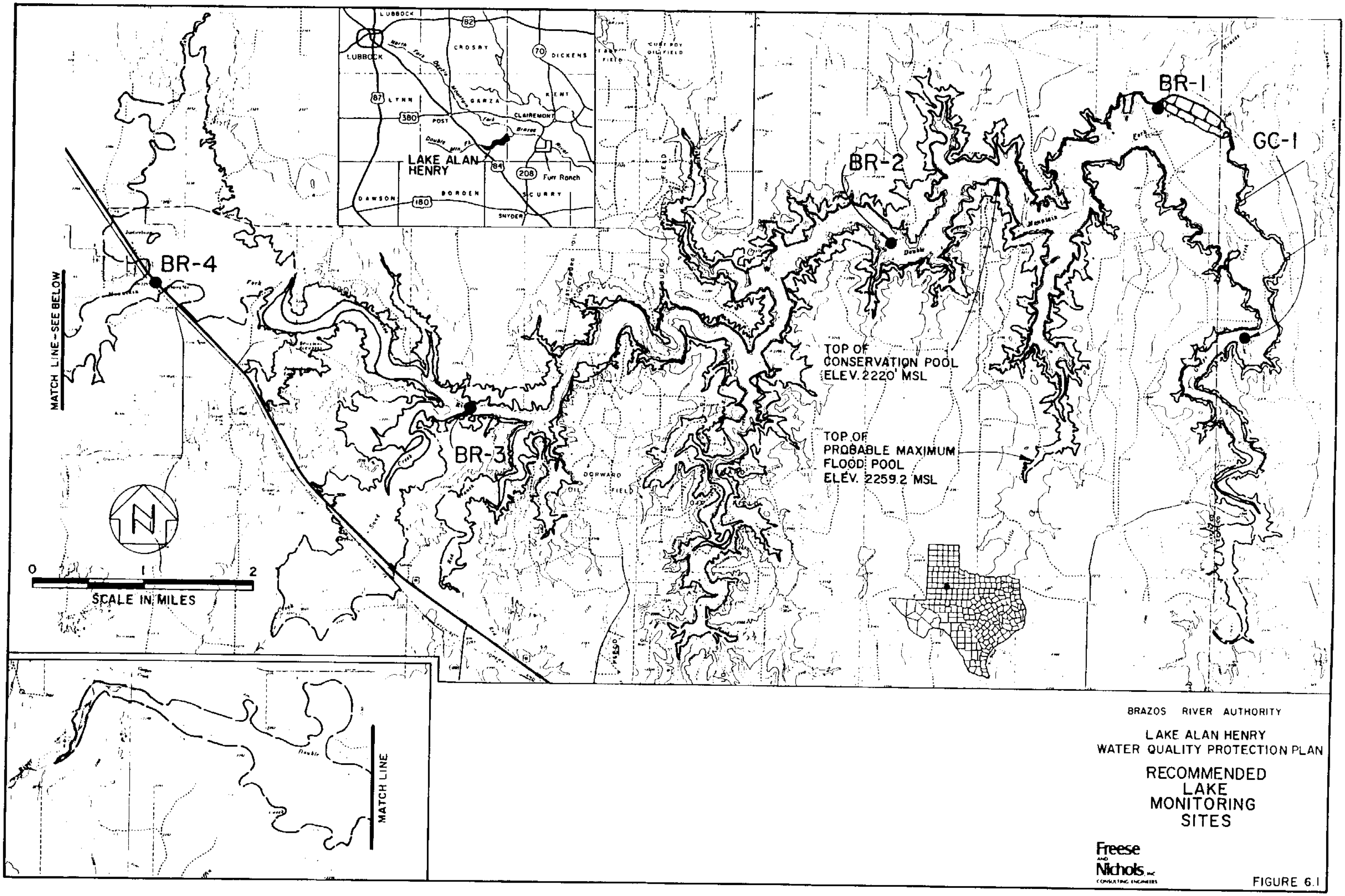
- Allow verification of conclusions regarding dissolved minerals, suspended solids, turbidity, and metals concentrations in the lake.

The water quality in some reservoirs can be adequately monitored with only one sampling site located in the deepest part of the lake. However, long, steep-sided reservoirs, such as Lake Alan Henry, may warrant several sampling sites to assess conditions throughout the reservoir (Olem and Flock, 1990; Wedepohl et al., 1990).

Five sampling sites are recommended for the continuing monitoring program at Lake Alan Henry (Figure 6.1). One sampling site, BR-1, should be located on the bridge to the intake tower. This will enable the City and the BRA to monitor water quality near the water supply intake gates. The four remaining sampling sites should be located in approximately the same places as river sampling sites BR-2, BR-3, BR-4 and GC-1. The use of these sites should allow for the detection of changes in water quality throughout the reservoir.

The City should continue its cooperative streamflow and water quality sampling program with the USGS at U.S. Highway 84 near Justiceburg (BR-4). In addition, the USGS may be able to participate in the reservoir monitoring program through cost sharing. The BRA should contact the USGS early in the 1993 fiscal year to allow time for budgetary planning.

Many of the screening parameters which were used in the pre-impoundment stream survey should be tested in the reservoir monitoring program. Additional measurements common to reservoir monitoring should be made, including Secchi disk



BRAZOS RIVER AUTHORITY

LAKE ALAN HENRY
WATER QUALITY PROTECTION PLAN

RECOMMENDED
LAKE
MONITORING
SITES

Freese and Nichols, Inc.
CONSULTING ENGINEERS

FIGURE 6.1

depth, chlorophyll a, and a depth profile of temperature and dissolved oxygen. The Secchi disk depth is a measurement of transparency in the reservoir and is used to evaluate the trophic status of a lake. Chlorophyll a is a measure of algal biomass and is used to estimate reservoir productivity. Water temperature and dissolved oxygen profiles are used to evaluate lake stratification. The recommended water quality parameters and the sampling frequency at each site are provided in Table 6.1. The parameters and testing frequencies should be evaluated annually and modified if appropriate.

Some of the water quality measurements should be made in the field with portable instruments. These include pH, dissolved oxygen, temperature, and conductivity. As shown in Table 6.1, these measurements should be performed weekly at BR-1. The USGS uses automated mini-monitors to measure these parameters at fixed sites such as BR-1. In addition, a staff gage should be installed on the intake tower for observations of the reservoir water surface elevation at the time of sampling. The lake level also could be monitored automatically using a stage recorder.

General weather observations also should be made when samples are collected. These records should include air temperature, the estimated percent of cloud cover, and wind direction and estimated speed.

Samples should be collected from three depths at each of the four reservoir sites. One sample should be collected at 1.5 fee below the water surface, another at 3 feet above the lake bottom, and one sample should be taken at 2 feet below the top of the hypolimnion, if present (Wedepohl et al., 1990). Samples collected at site BR-4 will provide information on the water quality of the

Table 6.1

Parameters and Sampling Frequency for Lake Alan Henry Continuing Water Quality Monitoring Program

Parameter	Sampling Frequency				
	BR-1	BR-2	BR-3	BR-4	GC-1
Nitrate-N	Q	Q	Q	Q	Q
Ammonia-N	Q	Q	Q	Q	Q
Total Kjeldahl N	Q	Q	Q	Q	Q
Total Phosphorus	Q	Q	Q	Q	Q
Suspended Solids	Q	Q	Q	Q	Q
Turbidity	Q	Q	Q	Q	Q
Total Diss. Solids	Q	Q	Q	Q	Q
Chloride	Q	Q	Q	Q	Q
Sulfate	Q	Q	Q	Q	Q
Fluoride	Q	Q	Q	Q	Q
Alkalinity	Q	Q	Q	Q	Q
Fecal Coliform	Q	Q	Q	Q	Q
Oil and Grease	Q	Q	Q	Q	Q
Total Petroleum Hydrocarbons	Q	Q	Q	Q	Q
Diss. Arsenic	Q	Q	Q	Q	Q
Diss. Cadmium	Q	Q	Q	Q	Q
Diss. Chromium	Q	Q	Q	Q	Q
Diss. Copper	Q	Q	Q	Q	Q
Diss. Selenium	Q	Q	Q	Q	Q
Diss. Silver	Q	Q	Q	Q	Q
Diss. Zinc	Q	Q	Q	Q	Q
pH	W	Q	Q	Q	Q
Diss. Oxygen	W	Q	Q	Q	Q
Secchi Disk Depth	W	Q	Q	-	Q
Chlorophyll a	M*	Q	Q	-	Q
Temperature	W	Q	Q	D	Q
Conductivity	W	Q	Q	D	Q

NOTE: W means weekly; M* means monthly from March through October; Q means quarterly.

inflow to the reservoir from the upper portion of the watershed. Instantaneous flow should be estimated by noting the USGS wire weight gage reading when collecting water quality samples at BR-4.

The components of the monitoring program should be evaluated at least annually. After the first year, the data may indicate that performing organics and metals analyses only once a year, or eliminating some tests altogether, is warranted. Conversely, the data may suggest that sampling frequency may need to be increased for certain parameters. Changes in the number or locations of sampling sites may also be indicated by the results of the observations.

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APPENDIX A

TABLES OF WATER QUALITY SAMPLING DATA, 1990-1992

TABLE A.1

LAKE ALAN HENRY WATER QUALITY MONITORING DATA

LISTING OF FIELD DATA

SITE	Date	Flow CFS	pH s.u. smcl=6.5-8.5	Temperature C	Conductivity umhos	Lab Conductivity umhos	Dissolved Oxygen mg/L
BR-1	900725	9.60	7.8	30.0	3400	3450	8.2
BR-2	900726	2.50	7.4	23.0	5000	5580	7.5
BR-3	900725	.70	7.5	29.0	5800	5710	7.2
BR-4	900725	.20	7.4	27.5	8100	8230	7.1
BR-5	900725	.	.	.	.	.	.
GC-1	900725	.	.	.	.	.	.
BR-1	900830	.20	8.0	24.0	7000	8040	6.7
BR-2	900830	.40	7.8	34.0	9000	7980	8.6
BR-3	900830	.20	7.7	37.0	10000	21900	8.2
BR-4	900830	.30	7.7	34.0	14000	13520	7.0
BR-5	900830	.	.	.	.	.	.
GC-1	900830	.	.	.	.	.	.
BR-1	900924	2.00	7.2	17.5	5500	6220	8.9
BR-2	900924	1.10	7.1	8.1	6500	6700	8.1
BR-3	900924	1.30	7.1	24.0	12000	11630	11.0
BR-4	900924	.50	7.5	26.0	11000	11490	8.8
BR-5	900924	.	.	.	.	.	.
BR-6	900924	.	.	.	.	.	.
GC-1	900924	.	.	.	.	.	.
BR-1	901024	.14	8.5	12.0	3650	5230	8.3
BR-2	901024	.05	7.9	12.0	5800	7820	7.5
BR-3	901024	.06	8.0	21.5	27000	31300	8.3
BR-4	901024	.05	8.1	17.0	11900	15640	8.5
BR-5	901024	.	.	.	.	.	.
BR-6	901024	.	.	.	.	.	.
GC-1	901024	.	.	.	.	.	.
BR-1	901104	125.00	8.9	7.0	750	1021	.
BR-2	901104	.	.	.	.	.	.
BR-3	901104	.	9.6	6.0	950	1264	.
BR-4	901104	.	.	.	.	.	.
BR-5	901104	2.99	9.4	5.0	700	1118	.
BR-6	901104	.	.	.	.	.	.
GC-1	901104	.	.	.	.	.	.
BR-1	901109	40.00	9.2	14.0	1000	1270	10.8
BR-2	901109	39.00	9.1	14.0	1050	1431	11.8
BR-3	901109	23.00	9.3	10.0	1000	1551	10.6
BR-4	901109	18.00	9.4	5.0	820	1430	12.1
BR-5	901109	.	.	.	.	.	.
BR-6	901109	.92	9.3	3.0	1700	3000	12.6
GC-1	901109	.	.	.	.	.	.

TABLE A.1, Continued

LISTING OF FIELD DATA

SITE	Date	Flow CFS	pH s.u. smcl=6.5-8.5	Temperature C	Conductivity umhos	Lab Conductivity umhos	Dissolved Oxygen mg/L
BR-1	901127	.48	8.4	14.0	3900	5060	9.9
BR-2	901127	.57	8.5	19.0	6600	7980	9.4
BR-3	901127	.19	8.5	16.0	18500	24000	9.4
BR-4	901127	.06	8.4	15.0	12000	14400	9.8
BR-5	901127	.	.	.	.	.	.
BR-6	901127	.	.	.	.	.	.
GC-1	901127	.	.	.	.	.	.
BR-1	901218	31.80	8.3	4.5	900	1780	11.8
BR-2	901218	21.17	9.0	8.0	1150	2100	10.6
BR-3	901218	9.40	8.2	10.0	1800	2910	11.8
BR-4	901218	3.80	8.2	11.5	2400	3480	10.4
BR-5	901218	.	.	.	.	.	.
BR-6	901218	.	.	.	.	.	.
GC-1	901218	.	.	.	.	.	.
BR-1	910129	1.15	8.0	6.0	4500	8060	12.6
BR-2	910129	1.19	8.0	8.0	7500	11300	11.8
BR-3	910129	.40	8.2	8.0	1200	18930	11.4
BR-4	910129	.17	8.0	9.0	10000	14960	9.8
BR-5	910129	.	.	.	.	.	.
BR-6	910129	.	.	.	.	.	.
GC-1	910129	.	.	.	.	.	.
BR-1	910508	367.07	8.6	18.0	.	2170	.
BR-2	910508	314.26	8.7	24.0	.	1996	.
BR-3	910508	261.45	8.5	26.0	.	1320	.
BR-4	910508	157.24	8.6	27.0	.	1802	.
BR-5	910508	28.52	8.1	27.0	.	2300	.
BR-6	910508	5.70	8.0	28.0	.	2230	.
GC-1	910508	27.98	8.0	18.0	.	1070	.
BR-1	910602	6590.00	7.9	.	.	2573	.
BR-2	910602	4819.40	8.8	.	.	1059	.
BR-3	910602	2865.50	8.9	.	.	635	.
BR-4	910602	1500.00	8.8	.	.	684	.
BR-5	910602	200.10	8.5	.	.	595	.
BR-6	910602	64.19	8.5	.	.	869	.
GC-1	910602	.	.	.	.	.	.
BR-1	910603	3925.10	8.9	19.5	.	1955	.
BR-2	910603	2572.80	8.5	21.0	.	496	.
BR-3	910603	1125.90	8.4	24.0	.	499	.
BR-4	910603	185.00	8.2	24.0	.	438	.
BR-5	910603	164.22	8.2	25.0	.	559	.
BR-6	910603	.	.	.	.	.	.
GC-1	910603	265.54	8.2	20.0	.	310	.

TABLE A.1, Continued

LISTING OF PRIORITY METALS DATA

SITE	Date	Diss. Arsenic DL<.002 MCL=.05 mg/L	Cadmium DL<.002 MCL=.005 mg/L	Ttl Chromium DL<.002 MCL=0.1 mg/L	Diss. Copper DL<.001 SCL=1.0 mg/L	Diss. Lead DL<.002 MCL=.05 mg/L	Diss. Mercury DL<0.001 MCL=.002 mg/L	Diss. Nickel DL<0.002 mg/L	Diss. Selenium DL<.002 MCL=.05 mg/L	Diss. Silver DL<.002 MCL=.05 SMCL=0.1 mg/L	Diss. Zinc DL<.002 SMCL=5.0 mg/L
BR-1	900725	.010	0.000	.010	0.000	0.000	.	.020	0.000	0.000	0.000
BR-2	900726	0.000	0.000	.010	.020	0.000	.	.080	0.000	.010	.010
BR-3	900725	0.000	.010	0.000	0.000	0.000	.	.040	0.000	0.000	.010
BR-4	900725	0.000	0.000	0.000	.010	.010	.	.050	0.000	0.000	0.000
BR-5	900725	.	.	.	.	.	.	.	.	.	.
GC-1	900725	.	.	.	.	.	.	.	.	.	.
BR-1	900830	.	.	.	.	.	.	.	.	.	.
BR-2	900830	.	.	.	.	.	.	.	.	.	.
BR-3	900830	.	.	.	.	.	.	.	.	.	.
BR-4	900830	.	.	.	.	.	.	.	.	.	.
BR-5	900830	.	.	.	.	.	.	.	.	.	.
GC-1	900830	.	.	.	.	.	.	.	.	.	.
BR-1	900924	.010	.010	0.000	.030	0.000	.	.067	0.000	.015	.027
BR-2	900924	0.000	.012	0.000	.020	0.000	.	.026	0.000	.006	0.000
BR-3	900924	0.000	.015	0.000	.040	0.000	.	.086	0.000	.020	0.000
BR-4	900924	.010	.028	0.000	.010	.009	.	.089	0.000	.020	0.000
BR-5	900924	.	.	.	.	.	.	.	.	.	.
BR-6	900924	.	.	.	.	.	.	.	.	.	.
GC-1	900924	.	.	.	.	.	.	.	.	.	.
BR-1	901024	.018	0.000	.006	.064	0.000	0.000	.013	0.000	0.000	0.000
BR-2	901024	0.000	0.000	.004	.005	0.000	0.000	.015	0.000	.007	.005
BR-3	901024	0.000	.008	.045	.009	0.000	0.000	.121	0.000	.036	.011
BR-4	901024	0.000	0.000	.017	.040	0.000	0.000	.049	0.000	.015	.007
BR-5	901024	.	.	.	.	.	.	.	.	.	.
BR-6	901024	.	.	.	.	.	.	.	.	.	.
GC-1	901024	.	.	.	.	.	.	.	.	.	.
BR-1	901104	.	.	.	.	.	.	.	.	.	.
BR-2	901104	.	.	.	.	.	.	.	.	.	.
BR-3	901104	.	.	.	.	.	.	.	.	.	.
BR-4	901104	.	.	.	.	.	.	.	.	.	.
BR-5	901104	.	.	.	.	.	.	.	.	.	.
BR-6	901104	.	.	.	.	.	.	.	.	.	.
GC-1	901104	.	.	.	.	.	.	.	.	.	.
BR-1	901109	.008	0.000	.005	.022	0.000	0.000	.014	0.000	.005	.010
BR-2	901109	.046	.008	.007	.007	0.000	0.000	.053	.007	0.000	.002
BR-3	901109	.040	0.000	.009	.007	0.000	0.000	.048	0.000	.004	.006
BR-4	901109	.013	.003	.013	.010	0.000	0.000	.015	0.000	.005	.003
BR-5	901109	.	.	.	.	.	.	.	.	.	.
BR-6	901109	0.000	.010	.006	.070	0.000	0.000	.038	0.000	.014	.020
GC-1	901109	.	.	.	.	.	.	.	.	.	.

TABLE A.1, Continued

LISTING OF PRIORITY METALS DATA

SITE	Date	Diss. Arsenic DL<.002 MCL=.05 mg/L	Cadmium DL<.002 MCL=.005 mg/L	Ttl Chromium DL<.002 MCL=0.1 mg/L	Diss. Copper DL<.001 SCL=1.0 mg/L	Diss. Lead DL<.002 MCL=.05 mg/L	Diss. Mercury DL<0.001 MCL=.002 mg/L	Diss. Nickel DL<0.002 mg/L	Diss. Selenium DL<.002 MCL=.05 mg/L	Diss. Silver DL<.002 MCL=.05 SMCL=0.1 mg/L	Diss. Zinc DL<.002 SMCL=5.0 mg/L
BR-1	901127	0.000	.006	0.000	.070	0.000	0.000	0.000	0.000	.120	.002
BR-2	901127	.005	.004	.017	.029	0.000	0.000	.045	0.000	.010	.013
BR-3	901127	.015	.022	.043	.059	0.000	0.000	.091	0.000	.040	.009
BR-4	901127	.015	.009	.027	.034	0.000	0.000	.091	0.000	.020	.014
BR-5	901127	.	.	.	.	.	.	.	.	.	.
BR-6	901127	.	.	.	.	.	.	.	.	.	.
GC-1	901127	.	.	.	.	.	.	.	.	.	.
BR-1	901218	0.000	.005	.002	.014	0.000	0.000	.065	0.000	0.000	.011
BR-2	901218	0.000	.006	.002	.008	0.000	0.000	.034	0.000	.005	.009
BR-3	901218	0.000	0.000	.002	.009	0.000	0.000	.036	0.000	.014	.003
BR-4	901218	.010	.010	.004	.003	0.000	0.000	.021	0.000	.004	.023
BR-5	901218	.	.	.	.	.	.	.	.	.	.
BR-6	901218	.	.	.	.	.	.	.	.	.	.
GC-1	901218	.	.	.	.	.	.	.	.	.	.
BR-1	910129	.006	.046	0.000	0.000	0.000	0.000	.100	0.000	.037	.015
BR-2	910129	0.000	.041	.006	.006	0.000	0.000	.085	0.000	.024	.012
BR-3	910129	.009	.042	.006	.021	0.000	0.000	.168	0.000	.050	.017
BR-4	910129	.013	.042	0.000	.010	0.000	0.000	.152	0.000	.028	.012
BR-5	910129	.	.	.	.	.	.	.	.	.	.
BR-6	910129	.	.	.	.	.	.	.	.	.	.
GC-1	910129	.	.	.	.	.	.	.	.	.	.
BR-1	910508	.003	.020	.009	.068	.003	0.000	.029	0.000	.042	.222
BR-2	910508	0.000	.027	.003	.005	0.000	0.000	.099	0.000	.006	.013
BR-3	910508	0.000	.038	.020	.100	0.000	0.000	.151	0.000	.004	.093
BR-4	910508	.003	.034	.003	.082	0.000	0.000	.138	0.000	.004	.083
BR-5	910508	.002	.010	.016	.013	0.000	0.000	.029	0.000	.011	.020
BR-6	910508	0.000	0.000	.009	.061	0.000	0.000	.165	0.000	.013	.051
GC-1	910508	.002	.004	.007	.021	.005	0.000	.029	0.000	.015	.034
BR-1	910602	0.000	.020	0.000	.015	0.000	0.000	.013	0.000	0.000	0.000
BR-2	910602	0.000	.011	.007	.010	0.000	0.000	.024	.205	0.000	.004
BR-3	910602	0.000	0.000	.016	.011	0.000	0.000	.020	.092	0.000	.016
BR-4	910602	0.000	.020	0.000	.015	0.000	0.000	.022	.069	.011	.026
BR-5	910602	0.000	.031	0.000	.019	0.000	0.000	.009	0.000	.008	.005
BR-6	910602	0.000	.002	.010	.004	0.000	0.000	.021	.205	.004	.016
GC-1	910602	.	.	.	.	.	.	.	.	.	.
BR-1	910603	.014	0.000	.008	.011	0.000	0.000	.004	.113	.006	0.000
BR-2	910603	.002	0.000	0.000	.021	0.000	0.000	.006	.200	.010	.008
BR-3	910603	.011	0.000	.010	.040	0.000	0.000	0.000	.218	.007	.003
BR-4	910603	0.000	.006	.004	.020	0.000	0.000	.007	.018	0.000	.009
BR-5	910603	0.000	.026	0.000	.009	.002	0.000	0.000	.129	.007	.013
BR-6	910603	.	.	.	.	.	.	.	.	.	.
GC-1	910603	0.000	0.000	.001	.014	0.000	0.000	0.000	.013	.015	.010

TABLE A.1, Continued

LISTING OF NUTRIENTS DATA

SITE	Date	Nitrate N DL<.01 MCL=10 mg/L	Ammonia N mg/L	Ttl Kjeldahl N mg/L	Organic Nitrogen mg/L	Ttl Phosphorus mg/L
BR-1	900725	0.00	.07	.54	.47	.14
BR-2	900726	0.00	.07	0.00	-.07	.57
BR-3	900725	0.00	.11	0.00	-.11	.12
BR-4	900725	0.00	.09	.26	.17	.13
BR-5	900725	.	.	.	.	.
GC-1	900725	.	.	.	.	.
BR-1	900830	.08	.15	.	.	.
BR-2	900830	.06	.38	.	.	.
BR-3	900830	.03	.36	.	.	.
BR-4	900830	1.85	.08	.	.	.
BR-5	900830	.	.	.	.	.
GC-1	900830	.	.	.	.	.
BR-1	900924	0.00	.14	.	.	.17
BR-2	900924	0.00	.12	.	.	.34
BR-3	900924	0.00	.19	.	.	.17
BR-4	900924	0.00	.06	.	.	.02
BR-5	900924	.	.	.	.	.
BR-6	900924	.	.	.	.	.
GC-1	900924	.	.	.	.	.
BR-1	901024	6.60	.06	.	.	.
BR-2	901024	7.58	.09	.	.	.
BR-3	901024	0.00	.85	.	.	.
BR-4	901024	1.81	.23	.	.	.
BR-5	901024	.	.	.	.	.
BR-6	901024	.	.	.	.	.
GC-1	901024	.	.	.	.	.
BR-1	901104	3.37	.21	1.72	1.51	.20
BR-2	901104	.	.	.	.	.
BR-3	901104	1.47	.23	9.39	9.16	.16
BR-4	901104	.	.	.	.	.
BR-5	901104	4.90	.64	5.33	4.70	.02
BR-6	901104	.	.	.	.	.
GC-1	901104	.	.	.	.	.
BR-1	901109	.53	.28	4.37	4.09	.18
BR-2	901109	.60	.17	4.19	4.03	.35
BR-3	901109	.54	.17	4.26	4.09	.36
BR-4	901109	.55	.07	4.23	4.17	.21
BR-5	901109	.	.	.	.	.
BR-6	901109	.90	.10	1.57	1.47	.14
GC-1	901109	.	.	.	.	.

TABLE A.1, Continued

LISTING OF NUTRIENTS DATA

SITE	Date	Nitrate N DL<.01 MCL=10 mg/L	Ammonia N mg/L	Ttl Kjeldahl N mg/L	Organic Nitrogen mg/L	Ttl Phosphorus mg/L
BR-1	901127	0.00	.07	.65	.58	.52
BR-2	901127	0.00	.06	.53	.47	1.17
BR-3	901127	0.00	.49	1.08	.59	.13
BR-4	901127	0.00	.09	.65	.56	.22
BR-5	901127	.	.	.	.	.
BR-6	901127	.	.	.	.	.
GC-1	901127	.	.	.	.	.
BR-1	901218	.72	.14	5.64	5.50	.29
BR-2	901218	.63	.12	3.85	3.72	.23
BR-3	901218	.65	.76	1.43	.68	.25
BR-4	901218	.76	0.00	2.58	2.58	.19
BR-5	901218	.	.	.	.	.
BR-6	901218	.	.	.	.	.
GC-1	901218	.	.	.	.	.
BR-1	910129	0.00	.09	.70	.61	.23
BR-2	910129	0.00	.08	.70	.62	.53
BR-3	910129	0.00	.29	.77	.48	.09
BR-4	910129	0.00	.13	.47	.34	.05
BR-5	910129	.	.	.	.	.
BR-6	910129	.	.	.	.	.
GC-1	910129	.	.	.	.	.
BR-1	910508	.88	.14	11.77	11.63	.89
BR-2	910508	1.63	.12	23.11	22.99	2.80
BR-3	910508	1.80	.12	25.21	25.09	1.40
BR-4	910508	2.89	.12	19.47	19.35	2.51
BR-5	910508	3.24	.17	25.38	25.21	1.14
BR-6	910508	3.32	.14	12.45	12.31	1.20
GC-1	910508	8.52	.14	.69	.55	2.33
BR-1	910602	2.14	1.10	21.83	20.74	.26
BR-2	910602	4.68	.63	19.73	19.10	.20
BR-3	910602	2.78	.52	11.05	10.53	.36
BR-4	910602	2.02	.37	13.85	13.49	.07
BR-5	910602	2.20	.30	7.99	7.70	.13
BR-6	910602	2.62	0.00	5.33	5.33	.33
GC-1	910602	.	.	.	.	.
BR-1	910603	2.22	.12	10.80	10.68	.07
BR-2	910603	1.27	.14	8.97	8.83	.19
BR-3	910603	.99	.08	6.11	6.04	.10
BR-4	910603	.99	.08	5.34	5.26	.07
BR-5	910603	1.69	.10	3.90	3.80	.01
BR-6	910603	.	.	.	.	.
GC-1	910603	2.53	.09	3.17	3.08	.03

TABLE A.1, Continued

LISTING OF BACTERIAL SAMPLES DATA

SITE	Date	Fecal Coliform Col./100mL	Fecal Streptococcus Col./100mL	Fec. Coli./ Fec. Strep. Ratio
BR-1	900725	1600.00	4.00	.
BR-2	900726	700.00	5.00	.
BR-3	900725	500.00	10.00	.
BR-4	900725	0.00	10.00	.
BR-5	900725	.	.	.
GC-1	900725	.	.	.
BR-1	900830	2540.00	47.00	.
BR-2	900830	1173.00	33.00	.
BR-3	900830	2513.00	0.00	.
BR-4	900830	5950.00	7.00	.
BR-5	900830	.	.	.
GC-1	900830	.	.	.
BR-1	900924	150.00	0.00	.
BR-2	900924	90.00	10.00	.
BR-3	900924	0.00	0.00	.
BR-4	900924	15.00	33.00	.
BR-5	900924	.	.	.
BR-6	900924	.	.	.
GC-1	900924	.	.	.
BR-1	901024	180.00	0.00	.
BR-2	901024	113.00	1907.00	.06
BR-3	901024	0.00	13.00	.
BR-4	901024	150.00	33.00	.
BR-5	901024	.	.	.
BR-6	901024	.	.	.
GC-1	901024	.	.	.
BR-1	901104	1100.00	400.00	2.75
BR-2	901104	.	.	.
BR-3	901104	0.00	1000.00	.
BR-4	901104	.	.	.
BR-5	901104	4333.00	1080.00	.
BR-6	901104	.	.	.
GC-1	901104	.	.	.
BR-1	901109	6333.00	0.00	.
BR-2	901109	2333.00	67.00	.
BR-3	901109	2667.00	67.00	.
BR-4	901109	0.00	300.00	.
BR-5	901109	.	.	.
BR-6	901109	1333.00	1000.00	.
GC-1	901109	.	.	.

TABLE A.1, Continued

LISTING OF BACTERIAL SAMPLES DATA

SITE	Date	Fecal Coliform Col./100mL	Fecal Streptococcus Col./100mL	Fec. Coli./ Fec. Strep. Ratio
BR-1	901127	0.00	0.00	.
BR-2	901127	1.00	0.00	.
BR-3	901127	0.00	0.00	.
BR-4	901127	0.00	0.00	.
BR-5	901127	.	.	.
BR-6	901127	.	.	.
GC-1	901127	.	.	.
BR-1	901218	487.00	3950.00	.12
BR-2	901218	2120.00	3790.00	.56
BR-3	901218	1060.00	3460.00	.31
BR-4	901218	1600.00	2170.00	.74
BR-5	901218	.	.	.
BR-6	901218	.	.	.
GC-1	901218	.	.	.
BR-1	910129	0.00	7.00	.
BR-2	910129	0.00	0.00	.
BR-3	910129	0.00	7.00	.
BR-4	910129	0.00	0.00	.
BR-5	910129	.	.	.
BR-6	910129	.	.	.
GC-1	910129	.	.	.
BR-1	910508	5000.00	2040.00	2.45
BR-2	910508	7750.00	4553.00	1.70
BR-3	910508	7550.00	4200.00	1.80
BR-4	910508	5200.00	3513.00	1.48
BR-5	910508	6400.00	2267.00	2.82
BR-6	910508	4750.00	1553.00	3.06
GC-1	910508	4750.00	9200.00	.52
BR-1	910602	1280.00	1300.00	.98
BR-2	910602	1320.00	2867.00	.46
BR-3	910602	560.00	2073.00	.27
BR-4	910602	420.00	3033.00	.14
BR-5	910602	1400.00	1893.00	.74
BR-6	910602	466.00	1427.00	.33
GC-1	910602	.	.	.
BR-1	910603	6350.00	6050.00	1.05
BR-2	910603	7400.00	6650.00	1.11
BR-3	910603	5950.00	5500.00	1.08
BR-4	910603	6000.00	4950.00	1.21
BR-5	910603	5800.00	6200.00	.94
BR-6	910603	.	.	.
GC-1	910603	5400.00	5800.00	.93

TABLE A.1, Continued

LISTING OF SOLIDS AND CONVENTIONAL CONSTITUENTS DATA

SITE	Date	Total Suspended Solids mg/L	Total Dissolved Solids SCL=1000 mg/L	Chloride SCL=300 mg/L	Sulfate SCL=300 mg/L	Dissolved Fluoride MCL=4 SCL=2 mg/L	Turbidity MCL=0.5-1.0 TU	5-Day BOD mg/L
BR-1	900725	79.70	1880	723	150	.57	75.00	0.00
BR-2	900726	52.80	3270	570	339	.64	31.00	0.00
BR-3	900725	74.00	3450	578	210	.48	45.00	0.00
BR-4	900725	23.10	5095	719	347	.80	11.40	0.00
BR-5	900725	.	.	.	.	.	.	.
GC-1	900725	.	.	.	.	.	.	.
BR-1	900830	19.20	4620	116	150	.74	75.00	0.00
BR-2	900830	8.40	4640	478	73	.70	31.00	0.00
BR-3	900830	20.50	14210	500	99	.77	45.00	0.00
BR-4	900830	4.70	8040	251	653	1.37	11.40	0.00
BR-5	900830	.	.	.	.	.	.	.
GC-1	900830	.	.	.	.	.	.	.
BR-1	900924	1.80	3800	622	359	.68	4.90	.42
BR-2	900924	20.00	4220	622	415	.84	20.00	.45
BR-3	900924	20.40	7460	827	464	.83	21.00	.63
BR-4	900924	4.60	7280	832	551	1.24	.78	.57
BR-5	900924	.	.	.	.	.	.	.
BR-6	900924	.	.	.	.	.	.	.
GC-1	900924	.	.	.	.	.	.	.
BR-1	901024	62.00	3080	692	217	.79	14.10	.
BR-2	901024	15.20	5170	647	437	.83	6.50	.
BR-3	901024	68.00	21410	500	617	.67	21.00	.
BR-4	901024	27.50	9570	677	450	1.31	8.80	.
BR-5	901024	.	.	.	.	.	.	.
BR-6	901024	.	.	.	.	.	.	.
GC-1	901024	.	.	.	.	.	.	.
BR-1	901104	1826.00	698	.	553	.49	34.00	6.00
BR-2	901104	.	.	.	.	.	.	.
BR-3	901104	753.00	1100	263	154	.84	188.00	12.00
BR-4	901104	.	.	.	.	.	.	.
BR-5	901104	1366.00	700	215	196	.95	79.00	6.00
BR-6	901104	.	.	.	.	.	.	.
GC-1	901104	.	.	.	.	.	.	.
BR-1	901109	8581.00	960	235	98	.77	195.00	4.00
BR-2	901109	10418.00	1000	258	114	.78	140.00	4.00
BR-3	901109	11270.00	1040	261	122	.88	156.00	4.00
BR-4	901109	11015.00	840	245	143	1.05	110.00	5.00
BR-5	901109	.	.	.	.	.	.	.
BR-6	901109	1334.00	1920	237	263	2.98	102.00	3.00
GC-1	901109	.	.	.	.	.	.	.

TABLE A.1, Continued

LISTING OF SOLIDS AND CONVENTIONAL CONSTITUENTS DATA

SITE	Date	Total Suspended Solids mg/L	Total Dissolved Solids SCL=1000 mg/L	Chloride SCL=300 mg/L	Sulfate SCL=300 mg/L	Dissolved Fluoride MCL=4 SCL=2 mg/L	Turbidity MCL=0.5-1.0 TU	5-Day BOD mg/L
BR-1	901127	8.00	2960	571	367	.80	8.90	.72
BR-2	901127	21.30	4840	691	673	.80	19.50	.50
BR-3	901127	10.90	16760	265	939	.81	1.90	.70
BR-4	901127	19.40	9560	969	774	1.51	2.60	.11
BR-5	901127	.	.	.	.	.	.	.
BR-6	901127	.	.	.	.	.	.	.
GC-1	901127	.	.	.	.	.	.	.
BR-1	901218	8374.00	1104	367	136	.55	51.00	5.00
BR-2	901218	4318.00	970	418	128	.62	121.30	5.00
BR-3	901218	1040.00	1578	502	157	.63	24.00	4.00
BR-4	901218	1938.00	1760	561	222	.84	28.00	5.00
BR-5	901218	.	.	.	.	.	.	.
BR-6	901218	.	.	.	.	.	.	.
GC-1	901218	.	.	.	.	.	.	.
BR-1	910129	23.80	4758	582	548	.74	14.50	1.00
BR-2	910129	49.70	7105	685	651	.69	36.00	1.00
BR-3	910129	43.70	11892	1015	792	.79	7.90	1.00
BR-4	910129	29.00	9184	941	672	1.20	4.90	1.00
BR-5	910129	.	.	.	.	.	.	.
BR-6	910129	.	.	.	.	.	.	.
GC-1	910129	.	.	.	.	.	.	.
BR-1	910508	13940.00	1496	492	342	.21	179.00	8.00
BR-2	910508	21840.00	1282	206	273	.77	188.00	0.00
BR-3	910508	25810.00	788	325	141	1.29	199.00	0.00
BR-4	910508	20380.00	1170	145	407	1.25	156.00	0.00
BR-5	910508	21060.00	1512	484	481	1.41	186.00	0.00
BR-6	910508	9340.00	1374	638	362	2.70	119.00	0.00
GC-1	910508	420.00	688	178	216	.23	195.00	0.00
BR-1	910602	54140.00	1450	846	142	1.24	151.00	10.00
BR-2	910602	33958.00	618	281	89	1.12	165.00	10.00
BR-3	910602	31752.00	452	150	55	.95	189.00	8.00
BR-4	910602	32916.00	462	79	73	.85	195.00	9.00
BR-5	910602	9650.00	374	142	68	1.11	166.00	7.00
BR-6	910602	4674.00	488	171	130	1.15	185.00	6.00
GC-1	910602	.	.	.	.	.	.	.
BR-1	910603	20036.00	1026	66	68	.61	79.00	11.00
BR-2	910603	15752.00	354	66	57	.65	152.00	10.00
BR-3	910603	7948.00	302	82	70	.59	170.00	7.00
BR-4	910603	6520.00	272	46	60	.61	185.00	7.00
BR-5	910603	3984.00	288	72	109	.86	205.00	5.00
BR-6	910603	.	.	.	.	.	.	.
GC-1	910603	2385.00	178	45	40	.31	96.00	8.00

TABLE A.1, Continued

LISTING OF ORGANIC CONSTITUENTS DATA

SITE	Date	Total Petroleum Hydrocarbons DL=.2 mg/L	Oil and Grease mg/L	Total PCBs DL=0.0005 mg/L
BR-1	900725	0.00	8.00	0.00
BR-2	900726	0.00	0.00	0.00
BR-3	900725	0.00	8.00	0.00
BR-4	900725	0.00	0.00	0.00
BR-5	900725	.	.	.
GC-1	900725	.	.	.
BR-1	900830	0.00	0.00	0.00
BR-2	900830	0.00	0.00	0.00
BR-3	900830	0.00	0.00	0.00
BR-4	900830	0.00	0.00	0.00
BR-5	900830	.	.	.
GC-1	900830	.	.	.
BR-1	900924	.	0.00	0.00
BR-2	900924	.	0.00	0.00
BR-3	900924	.	0.00	0.00
BR-4	900924	.	1.30	0.00
BR-5	900924	.	.	.
BR-6	900924	.	.	.
GC-1	900924	.	.	.
BR-1	901024	.	0.00	0.00
BR-2	901024	.	0.00	0.00
BR-3	901024	.	0.00	0.00
BR-4	901024	.	0.00	0.00
BR-5	901024	.	.	.
BR-6	901024	.	.	.
GC-1	901024	.	.	.
BR-1	901104	1.00	0.00	0.00
BR-2	901104	.	.	.
BR-3	901104	1.02	0.00	0.00
BR-4	901104	.	.	.
BR-5	901104	.51	0.00	0.00
BR-6	901104	.	.	.
GC-1	901104	.	.	.
BR-1	901109	1.21	0.00	0.00
BR-2	901109	.45	0.00	0.00
BR-3	901109	.03	0.00	0.00
BR-4	901109	0.00	0.00	0.00
BR-5	901109	.	.	.
BR-6	901109	.08	0.00	0.00
GC-1	901109	.	.	.

TABLE A.1, Continued

LISTING OF ORGANIC CONSTITUENTS DATA

SITE	Date	Total Petroleum Hydrocarbons DL=.2 mg/L	Oil and Grease mg/L	Total PCBs DL=0.0005 mg/L
BR-1	901127	.50	2.00	0.00
BR-2	901127	1.05	0.00	0.00
BR-3	901127	.07	0.00	0.00
BR-4	901127	2.80	0.00	0.00
BR-5	901127	.	.	.
BR-6	901127	.	.	.
GC-1	901127	.	.	.
BR-1	901218	.07	1.00	0.00
BR-2	901218	.50	0.00	0.00
BR-3	901218	1.58	0.00	0.00
BR-4	901218	.21	0.00	0.00
BR-5	901218	.	.	.
BR-6	901218	.	.	.
GC-1	901218	.	.	.
BR-1	910129	0.00	0.00	0.00
BR-2	910129	0.00	0.00	0.00
BR-3	910129	.06	1.00	0.00
BR-4	910129	0.00	0.00	0.00
BR-5	910129	.	.	.
BR-6	910129	.	.	.
GC-1	910129	.	.	.
BR-1	910508	0.00	40.00	0.00
BR-2	910508	0.00	60.00	0.00
BR-3	910508	0.00	60.00	0.00
BR-4	910508	0.00	40.00	0.00
BR-5	910508	0.00	40.00	0.00
BR-6	910508	0.00	40.00	0.00
GC-1	910508	0.00	0.00	0.00
BR-1	910602	0.00	6.00	0.00
BR-2	910602	0.00	6.00	0.00
BR-3	910602	0.00	2.00	0.00
BR-4	910602	0.00	2.00	0.00
BR-5	910602	0.00	0.00	0.00
BR-6	910602	0.00	4.00	0.00
GC-1	910602	.	.	.
BR-1	910603	0.00	.	0.00
BR-2	910603	0.00	.	0.00
BR-3	910603	.	.	.
BR-4	910603	.	.	.
BR-5	910603	0.00	.	0.00
BR-6	910603	.	.	.
GC-1	910603	0.00	.	0.00

TABLE A.2

SURVEY DURING LOW FLOW FROM BR-2 TO BR-4 LISTING OF CONDUCTIVITY AND pH READINGS

Distance Upstream of BR-2 (ft.)	Conductivity (umhos)	pH (s.u.)
0 (BR-2)	7500	8.10
300	7500	8.12
600	7500	8.16
900	7500	8.17
1200	7700	8.17
1500	7500	8.18
1800	7700	8.18
1915	7800	ND
2100	7000	8.20
2400	7500	8.21
2700	8000	8.21
3000	8100	8.20
3300	8000	8.13
3640	8000	8.18
3940	8200	8.22
4240	8200	8.26
4540	8700	8.25
4840	7900	8.27
5140	8700	8.25
5440	8500	8.25
5740	8200	8.24
6040	8800	8.25
6340	8000	8.25
6640	8200	8.26
6940	9000	8.26
7240	9000	8.24
7540	9100	8.25
7840	9000	8.26
8140	8900	8.25
8440	9100	8.26
8740	9100	8.25

ND means "no data".

TABLE A.2, Continued

TABLE A.2, continued

Distance Upstream of BR-2 (ft.)	Conductivity (umhos)	pH (s.u.)
9040	8900	8.26
9340	9500	8.27
9640	9200	8.27
9756	9500	ND
9940	9500	8.27
10240	9500	8.29
10740	9700	8.30
11240	9500	8.27
11740	9800	8.27
12340	9900	8.27
12940	10800	8.28
13240	10500	8.29
13540	10500	8.25
13840	10100	8.28
14440	10800	8.30
15040	11000	8.32
15640	11000	8.33
16240	11300	8.31
16840	11200	8.30
17440	11500	8.31
18040	11500	8.31
18640	11700	8.30
19240	11800	8.31
21140	11700	8.31
22340	11700	8.24
23540	11900	8.25
24740	11500	8.27
25940	12000	8.29
27140	11500	8.29
28340	11500	8.33
29540	11900	8.32
30740	11800	8.30
31940	11700	8.26
33140	11900	8.27
34340	12000	8.30

TABLE A.2, Continued

TABLE A.2, continued

Distance Upstream of BR-2 (ft.)	Conductivity (umhos)	pH (s.u.)
34940 (BR-3)	12000	8.28
35540	12000	8.29
36140	12100	8.31
36440	11800	ND
36640	12000	ND
36740	11800	8.31
37040	11800	8.34
37640	11500	8.32
38240	11700	8.34
38840	11500	8.32
39740	11500	8.33
40340	11200	8.31
40640	11000	8.32
41240	11000	8.27
41840	11000	8.31
42440	11000	8.34
43040	11000	8.32
43640	10700	8.30
43940	9000	ND
44240	10500	8.29
44840	9200	8.29
45440	9500	8.31
46040	9800	8.31
46640	9800	8.34
47240	9900	8.33
48140	9900	8.32
50040	10000	8.30
50940	9200	8.33
51840	9200	8.32
52740	9800	8.27
53640	9100	8.31
54540	9500	8.28
55740	9200	8.28
57240	8500	8.31
59607 (BR-4)	7500	8.33

APPENDIX B

RESERVOIR WATER QUALITY MODEL FOR TOTAL DISSOLVED SOLIDS, CHLORIDE, AND SULFATE

APPENDIX B

RESERVOIR WATER QUALITY MODEL

As mentioned in Section 4, Freese and Nichols (1978) developed a computer model in a previous water quality study of the Lake Alan Henry site, then known as Justiceburg Reservoir, to predict the concentration of dissolved solids in the reservoir. Following the methodology developed in that study, the computer model was updated using sampling data collected since that time, and it was rerun to estimate total dissolved solids (TDS), chloride, and sulfate concentrations in the reservoir.

The earlier study established that the monthly tonnages of TDS were closely related to the volume of discharges at the U.S. Geological Survey (USGS) gaging station on the Double Mountain Fork of the Brazos River near Justiceburg. For flows less than 15 acre-feet/month and greater than 150 acre-feet/month, the relationship of TDS versus flow is a straight line when plotted on a logarithmic scale. In the range from 15 to 150 acre-feet per month flow, there is an S-curve transition. The transition portion of the curve was updated by regressing monthly TDS loads of monthly flows measured by the USGS between 1975 and 1990.

In view of the size of the intervening drainage area between the gage and the dam, and also because of the known oil field activity on that part of the watershed, it was recognized that water quality at the dam might not be the same as the gaging station. A regression procedure was used on the concurrent samples collected at the Justiceburg gage (BR-4) and near the dam (BR-1), previously and during the current study, to define the relationship between quality conditions at the Justiceburg gage and at the downstream sampling point (Figure B.1). The concentrations were found to be lower at the downstream location than at the gaging station when the discharge rate was low, but they were higher at the downstream site than at the gage under high-flow conditions.

The mathematical relationship between runoff and water quality at the Lake Alan Henry dam was derived by combining the equations for flow and TDS at the Justiceburg gage and between BR-4 and BR-1 (Figure B.2). The low flow and high flow break points of 25 ac-ft/mo and 250 ac-ft/mo at the dam were estimated by multiplying the 15 ac-ft/mo and 150 ac-ft/mo break points at the gage by the drainage basin ratio of 1.62. The curve in Figure B.2 is defined by the following equations, in which C represents the monthly flow-weighted average concentration of total dissolved solids in milligrams per liter, and Q represents the monthly runoff in acre-feet:

a. For monthly runoff less that 25 acre-feet:

$$C = 3{,}496 \times Q^{-0.042}$$

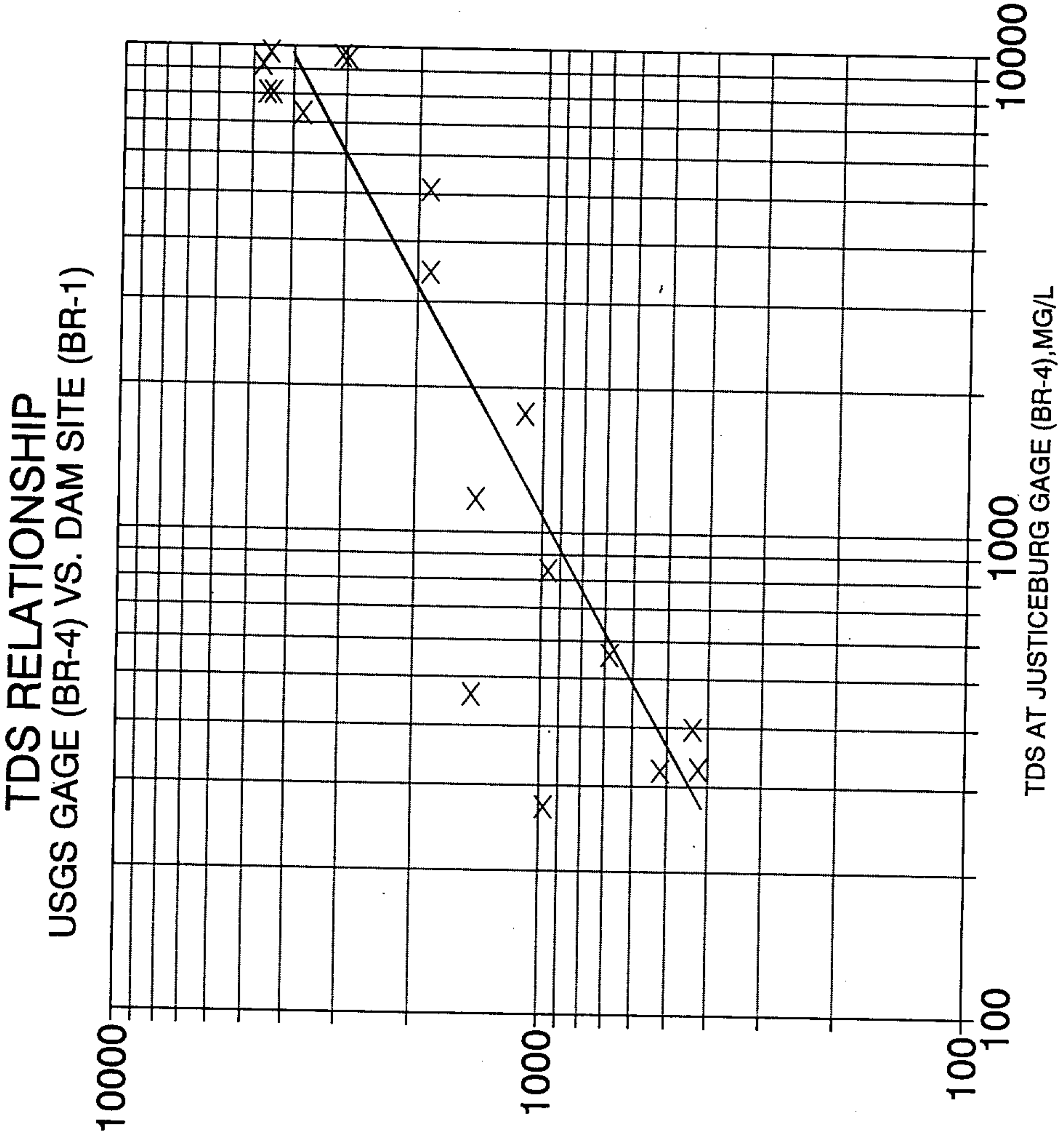
b. For monthly runoff between 25 and 250 acre-feet:

$$C = 9{,}952 \times Q^{-0.367}$$

c. For monthly runoff greater than 250 acre-feet:

$$C = 3{,}090 \times Q^{-0.155}$$

These equations were input to the model along with hydrologic data, such as area and capacity of the reservoir and historical monthly inflow and evaporation between 1940 and 1988, to simulate monthly TDS concentrations in Lake



TDS RELATIONSHIP

USGS GAGE (BR-4) VS. DAM SITE (BR-1)

FIGURE B.1

TDS Vs.MONTHLY RUNOFF

LAKE ALAN HENRY DAM

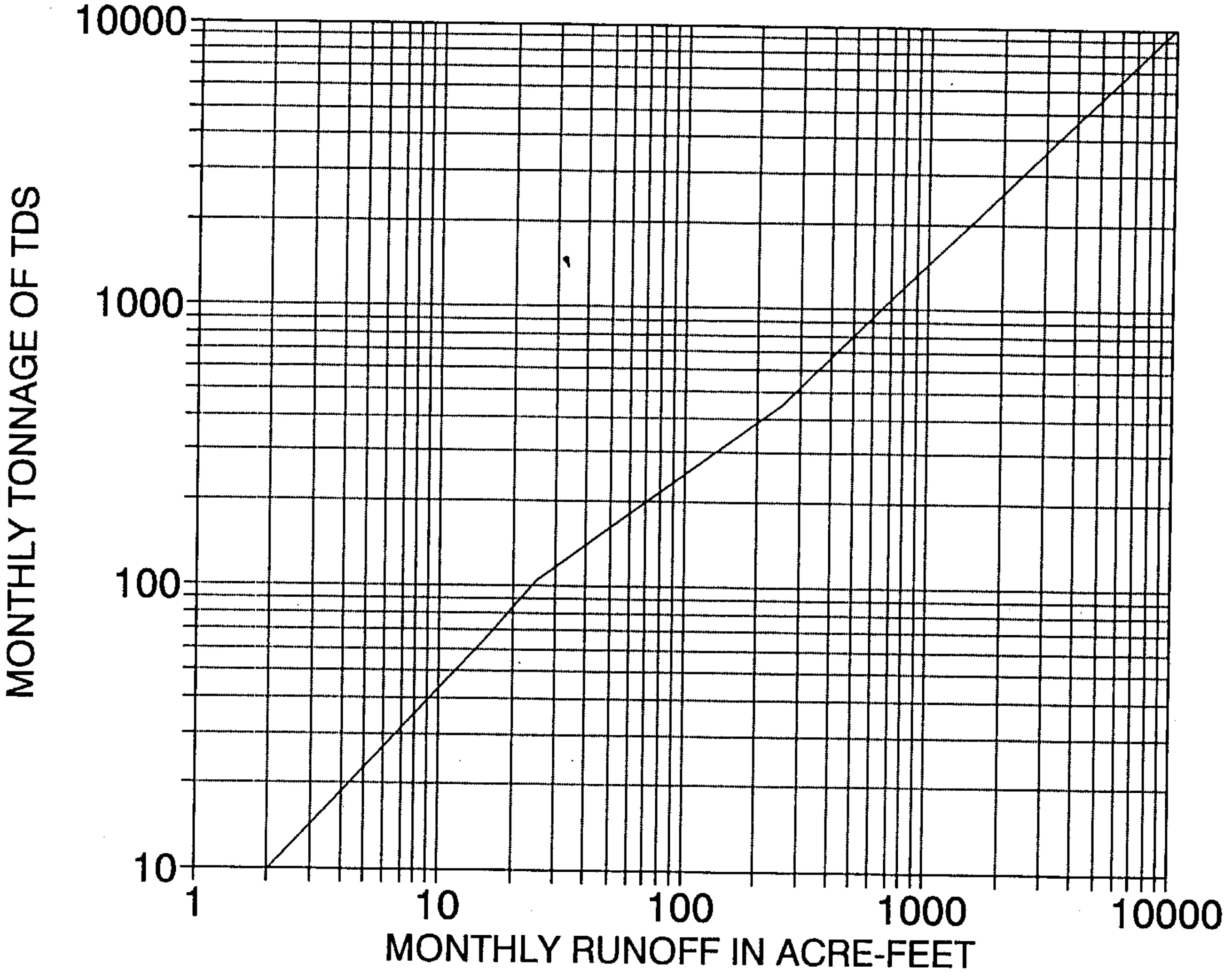


FIGURE B.2

Alan Henry. A printout of the quality routing is presented in Table B.1.

The ratios of chloride to TDS and sulfate to TDS were calculated based on the water quality sampling data for the dam site. Approximately 35 percent of the dissolved solids concentration was due to chloride, while 9 percent was due to sulfate. Monthly reservoir chloride and sulfate concentrations were estimated by applying the ratios to the predicted monthly TDS concentrations in Lake Alan Henry.

Table B.1

Output from Reservoir Water Quality Model

```
LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND


*** THE DEMAND VARIES WITH THE RESERVOIR CONTENT. ***


THERE ARE   1 OPERATION STUDIES IN THIS RUN.

RUN MAXIMUM  START.    1ST     1ST      2ND     2ND      3RD     3RD      4TH     4TH
 # CAPACITY CONTENT  DEMAND CONTROL  DEMAND CONTROL  DEMAND CONTROL  DEMAND CONTROL

  1 115937. 115937.  35000.  60000.  25000.  30000.  20000.      0.      0.      0.

THE DEMAND PATTERN (IN PERCENT OF ANNUAL) IS:

     JAN     FEB     MAR     APR     MAY     JUN     JUL     AUG     SEP     OCT     NOV     DEC

    6.17    6.59    7.34    8.42    8.67   10.68   11.35   11.59    9.09    7.34    6.34    6.42


THE DOWNSTREAM RELEASE IS NOT AFFECTED BY INFLOW.

THE DOWNSTREAM RELEASE IS CONSTANT. MONTHLY RELEASES ARE GIVEN BELOW (IN ACRE-FEET):

 JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC   TOTAL

   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.   0.      0.
```

```
LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND


MAXIMUM CAPACITY    =    115937. ACRE-FEET.
STARTING CONTENT    =    115937. ACRE-FEET.
DEMAND VS. CONTENT =
/  35000./  60000./  25000./  30000./  20000./       0./       0./       0./

DATE  EVAP.    DEMAND     INFLOW    INFLOW   SHORT-    D/S      SPILLS    -------END OF MONTH-------
      LOSS                          QUALITY   AGE    RELEASE              CONTENT     ELEV.   QUALITY
     *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*    *AC-FT*   *AC-FT*      *FT*   *MG/L*

1940
   1    258.     2160.       20.    3083.      0.        0.         0.   113539.    2219.1     805.
   2    113.     2307.      190.    1451.      0.        0.         0.   111309.    2218.3     807.
   3   1277.     2569.        0.       0.      0.        0.         0.   107463.    2216.9     817.
   4   1005.     2947.      570.    1156.      0.        0.         0.   104081.    2215.7     826.
   5   1496.     3035.     2650.     911.      0.        0.         0.   102200.    2215.0     840.
   6   1277.     3738.     5570.     812.      0.        0.         0.   102755.    2215.2     849.
   7   2687.     3973.      100.    1836.      0.        0.         0.    96195.    2212.7     873.
   8   1531.     4057.    15780.     691.      0.        0.         0.   106387.    2216.5     859.
   9   2159.     3182.     6280.     797.      0.        0.         0.   107326.    2216.9     872.
  10   1057.     2569.        0.       0.      0.        0.         0.   103700.    2215.6     881.
  11    107.     2219.     2910.     898.      0.        0.         0.   104284.    2215.8     882.
  12    427.     2244.      130.    1668.      0.        0.         0.   101743.    2214.9     887.

      13394.    35000.    34200.               0.        0.         0.

1941
   1    315.     2160.        0.       0.      0.        0.         0.    99268.    2213.9     890.
   2    233.     2307.      870.    1082.      0.        0.         0.    97598.    2213.2     894.
   3     52.     2569.     5530.     813.      0.        0.         0.   100507.    2214.4     890.
   4    496.     2947.    30830.     623.      0.        0.     11957.   115937.    2220.0     832.
   5  -1384.     3035.    68820.     550.      0.        0.     67169.   115937.    2220.0     721.
   6   1009.     3738.    21700.     657.      0.        0.     16953.   115937.    2220.0     718.
   7   1442.     3973.    11210.     728.      0.        0.      5795.   115937.    2220.0     727.
   8   1816.     4057.     5670.     809.      0.        0.         0.   115734.    2219.9     743.
   9    519.     3182.    10730.     733.      0.        0.      6826.   115937.    2220.0     745.
  10   -808.     2569.    54660.     570.      0.        0.     52899.   115937.    2220.0     688.
  11    749.     2219.     2500.     919.      0.        0.         0.   115469.    2219.8     697.
  12    401.     2244.      890.    1078.      0.        0.         0.   113714.    2219.2     702.

       4840.    35000.   213410.               0.        0.    161599.

1942
   1    509.     2160.      250.    1312.      0.        0.         0.   111295.    2218.3     707.
   2    696.     2307.       40.    2570.      0.        0.         0.   108332.    2217.3     712.
   3   1036.     2569.       10.    3174.      0.        0.         0.   104737.    2216.0     719.
   4    216.     2947.     3250.     882.      0.        0.         0.   104824.    2216.0     726.
   5   1733.     3035.      760.    1105.      0.        0.         0.   100816.    2214.5     741.
   6   1309.     3738.     3530.     871.      0.        0.         0.    99299.    2213.9     755.
   7   1590.     3973.      650.    1132.      0.        0.         0.    94386.    2212.0     770.
   8   1346.     4057.     7360.     777.      0.        0.         0.    96343.    2212.7     781.
   9    -78.     3182.     9400.     748.      0.        0.         0.   102639.    2215.2     778.
  10    331.     2569.    13950.     704.      0.        0.         0.   113689.    2219.2     771.
  11    961.     2219.      730.    1112.      0.        0.         0.   111239.    2218.3     780.
  12   -364.     2244.     1430.    1002.      0.        0.         0.   110789.    2218.1     780.

       9285.    35000.    41360.               0.        0.         0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND    INFLOW   INFLOW    SHORT-    D/S       SPILLS   -------END OF MONTH-------
      LOSS                         QUALITY   AGE       RELEASE            CONTENT     ELEV.   QUALITY
      *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*    *AC-FT*   *AC-FT*   *AC-FT*  *AC-FT*      *FT*   *MG/L*
1943
   1    584.     2160.     700.     1119.       0.        0.        0.    108745.   2217.4     786.
   2    958.     2307.      40.     2570.       0.        0.        0.    105520.   2216.2     794.
   3    940.     2569.     620.     1141.       0.        0.        0.    102631.   2215.2     803.
   4   1370.     2947.     970.     1064.       0.        0.        0.     99284.   2213.9     817.
   5    702.     3035.    3000.      893.       0.        0.        0.     98547.   2213.6     825.
   6   1447.     3738.    4190.      848.       0.        0.        0.     97552.   2213.2     838.
   7   1304.     3973.    3050.      891.       0.        0.        0.     95325.   2212.3     851.
   8   2777.     4057.       0.        0.       0.        0.        0.     88491.   2209.6     877.
   9   1405.     3182.       0.        0.       0.        0.        0.     83904.   2207.6     891.
  10   1223.     2569.       0.        0.       0.        0.        0.     80112.   2206.0     904.
  11    697.     2219.       0.        0.       0.        0.        0.     77196.   2204.7     912.
  12    -22.     2244.       0.        0.       0.        0.        0.     74974.   2203.7     912.

      13385.    35000.   12570.                 0.        0.        0.

1944
   1     65.     2160.       0.        0.       0.        0.        0.     72749.   2202.7     913.
   2    106.     2307.      20.     3083.       0.        0.        0.     70356.   2201.5     915.
   3    602.     2569.       0.        0.       0.        0.        0.     67185.   2200.1     923.
   4    965.     2947.      60.     2215.       0.        0.        0.     63333.   2198.1     938.
   5    807.     3035.    3510.      872.       0.        0.        0.     63001.   2197.9     946.
   6   1310.     3738.     990.     1061.       0.        0.        0.     58943.   2195.8     968.
   7    860.     2838.    6250.      797.       0.        0.        0.     61495.   2197.1     964.
   8   1247.     4057.     540.     1165.       0.        0.        0.     56731.   2194.7     987.
   9    600.     2273.     220.     1375.       0.        0.        0.     54078.   2193.2     999.
  10    568.     1835.     590.     1149.       0.        0.        0.     52265.   2192.1    1011.
  11    226.     1585.     300.     1276.       0.        0.        0.     50754.   2191.3    1017.
  12     17.     1602.     920.     1073.       0.        0.        0.     50055.   2190.9    1019.

       7373.    30946.   13400.                 0.        0.        0.

1945
   1    187.     1543.      60.     2215.       0.        0.        0.     48385.   2189.9    1024.
   2    216.     1648.      20.     3083.       0.        0.        0.     46541.   2188.7    1029.
   3    549.     1835.     570.     1156.       0.        0.        0.     44727.   2187.5    1043.
   4    610.     2105.     170.     1511.       0.        0.        0.     42182.   2185.8    1060.
   5    961.     2168.     230.     1353.       0.        0.        0.     39283.   2183.9    1087.
   6   1145.     2670.    3910.      857.       0.        0.        0.     39378.   2184.0    1095.
   7    769.     2838.   12140.      719.       0.        0.        0.     47911.   2189.6    1020.
   8    861.     2898.       0.        0.       0.        0.        0.     44152.   2187.1    1039.
   9    956.     2273.    2020.      950.       0.        0.        0.     42943.   2186.3    1057.
  10    215.     1835.   10990.      730.       0.        0.        0.     51883.   2191.9     994.
  11    553.     1585.      60.     2215.       0.        0.        0.     49805.   2190.7    1006.
  12    321.     1602.       0.        0.       0.        0.        0.     47882.   2189.6    1013.

       7343.    25000.   30170.                 0.        0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND

DATE  EVAP.    DEMAND    INFLOW   INFLOW   SHORT-    D/S      SPILLS    -------END OF MONTH-------
       LOSS                      QUALITY    AGE    RELEASE              CONTENT     ELEV.  QUALITY
     *AC-FT*  *AC-FT*   *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*   *AC-FT*    *AC-FT*     *FT*   *MG/L*
1946
  1   132.     1543.       0.       0.      0.       0.        0.      46207.    2188.5   1015.
  2   449.     1648.       0.       0.      0.       0.        0.      44110.    2187.1   1026.
  3   605.     1835.       0.       0.      0.       0.        0.      41670.    2185.5   1040.
  4   863.     2105.      10.    3174.      0.       0.        0.      38712.    2183.5   1063.
  5   745.     2168.    1100.    1044.      0.       0.        0.      36899.    2182.3   1083.
  6   966.     2670.    2680.     909.      0.       0.        0.      35943.    2181.7   1099.
  7  1211.     2838.     330.    1258.      0.       0.        0.      32224.    2179.0   1140.
  8   953.     2898.    4180.     849.      0.       0.        0.      32553.    2179.3   1136.
  9   440.     2273.    4840.     829.      0.       0.        0.      34680.    2180.8   1109.
 10   195.     1835.   13740.     706.      0.       0.        0.      46390.    2188.6    996.
 11   419.     1585.     320.    1264.      0.       0.        0.      44706.    2187.5   1007.
 12   224.     1602.    2470.     921.      0.       0.        0.      45350.    2187.9   1007.

     7202.    25000.   29670.               0.       0.        0.
1947
  1    80.     1543.     240.    1332.      0.       0.        0.      43967.    2187.0   1011.
  2   357.     1648.       0.       0.      0.       0.        0.      41962.    2185.7   1019.
  3   211.     1835.      10.    3174.      0.       0.        0.      39926.    2184.3   1025.
  4   522.     2105.       0.       0.      0.       0.        0.      37299.    2182.6   1039.
  5   171.     2168.   47310.     583.      0.       0.        0.      82270.    2206.9    782.
  6  1534.     3738.    2700.     908.      0.       0.        0.      79698.    2205.8    801.
  7  1758.     3973.    1060.    1050.      0.       0.        0.      75027.    2203.7    823.
  8  1793.     4057.     100.    1836.      0.       0.        0.      69277.    2201.0    845.
  9  2210.     3182.    1130.    1039.      0.       0.        0.      65015.    2198.9    876.
 10  1184.     2569.     540.    1165.      0.       0.        0.      61802.    2197.3    895.
 11   422.     2219.      30.    2856.      0.       0.        0.      59191.    2196.0    902.
 12   228.     1602.    2350.     928.      0.       0.        0.      59711.    2196.2    907.

    10470.    30639.   55470.               0.       0.        0.
1948
  1   245.     1543.      10.    3174.      0.       0.        0.      57933.    2195.3    911.
  2   208.     1648.    4380.     842.      0.       0.        0.      60457.    2196.6    909.
  3   773.     2569.     290.    1283.      0.       0.        0.      57405.    2195.0    923.
  4  1041.     2105.       0.       0.      0.       0.        0.      54259.    2193.3    940.
  5   802.     2168.    1560.     989.      0.       0.        0.      52849.    2192.5    955.
  6  1061.     2670.   10120.     740.      0.       0.        0.      59238.    2196.0    936.
  7  1420.     2838.   15350.     694.      0.       0.        0.      70330.    2201.5    903.
  8  1678.     4057.    2300.     931.      0.       0.        0.      66895.    2199.9    926.
  9  1378.     3182.      30.    2856.      0.       0.        0.      62365.    2197.6    946.
 10   776.     2569.    2040.     948.      0.       0.        0.      61060.    2196.9    958.
 11   795.     2219.    4220.     847.      0.       0.        0.      62266.    2197.5    963.
 12   635.     2244.      10.    3174.      0.       0.        0.      59397.    2196.1    973.

    10812.    29812.   40310.               0.       0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.    DEMAND    INFLOW    INFLOW   SHORT-    D/S      SPILLS   -------END OF MONTH-------
      LOSS                         QUALITY   AGE    RELEASE             CONTENT    ELEV.   QUALITY
     *AC-FT*  *AC-FT*   *AC-FT*   *MG/L*  *AC-FT*  *AC-FT*   *AC-FT*   *AC-FT*    *FT*    *MG/L*
1949
  1   -226.    1543.       0.        0.      0.       0.        0.     58080.   2195.4     970.
  2    315.    1648.       0.        0.      0.       0.        0.     56117.   2194.3     975.
  3    542.    1835.       0.        0.      0.       0.        0.     53740.   2193.0     985.
  4    425.    2105.    1290.     1018.      0.       0.        0.     52500.   2192.3     993.
  5     37.    2168.    9420.      748.      0.       0.        0.     59715.   2196.2     956.
  6    657.    2670.   12340.      717.      0.       0.        0.     68728.   2200.8     923.
  7   1116.    3973.     120.     1717.      0.       0.        0.     63759.   2198.3     940.
  8   1275.    4057.     270.     1297.      0.       0.        0.     58697.   2195.7     961.
  9    665.    2273.   10450.      736.      0.       0.        0.     66209.   2199.6     936.
 10    442.    2569.    1220.     1027.      0.       0.        0.     64418.   2198.6     944.
 11    923.    2219.     140.     1623.      0.       0.        0.     61416.   2197.1     959.
 12    439.    2244.      10.     3174.      0.       0.        0.     58743.   2195.7     967.

      6610.   29304.   35260.                0.       0.        0.

1950
  1    503.    1543.      10.     3174.      0.       0.        0.     56707.   2194.7     975.
  2    438.    1648.     130.     1668.      0.       0.        0.     54751.   2193.5     985.
  3    783.    1835.       0.        0.      0.       0.        0.     52133.   2192.1     999.
  4    670.    2105.    3650.      867.      0.       0.        0.     53008.   2192.6    1003.
  5    291.    2168.   19950.      666.      0.       0.        0.     70499.   2201.6     913.
  6    895.    3738.    1790.      968.      0.       0.        0.     67656.   2200.3     926.
  7    268.    3973.    5370.      816.      0.       0.        0.     68785.   2200.8     921.
  8   1224.    4057.    1260.     1022.      0.       0.        0.     64764.   2198.8     940.
  9    386.    3182.   19770.      667.      0.       0.        0.     80966.   2206.4     879.
 10   1556.    2569.     360.     1241.      0.       0.        0.     77201.   2204.7     898.
 11   1162.    2219.      10.     3174.      0.       0.        0.     73830.   2203.2     912.
 12    705.    2244.      10.     3174.      0.       0.        0.     70891.   2201.8     921.

      8881.   31281.   52310.                0.       0.        0.

1951
  1    480.    2160.      10.     3174.      0.       0.        0.     68261.   2200.6     928.
  2    368.    2307.       0.        0.      0.       0.        0.     65586.   2199.2     933.
  3    754.    2569.       0.        0.      0.       0.        0.     62263.   2197.5     944.
  4    938.    2947.      20.     3083.      0.       0.        0.     58398.   2195.6     960.
  5    713.    2168.    2800.      903.      0.       0.        0.     58317.   2195.5     969.
  6   1216.    2670.    9650.      745.      0.       0.        0.     64081.   2198.5     954.
  7   1475.    3973.     790.     1099.      0.       0.        0.     59423.   2196.1     978.
  8    954.    2898.    5170.      821.      0.       0.        0.     60741.   2196.8     980.
  9   1372.    3182.     210.     1398.      0.       0.        0.     56397.   2194.5    1005.
 10    905.    1835.      10.     3174.      0.       0.        0.     53667.   2192.9    1022.
 11    582.    1585.       0.        0.      0.       0.        0.     51500.   2191.7    1033.
 12    568.    1602.       0.        0.      0.       0.        0.     49330.   2190.5    1045.

     10325.   29896.   18660.                0.       0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND


DATE  EVAP.     DEMAND     INFLOW    INFLOW    SHORT-     D/S       SPILLS    -------END OF MONTH-------
      LOSS                           QUALITY    AGE     RELEASE               CONTENT     ELEV.   QUALITY
     *AC-FT*   *AC-FT*    *AC-FT*   *MG/L*   *AC-FT*   *AC-FT*    *AC-FT*    *AC-FT*     *FT*    *MG/L*
1952
   1    336.     1543.        0.        0.        0.        0.        0.     47451.    2189.3    1052.
   2    571.     1648.        0.        0.        0.        0.        0.     45232.    2187.8    1065.
   3    835.     1835.        0.        0.        0.        0.        0.     42562.    2186.1    1086.
   4    394.     2105.        0.        0.        0.        0.        0.     40063.    2184.4    1096.
   5    649.     2168.     4940.      827.        0.        0.        0.     42186.    2185.8    1082.
   6   1459.     2670.      170.     1511.        0.        0.        0.     38227.    2183.2    1124.
   7    884.     2838.     2300.      931.        0.        0.        0.     36805.    2182.2    1138.
   8   1377.     2898.      340.     1252.        0.        0.        0.     32870.    2179.5    1185.
   9    960.     2273.      170.     1511.        0.        0.        0.     29807.    2177.0    1223.
  10    972.     1468.        0.        0.        0.        0.        0.     27367.    2174.9    1265.
  11    489.     1268.       90.     1909.        0.        0.        0.     25700.    2173.5    1291.
  12    270.     1284.       20.     3083.        0.        0.        0.     24166.    2172.2    1307.

       9196.    23998.     8030.                  0.        0.        0.

1953
   1    381.     1234.        0.        0.        0.        0.        0.     22551.    2170.8    1328.
   2    284.     1318.       10.     3174.        0.        0.        0.     20959.    2169.3    1346.
   3    361.     1468.      160.     1545.        0.        0.        0.     19290.    2167.5    1372.
   4    532.     1684.      540.     1165.        0.        0.        0.     17614.    2165.6    1405.
   5    581.     1734.     5140.      822.        0.        0.        0.     20439.    2168.8    1303.
   6    993.     2136.      670.     1127.        0.        0.        0.     17980.    2166.0    1365.
   7    773.     2270.     2810.      902.        0.        0.        0.     17747.    2165.8    1352.
   8    638.     2318.     4540.      838.        0.        0.        0.     19331.    2167.5    1280.
   9    787.     1818.       60.     2215.        0.        0.        0.     16786.    2164.7    1340.
  10    178.     1468.    22670.      653.        0.        0.        0.     37810.    2182.9     942.
  11    398.     1585.     1020.     1056.        0.        0.        0.     36847.    2182.3     955.
  12    430.     1602.       70.     2093.        0.        0.        0.     34885.    2181.0     969.

       6336.    20635.    37690.                  0.        0.        0.

1954
   1    429.     1543.       20.     3083.        0.        0.        0.     32933.    2179.6     982.
   2    543.     1648.       10.     3174.        0.        0.        0.     30752.    2177.8    1000.
   3    655.     1835.        0.        0.        0.        0.        0.     28262.    2175.7    1022.
   4    450.     1684.    22990.      652.        0.        0.        0.     49118.    2190.4     861.
   5     58.     2168.    25360.      642.        0.        0.        0.     72252.    2202.4     786.
   6   1873.     3738.     2030.      949.        0.        0.        0.     68671.    2200.8     811.
   7   2058.     3973.        0.        0.        0.        0.        0.     62640.    2197.7     837.
   8   1486.     4057.        0.        0.        0.        0.        0.     57097.    2194.9     858.
   9   1685.     2273.        0.        0.        0.        0.        0.     53139.    2192.6     885.
  10   1030.     1835.        0.        0.        0.        0.        0.     50274.    2191.0     903.
  11    797.     1585.      260.     1305.        0.        0.        0.     48152.    2189.8     919.
  12    561.     1602.        0.        0.        0.        0.        0.     45989.    2188.3     930.

      11625.    27941.    50670.                  0.        0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND


DATE  EVAP.     DEMAND    INFLOW   INFLOW   SHORT-    D/S       SPILLS   -------END OF MONTH-------
      LOSS                         QUALITY  AGE      RELEASE             CONTENT     ELEV.  QUALITY
     *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*   *AC-FT*  *AC-FT*    *AC-FT*   *AC-FT*      *FT*  *MG/L*
1955
  1    288.     1543.       10.    3174.      0.       0.         0.     44168.    2187.1    937.
  2    331.     1648.     1620.     983.      0.       0.         0.     43809.    2186.9    945.
  3   1021.     1835.     6970.     784.      0.       0.         0.     47923.    2189.6    942.
  4    981.     2105.      160.    1545.      0.       0.         0.     44997.    2187.7    964.
  5    592.     2168.    46440.     584.      0.       0.         0.     88677.    2209.7    774.
  6   1273.     3738.    13480.     708.      0.       0.         0.     97146.    2213.0    775.
  7   1528.     3973.    24380.     646.      0.       0.        88.    115937.    2220.0    758.
  8   2158.     4057.      910.    1075.      0.       0.         0.    110632.    2218.1    775.
  9   1164.     3182.    70500.     548.      0.       0.     60849.    115937.    2220.0    692.
 10    952.     2569.    31510.     620.      0.       0.     27989.    115937.    2220.0    683.
 11   1431.     2219.      940.    1069.      0.       0.         0.    113227.    2219.0    695.
 12   1322.     2244.      460.    1195.      0.       0.         0.    110121.    2217.9    705.

      13041.    31281.   197380.              0.       0.     88926.

1956
  1    857.     2160.      280.    1290.      0.       0.         0.    107384.    2216.9    713.
  2    707.     2307.      100.    1836.      0.       0.         0.    104470.    2215.9    718.
  3   1595.     2569.       20.    3083.      0.       0.         0.    100326.    2214.3    730.
  4   1834.     2947.       10.    3174.      0.       0.         0.     95555.    2212.4    744.
  5   1325.     3035.     5010.     825.      0.       0.         0.     96205.    2212.7    758.
  6   1609.     3738.      690.    1122.      0.       0.         0.     91548.    2210.8    774.
  7   2255.     3973.      510.    1176.      0.       0.         0.     85830.    2208.5    796.
  8   2462.     4057.      620.    1141.      0.       0.         0.     79931.    2205.9    823.
  9   2267.     3182.        0.       0.      0.       0.         0.     74482.    2203.5    847.
 10   1372.     2569.      320.    1264.      0.       0.         0.     70861.    2201.8    865.
 11    730.     2219.       40.    2570.      0.       0.         0.     67952.    2200.4    875.
 12    813.     2244.       20.    3083.      0.       0.         0.     64915.    2198.9    887.

      17826.    35000.     7620.              0.       0.         0.

1957
  1    475.     2160.        0.       0.      0.       0.         0.     62280.    2197.5    894.
  2    238.     2307.     5670.     809.      0.       0.         0.     65405.    2199.1    890.
  3    792.     2569.      110.    1773.      0.       0.         0.     62154.    2197.5    902.
  4    250.     2947.    17620.     679.      0.       0.         0.     76577.    2204.5    855.
  5   -230.     3035.    43810.     590.      0.       0.      1645.    115937.    2220.0    756.
  6   1182.     3738.    32360.     618.      0.       0.     27440.    115937.    2220.0    735.
  7   2235.     3973.     3920.     857.      0.       0.         0.    113649.    2219.2    753.
  8   2442.     4057.     1770.     969.      0.       0.         0.    108920.    2217.5    773.
  9   1732.     3182.     2810.     902.      0.       0.         0.    106816.    2216.7    789.
 10    276.     2569.     6760.     788.      0.       0.         0.    110731.    2218.1    791.
 11    141.     2219.     5490.     813.      0.       0.         0.    113861.    2219.2    793.
 12    960.     2244.      150.    1582.      0.       0.         0.    110807.    2218.1    801.

      10493.    35000.   120470.              0.       0.     29085.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND    INFLOW    INFLOW   SHORT-    D/S       SPILLS    -------END OF MONTH-------
      LOSS                          QUALITY  AGE       RELEASE             CONTENT    ELEV.    QUALITY
      *AC-FT*   *AC-FT*   *AC-FT*   *MG/L*   *AC-FT*   *AC-FT*   *AC-FT*   *AC-FT*     *FT*    *MG/L*
1958
  1      83.     2160.       60.    2215.       0.        0.        0.    108624.   2217.4     802.
  2     247.     2307.       80.    1993.       0.        0.        0.    106150.   2216.5     805.
  3    -135.     2569.      210.    1398.       0.        0.        0.    103926.   2215.7     805.
  4     321.     2947.     2560.     916.       0.        0.        0.    103218.   2215.4     810.
  5     416.     3035.    15300.     694.       0.        0.        0.    115067.   2219.7     798.
  6    1739.     3738.     3160.     886.       0.        0.        0.    112750.   2218.8     812.
  7    1976.     3973.      270.    1297.       0.        0.        0.    107071.   2216.8     828.
  8    2182.     4057.     1030.    1054.       0.        0.        0.    101862.   2214.9     848.
  9    1323.     3182.     4100.     851.       0.        0.        0.    101457.   2214.7     859.
 10     733.     2569.      430.    1207.       0.        0.        0.     98585.   2213.6     867.
 11     695.     2219.      530.    1169.       0.        0.        0.     96201.   2212.7     875.
 12     531.     2244.       30.    2856.       0.        0.        0.     93456.   2211.6     880.

      10111.    35000.    27760.               0.        0.        0.

1959
  1     422.     2160.       10.    3174.       0.        0.        0.     90884.   2210.6     884.
  2     488.     2307.        0.       0.       0.        0.        0.     88089.   2209.4     889.
  3    1143.     2569.        0.       0.       0.        0.        0.     84377.   2207.8     901.
  4     695.     2947.      170.    1511.       0.        0.        0.     80905.   2206.4     910.
  5     523.     3035.     2240.     935.       0.        0.        0.     79587.   2205.8     916.
  6    -149.     3738.    28180.     631.       0.        0.        0.    104178.   2215.7     839.
  7     919.     3973.    31380.     621.       0.        0.    14729.    115937.   2220.0     797.
  8    2208.     4057.     4310.     845.       0.        0.        0.    113982.   2219.3     814.
  9    2189.     3182.        0.       0.       0.        0.        0.    108611.   2217.4     830.
 10     698.     2569.     6820.     787.       0.        0.        0.    112164.   2218.6     832.
 11    1118.     2219.      260.    1305.       0.        0.        0.    109087.   2217.5     842.
 12     777.     2244.     3760.     863.       0.        0.        0.    109826.   2217.8     848.

      11031.    35000.    77130.               0.        0.    14729.

1960
  1     138.     2160.      380.    1231.       0.        0.        0.    107908.   2217.1     851.
  2     246.     2307.      240.    1332.       0.        0.        0.    105595.   2216.3     854.
  3     618.     2569.       70.    2093.       0.        0.        0.    102478.   2215.1     860.
  4    1207.     2947.        0.       0.       0.        0.        0.     98324.   2213.5     870.
  5    1180.     3035.     1310.    1016.       0.        0.        0.     95419.   2212.4     883.
  6     905.     3738.     1590.     986.       0.        0.        0.     92366.   2211.2     893.
  7      27.     3973.    32380.     618.       0.        0.     4809.    115937.   2220.0     821.
  8    2465.     4057.      460.    1195.       0.        0.        0.    109875.   2217.8     841.
  9    1591.     3182.       20.    3083.       0.        0.        0.    105122.   2216.1     854.
 10       0.     2569.    60090.     561.       0.        0.    46706.    115937.   2220.0     749.
 11    1063.     2219.     1830.     964.       0.        0.        0.    114485.   2219.5     759.
 12      85.     2244.     1020.    1056.       0.        0.        0.    113176.   2219.0     762.

       9525.    35000.    99390.               0.        0.    51515.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND


DATE  EVAP.     DEMAND     INFLOW    INFLOW    SHORT-     D/S       SPILLS     -------END OF MONTH-------
      LOSS                           QUALITY    AGE     RELEASE                CONTENT     ELEV.   QUALITY
     *AC-FT*    *AC-FT*    *AC-FT*   *MG/L*   *AC-FT*   *AC-FT*    *AC-FT*     *AC-FT*      *FT*   *MG/L*
1961
   1    226.     2160.      1140.     1038.       0.        0.         0.      111930.    2218.6     767.
   2     28.     2307.      1200.     1030.       0.        0.         0.      110795.    2218.1     770.
   3    611.     2569.       810.     1094.       0.        0.         0.      108425.    2217.3     776.
   4   1389.     2947.       180.     1480.       0.        0.         0.      104269.    2215.8     788.
   5   1089.     3035.        50.     2368.       0.        0.         0.      100195.    2214.2     797.
   6    716.     3738.     26460.      637.       0.        0.      6264.      115937.    2220.0     769.
   7    404.     3973.     31050.      622.       0.        0.     26673.      115937.    2220.0     743.
   8   1455.     4057.      1780.      969.       0.        0.         0.      112205.    2218.7     756.
   9   1811.     3182.       600.     1146.       0.        0.         0.      107812.    2217.1     771.
  10   1413.     2569.       280.     1290.       0.        0.         0.      104110.    2215.7     782.
  11    402.     2219.      2110.      943.       0.        0.         0.      103599.    2215.5     789.
  12    425.     2244.        30.     2856.       0.        0.         0.      100960.    2214.5     793.

       9969.    35000.     65690.                 0.        0.     32937.

1962
   1    314.     2160.        20.     3083.       0.        0.         0.       98506.    2213.6     795.
   2    744.     2307.        10.     3174.       0.        0.         0.       95465.    2212.4     802.
   3    829.     2569.         0.        0.       0.        0.         0.       92067.    2211.0     809.
   4    809.     2947.        10.     3174.       0.        0.         0.       88321.    2209.5     816.
   5   1900.     3035.         0.        0.       0.        0.         0.       83386.    2207.4     835.
   6   1286.     3738.     10680.      734.       0.        0.         0.       89042.    2209.8     835.
   7   1039.     3973.      3490.      873.       0.        0.         0.       87520.    2209.2     846.
   8   1449.     4057.      2210.      937.       0.        0.         0.       84224.    2207.8     862.
   9    367.     3182.     35350.      609.       0.        0.        88.      115937.    2220.0     789.
  10    886.     2569.       480.     1187.       0.        0.         0.      112962.    2218.9     797.
  11    731.     2219.        20.     3083.       0.        0.         0.      110032.    2217.9     802.
  12    415.     2244.       340.     1252.       0.        0.         0.      107713.    2217.0     807.

      10769.    35000.     52610.                 0.        0.        88.

1963
   1    491.     2160.        40.     2570.       0.        0.         0.      105102.    2216.1     811.
   2    402.     2307.        20.     3083.       0.        0.         0.      102413.    2215.1     815.
   3    947.     2569.        80.     1993.       0.        0.         0.       98977.    2213.8     824.
   4   1257.     2947.        60.     2215.       0.        0.         0.       94833.    2212.1     835.
   5    -26.     3035.     12740.      714.       0.        0.         0.      104564.    2215.9     820.
   6    474.     3738.     39630.      599.       0.        0.     24045.      115937.    2220.0     765.
   7   2069.     3973.       100.     1836.       0.        0.         0.      109995.    2217.9     780.
   8   1673.     4057.       560.     1159.       0.        0.         0.      104825.    2216.0     794.
   9   1361.     3182.       900.     1077.       0.        0.         0.      101182.    2214.6     807.
  10   1493.     2569.      1820.      965.       0.        0.         0.       98940.    2213.8     822.
  11    854.     2219.      1700.      976.       0.        0.         0.       97567.    2213.2     832.
  12    536.     2244.        10.     3174.       0.        0.         0.       94797.    2212.1     836.

      11531.    35000.     57660.                 0.        0.     24045.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.    DEMAND    INFLOW   INFLOW   SHORT-    D/S      SPILLS   -------END OF MONTH-------
      LOSS                       QUALITY    AGE    RELEASE             CONTENT     ELEV.  QUALITY
    *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*   *AC-FT*  *AC-FT*   *AC-FT*   *AC-FT*      *FT*  *MG/L*

1964
   1    502.     2160.      480.    1187.       0.       0.        0.    92615.   2211.3     843.
   2    370.     2307.       20.    3083.       0.       0.        0.    89958.   2210.2     847.
   3   1087.     2569.        0.       0.       0.       0.        0.    86302.   2208.7     857.
   4   1523.     2947.        0.       0.       0.       0.        0.    81832.   2206.8     873.
   5   1190.     3035.     2370.     927.       0.       0.        0.    79977.   2206.0     887.
   6   1105.     3738.     2920.     897.       0.       0.        0.    78054.   2205.1     900.
   7   1728.     3973.        0.       0.       0.       0.        0.    72353.   2202.5     921.
   8   1287.     4057.     2120.     943.       0.       0.        0.    69129.   2201.0     938.
   9    844.     3182.     1570.     988.       0.       0.        0.    66673.   2199.8     951.
  10   1101.     2569.        0.       0.       0.       0.        0.    63003.   2197.9     967.
  11    640.     2219.      210.    1398.       0.       0.        0.    60354.   2196.6     978.
  12    379.     2244.      490.    1183.       0.       0.        0.    58221.   2195.5     986.

      11756.    35000.    10180.                0.       0.        0.

1965
   1    648.     1543.        0.       0.       0.       0.        0.    56030.   2194.3     998.
   2    542.     1648.        0.       0.       0.       0.        0.    53840.   2193.0    1007.
   3    529.     1835.      100.    1836.       0.       0.        0.    51576.   2191.7    1019.
   4    654.     2105.      640.    1135.       0.       0.        0.    49457.   2190.5    1034.
   5    579.     2168.    26260.     638.       0.       0.        0.    72970.   2202.8     902.
   6   1162.     3738.      810.    1094.       0.       0.        0.    68880.   2200.9     919.
   7   1460.     3973.       30.    2856.       0.       0.        0.    63477.   2198.2     940.
   8    940.     4057.    12110.     720.       0.       0.        0.    70590.   2201.7     915.
   9    709.     3182.     1570.     988.       0.       0.        0.    68269.   2200.6     926.
  10   1159.     2569.      210.    1398.       0.       0.        0.    64751.   2198.8     944.
  11    749.     2219.       10.    3174.       0.       0.        0.    61793.   2197.3     956.
  12    366.     2244.      940.    1069.       0.       0.        0.    60123.   2196.4     963.

       9497.    31281.    42680.                0.       0.        0.

1966
   1    170.     2160.       30.    2856.       0.       0.        0.    57823.   2195.3     967.
   2    148.     1648.       10.    3174.       0.       0.        0.    56037.   2194.3     970.
   3    668.     1835.       20.    3083.       0.       0.        0.    53554.   2192.9     982.
   4    281.     2105.    11560.     725.       0.       0.        0.    62728.   2197.8     940.
   5    487.     3035.     2100.     944.       0.       0.        0.    61306.   2197.0     947.
   6    946.     3738.      600.    1146.       0.       0.        0.    57222.   2194.9     965.
   7    872.     2838.       30.    2856.       0.       0.        0.    53542.   2192.9     981.
   8    431.     2898.     4800.     831.       0.       0.        0.    55013.   2193.7     976.
   9    412.     2273.      720.    1114.       0.       0.        0.    53048.   2192.6     985.
  10    890.     1835.       10.    3174.       0.       0.        0.    50333.   2191.0    1002.
  11    662.     1585.       10.    3174.       0.       0.        0.    48096.   2189.7    1016.
  12    363.     1602.       10.    3174.       0.       0.        0.    46141.   2188.4    1025.

       6330.    27552.    19900.                0.       0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.    DEMAND    INFLOW    INFLOW   SHORT-    D/S       SPILLS   -------END OF MONTH-------
      LOSS                         QUALITY   AGE    RELEASE              CONTENT     ELEV.  QUALITY
     *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*    *AC-FT*   *AC-FT*      *FT*  *MG/L*

1967
   1    209.     1543.       0.       0.        0.       0.         0.    44389.   2187.3    1029.
   2    313.     1648.      10.    3174.        0.       0.         0.    42438.   2186.0    1037.
   3    392.     1835.    4440.     841.        0.       0.         0.    44651.   2187.5    1027.
   4    598.     2105.    1150.    1036.        0.       0.         0.    43098.   2186.4    1041.
   5    583.     2168.     920.    1073.        0.       0.         0.    41267.   2185.2    1056.
   6   1189.     2670.   49000.     579.        0.       0.         0.    86408.   2208.7     804.
   7   1068.     3973.   23340.     650.        0.       0.         0.   104707.   2215.9     778.
   8   1538.     4057.      60.    2215.        0.       0.         0.    99172.   2213.8     791.
   9    415.     3182.    2680.     909.        0.       0.         0.    98255.   2213.5     798.
  10   1616.     2569.    1560.     989.        0.       0.         0.    95630.   2212.4     814.
  11    479.     2219.      10.    3174.        0.       0.         0.    92942.   2211.4     818.
  12    347.     2244.      10.    3174.        0.       0.         0.    90361.   2210.4     822.

       8747.    30213.   83180.                 0.       0.         0.

1968
   1     98.     2160.     700.    1119.        0.       0.         0.    88803.   2209.7     825.
   2    121.     2307.    1300.    1017.        0.       0.         0.    87675.   2209.3     829.
   3   -145.     2569.    2750.     905.        0.       0.         0.    88001.   2209.4     830.
   4    596.     2947.     370.    1236.        0.       0.         0.    84828.   2208.0     837.
   5    770.     3035.    1070.    1048.        0.       0.         0.    82093.   2206.9     848.
   6    911.     3738.    1170.    1034.        0.       0.         0.    78614.   2205.4     860.
   7    931.     3973.    1350.    1011.        0.       0.         0.    75060.   2203.7     873.
   8   1035.     4057.    1740.     972.        0.       0.         0.    71708.   2202.2     888.
   9   1003.     3182.       0.       0.        0.       0.         0.    67523.   2200.2     900.
  10    668.     2569.     330.    1258.        0.       0.         0.    64616.   2198.7     911.
  11    201.     2219.    3710.     864.        0.       0.         0.    65906.   2199.4     911.
  12    300.     2244.      60.    2215.        0.       0.         0.    63422.   2198.1     917.

       6489.    35000.   14550.                 0.       0.         0.

1969
   1    293.     2160.       0.       0.        0.       0.         0.    60969.   2196.9     921.
   2    133.     2307.      10.    3174.        0.       0.         0.    58539.   2195.6     924.
   3    132.     1835.    2700.     908.        0.       0.         0.    59272.   2196.0     925.
   4    549.     2105.    2550.     916.        0.       0.         0.    59168.   2195.9     933.
   5    132.     2168.   35450.     609.        0.       0.         0.    92318.   2211.1     811.
   6   1325.     3738.    1160.    1035.        0.       0.         0.    88415.   2209.6     826.
   7   1636.     3973.      10.    3174.        0.       0.         0.    82816.   2207.2     842.
   8   1404.     4057.    3290.     881.        0.       0.         0.    80645.   2206.2     858.
   9    505.     3182.   17510.     680.        0.       0.         0.    94468.   2212.0     830.
  10   -233.     2569.    9480.     747.        0.       0.         0.   101612.   2214.8     821.
  11    476.     2219.    2450.     922.        0.       0.         0.   101367.   2214.7     827.
  12    445.     2244.      50.    2368.        0.       0.         0.    98728.   2213.7     831.

       6797.    32557.   74660.                 0.       0.         0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND


DATE  EVAP.      DEMAND      INFLOW    INFLOW    SHORT-     D/S        SPILLS     -------END OF MONTH-------
      LOSS                             QUALITY   AGE      RELEASE                CONTENT       ELEV.  QUALITY
    *AC-FT*     *AC-FT*     *AC-FT*   *MG/L*   *AC-FT*   *AC-FT*     *AC-FT*    *AC-FT*        *FT*   *MG/L*

1970
   1    438.       2160.        20.      3083.        0.        0.         0.    96150.     2212.7      836.
   2    480.       2307.        10.      3174.        0.        0.         0.    93373.     2211.6      840.
   3    204.       2569.      8110.       766.        0.        0.         0.    98710.     2213.7      836.
   4   1230.       2947.       240.      1332.        0.        0.         0.    94773.     2212.1      848.
   5   1442.       3035.      4670.       834.        0.        0.         0.    94966.     2212.2      860.
   6   1471.       3738.       690.      1122.        0.        0.         0.    90447.     2210.4      875.
   7   1994.       3973.         0.         0.        0.        0.         0.    84480.     2207.9      895.
   8   1314.       4057.       320.      1264.        0.        0.         0.    79429.     2205.7      911.
   9    540.       3182.      2260.       933.        0.        0.         0.    77967.     2205.1      918.
  10    774.       2569.       400.      1221.        0.        0.         0.    75024.     2203.7      929.
  11    949.       2219.         0.         0.        0.        0.         0.    71856.     2202.2      941.
  12    799.       2244.         0.         0.        0.        0.         0.    68813.     2200.8      952.

      11635.      35000.     16720.                   0.        0.         0.

1971
   1    574.       2160.         0.         0.        0.        0.         0.    66079.     2199.5      960.
   2    559.       2307.         0.         0.        0.        0.         0.    63213.     2198.0      968.
   3    968.       2569.         0.         0.        0.        0.         0.    59676.     2196.2      984.
   4    936.       2105.        10.      3174.        0.        0.         0.    56645.     2194.6     1000.
   5   1179.       2168.      3360.       878.        0.        0.         0.    56658.     2194.6     1013.
   6   1052.       2670.       770.      1103.        0.        0.         0.    53706.     2193.0     1034.
   7   1333.       2838.      1130.      1039.        0.        0.         0.    50665.     2191.2     1060.
   8    411.       2898.      9530.       747.        0.        0.         0.    56886.     2194.8     1017.
   9    608.       2273.     21370.       659.        0.        0.         0.    75375.     2203.9      925.
  10    456.       2569.      1060.      1050.        0.        0.         0.    73410.     2203.0      932.
  11    491.       2219.        40.      2570.        0.        0.         0.    70740.     2201.7      939.
  12    313.       2244.        80.      1993.        0.        0.         0.    68263.     2200.6      945.

       8880.      29020.     37350.                   0.        0.         0.

1972
   1    531.       2160.        20.      3083.        0.        0.         0.    65592.     2199.2      953.
   2    497.       2307.        10.      3174.        0.        0.         0.    62798.     2197.8      961.
   3    829.       2569.        10.      3174.        0.        0.         0.    59410.     2196.1      974.
   4    914.       2105.         0.         0.        0.        0.         0.    56391.     2194.5      990.
   5    566.       2168.      1650.       980.        0.        0.         0.    55307.     2193.9      999.
   6    750.       2670.      4860.       829.        0.        0.         0.    56747.     2194.7      998.
   7    886.       2838.      3990.       855.        0.        0.         0.    57013.     2194.8     1003.
   8    636.       2898.     40550.       597.        0.        0.         0.    94029.     2211.8      837.
   9    653.       3182.      3410.       876.        0.        0.         0.    93604.     2211.7      844.
  10    572.       2569.       710.      1117.        0.        0.         0.    91173.     2210.7      852.
  11    391.       2219.       100.      1836.        0.        0.         0.    88663.     2209.7      856.
  12    408.       2244.        50.      2368.        0.        0.         0.    86061.     2208.6      861.

       7633.      29929.     55360.                   0.        0.         0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND     INFLOW   INFLOW   SHORT-    D/S      SPILLS   -------END OF MONTH-------
       LOSS                         QUALITY   AGE    RELEASE            CONTENT     ELEV.  QUALITY
     *AC-FT*   *AC-FT*    *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*   *AC-FT*  *AC-FT*     *FT*   *MG/L*

1973
   1    165.     2160.      740.    1110.       0.       0.        0.   84476.   2207.9     865.
   2    141.     2307.     1730.     973.       0.       0.        0.   83758.   2207.6     869.
   3    442.     2569.     1950.     955.       0.       0.        0.   82697.   2207.1     875.
   4    595.     2947.      110.    1773.       0.       0.        0.   79265.   2205.7     883.
   5   1377.     3035.      120.    1717.       0.       0.        0.   74973.   2203.7     900.
   6   1647.     3738.      240.    1332.       0.       0.        0.   69828.   2201.3     922.
   7   1016.     3973.     2680.     909.       0.       0.        0.   67519.   2200.2     935.
   8   1462.     4057.      270.    1297.       0.       0.        0.   62270.   2197.5     958.
   9    735.     3182.     2150.     941.       0.       0.        0.   60503.   2196.6     969.
  10    866.     2569.       10.    3174.       0.       0.        0.   57078.   2194.9     983.
  11    749.     1585.        0.       0.       0.       0.        0.   54744.   2193.5     997.
  12    748.     1602.        0.       0.       0.       0.        0.   52394.   2192.2    1011.

       9943.    33724.    10000.                0.       0.        0.

1974
   1    435.     1543.        0.       0.       0.       0.        0.   50416.   2191.1    1019.
   2    628.     1648.        0.       0.       0.       0.        0.   48140.   2189.8    1032.
   3    625.     1835.        0.       0.       0.       0.        0.   45680.   2188.1    1046.
   4    950.     2105.      210.    1398.       0.       0.        0.   42835.   2186.3    1070.
   5   1030.     2168.      140.    1623.       0.       0.        0.   39777.   2184.2    1099.
   6   1091.     2670.       40.    2570.       0.       0.        0.   36056.   2181.8    1133.
   7   1198.     2838.      140.    1623.       0.       0.        0.   32160.   2178.9    1175.
   8    420.     2898.      990.    1061.       0.       0.        0.   29832.   2177.0    1188.
   9    218.     1818.     5220.     820.       0.       0.        0.   33016.   2179.7    1139.
  10    186.     1835.     2740.     906.       0.       0.        0.   33735.   2180.2    1126.
  11    303.     1585.      140.    1623.       0.       0.        0.   31987.   2178.8    1139.
  12    242.     1602.       10.    3174.       0.       0.        0.   30153.   2177.2    1148.

       7326.    24545.     9630.                0.       0.        0.

1975
   1    271.     1543.       10.    3174.       0.       0.        0.   28349.   2175.7    1160.
   2    107.     1318.       40.    2570.       0.       0.        0.   26964.   2174.6    1166.
   3    461.     1468.        0.       0.       0.       0.        0.   25035.   2172.9    1187.
   4    530.     1684.       30.    2856.       0.       0.        0.   22851.   2171.1    1215.
   5    485.     1734.      360.    1241.       0.       0.        0.   20992.   2169.4    1243.
   6    630.     2136.     1950.     955.       0.       0.        0.   20176.   2168.5    1253.
   7    358.     2270.     6040.     801.       0.       0.        0.   23588.   2171.7    1161.
   8    629.     2318.     5390.     816.       0.       0.        0.   26031.   2173.8    1119.
   9    331.     1818.     8160.     765.       0.       0.        0.   32042.   2178.8    1043.
  10    722.     1835.       10.    3174.       0.       0.        0.   29495.   2176.7    1068.
  11    330.     1268.      570.    1156.       0.       0.        0.   28467.   2175.8    1082.
  12    286.     1284.       10.    3174.       0.       0.        0.   26907.   2174.5    1094.

       5140.    20676.    22570.                0.       0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND    INFLOW   INFLOW   SHORT-    D/S        SPILLS   -------END OF MONTH-------
      LOSS                         QUALITY   AGE    RELEASE              CONTENT    ELEV.   QUALITY
     *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*    *AC-FT*   *AC-FT*     *FT*   *MG/L*

1976
   1   462.     1234.       20.    3083.       0.        0.        0.    25231.   2173.1    1115.
   2   512.     1318.        0.       0.       0.        0.        0.    23401.   2171.6    1139.
   3   586.     1468.        0.       0.       0.        0.        0.    21347.   2169.8    1169.
   4   -64.     1684.     3070.     890.       0.        0.        0.    22797.   2171.1    1129.
   5   620.     1734.      260.    1305.       0.        0.        0.    20703.   2169.1    1164.
   6   811.     2136.      180.    1480.       0.        0.        0.    17936.   2166.0    1217.
   7   228.     2270.     9170.     751.       0.        0.        0.    24608.   2172.6    1062.
   8   405.     2318.      700.    1119.       0.        0.        0.    22585.   2170.9    1081.
   9   202.     1818.     1390.    1006.       0.        0.        0.    21955.   2170.3    1086.
  10   126.     1468.      830.    1090.       0.        0.        0.    21191.   2169.6    1093.
  11   293.     1268.       30.    2856.       0.        0.        0.    19660.   2167.9    1111.
  12   289.     1284.        0.       0.       0.        0.        0.    18087.   2166.2    1128.

      4470.    20000.    15650.                0.        0.        0.

1977
   1   101.     1234.        0.       0.       0.        0.        0.    16752.   2164.7    1135.
   2   201.     1318.        0.       0.       0.        0.        0.    15233.   2163.0    1149.
   3   386.     1468.        0.       0.       0.        0.        0.    13379.   2161.0    1180.
   4   197.     1684.     1660.     979.       0.        0.        0.    13158.   2160.7    1173.
   5   -79.     1734.     7360.     777.       0.        0.        0.    18863.   2167.0    1021.
   6   646.     2136.     2870.     899.       0.        0.        0.    18951.   2167.1    1036.
   7   861.     2270.        0.       0.       0.        0.        0.    15820.   2163.7    1089.
   8   275.     2318.     3800.     861.       0.        0.        0.    17027.   2165.0    1057.
   9   702.     1818.       20.    3083.       0.        0.        0.    14527.   2162.2    1108.
  10   431.     1468.       30.    2856.       0.        0.        0.    12658.   2160.2    1148.
  11   339.     1268.        0.       0.       0.        0.        0.    11051.   2157.7    1181.
  12   309.     1284.        0.       0.       0.        0.        0.     9458.   2155.2    1217.

      4369.    20000.    15740.                0.        0.        0.

1978
   1   104.     1234.        0.       0.       0.        0.        0.     8120.   2153.1    1231.
   2    56.     1318.        0.       0.       0.        0.        0.     6746.   2150.9    1240.
   3   224.     1468.        0.       0.       0.        0.        0.     5054.   2147.0    1288.
   4   270.     1684.        0.       0.       0.        0.        0.     3100.   2141.8    1376.
   5   177.     1734.    12130.     719.       0.        0.        0.    13319.   2160.9     832.
   6   504.     2136.     4100.     851.       0.        0.        0.    14779.   2162.5     863.
   7   803.     2270.      970.    1064.       0.        0.        0.    12676.   2160.2     927.
   8   574.     2318.      270.    1297.       0.        0.        0.    10054.   2156.1     984.
   9   126.     1818.     5640.     810.       0.        0.        0.    13750.   2161.4     925.
  10   398.     1468.      400.    1221.       0.        0.        0.    12284.   2159.6     963.
  11    15.     1268.      250.    1312.       0.        0.        0.    11251.   2158.0     971.
  12   171.     1284.       30.    2856.       0.        0.        0.     9826.   2155.8     992.

      3422.    20000.    23790.                0.        0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND     INFLOW    INFLOW    SHORT-    D/S        SPILLS    -------END OF MONTH-------
      LOSS                           QUALITY   AGE       RELEASE              CONTENT      ELEV.  QUALITY
    *AC-FT*    *AC-FT*    *AC-FT*   *MG/L*    *AC-FT*   *AC-FT*    *AC-FT*   *AC-FT*       *FT*  *MG/L*

1979
   1     82.     1234.        40.     2570.        0.        0.        0.     8550.   2153.7    1008.
   2    143.     1318.        20.     3083.        0.        0.        0.     7109.   2151.5    1032.
   3    144.     1468.        90.     1909.        0.        0.        0.     5587.   2148.4    1067.
   4    194.     1684.        20.     3083.        0.        0.        0.     3729.   2143.5    1121.
   5    153.     1734.      1420.     1003.        0.        0.        0.     3262.   2142.3    1122.
   6    428.     2136.     25890.      640.        0.        0.        0.    26588.   2174.2     688.
   7    840.     2270.     24740.      644.        0.        0.        0.    48218.   2189.8     678.
   8   1270.     2898.      5860.      805.        0.        0.        0.    49910.   2190.8     709.
   9   1256.     2273.         0.        0.        0.        0.        0.    46381.   2188.6     728.
  10   1199.     1835.        90.     1909.        0.        0.        0.    43437.   2186.7     750.
  11    431.     1585.         0.        0.        0.        0.        0.    41421.   2185.3     757.
  12    180.     1602.        90.     1909.        0.        0.        0.    39729.   2184.2     763.

       6320.    22037.     58260.                  0.        0.        0.

1980
   1    277.     1543.         0.        0.        0.        0.        0.    37909.   2183.0     769.
   2    297.     1648.         0.        0.        0.        0.        0.    35964.   2181.7     775.
   3    639.     1835.         0.        0.        0.        0.        0.    33490.   2180.0     789.
   4    765.     2105.         0.        0.        0.        0.        0.    30620.   2177.6     808.
   5    167.     2168.      4280.      845.        0.        0.        0.    32565.   2179.3     817.
   6    979.     2670.      4810.      830.        0.        0.        0.    33726.   2180.2     842.
   7   1669.     2838.         0.        0.        0.        0.        0.    29219.   2176.5     887.
   8   1240.     2318.       420.     1212.        0.        0.        0.    26081.   2173.8     933.
   9    241.     1818.     24190.      646.        0.        0.        0.    48212.   2189.8     796.
  10    954.     1835.       150.     1582.        0.        0.        0.    45573.   2188.1     815.
  11    509.     1585.        70.     2093.        0.        0.        0.    43549.   2186.7     827.
  12    297.     1602.      1470.      998.        0.        0.        0.    43120.   2186.4     838.

       8034.    23965.     35390.                  0.        0.        0.

1981
   1    261.     1543.        10.     3174.        0.        0.        0.    41326.   2185.2     844.
   2    121.     1648.      1340.     1012.        0.        0.        0.    40897.   2185.0     851.
   3    341.     1835.       460.     1195.        0.        0.        0.    39181.   2183.8     863.
   4     87.     2105.      1100.     1044.        0.        0.        0.    38089.   2183.1     870.
   5    397.     2168.       620.     1141.        0.        0.        0.    36144.   2181.8     883.
   6    532.     2670.       730.     1112.        0.        0.        0.    33672.   2180.2     901.
   7    981.     2838.         0.        0.        0.        0.        0.    29853.   2177.0     930.
   8    443.     2318.      1550.      990.        0.        0.        0.    28642.   2176.0     947.
   9    530.     1818.      1480.      997.        0.        0.        0.    27774.   2175.2     967.
  10   -510.     1468.     26920.      636.        0.        0.        0.    53736.   2193.0     794.
  11    547.     1585.        70.     2093.        0.        0.        0.    51674.   2191.8     804.
  12    500.     1602.        20.     3083.        0.        0.        0.    49592.   2190.6     813.

       4230.    23598.     34300.                  0.        0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND

DATE  EVAP.     DEMAND     INFLOW    INFLOW    SHORT-     D/S       SPILLS    -------END OF MONTH-------
      LOSS                           QUALITY   AGE      RELEASE              CONTENT      ELEV.   QUALITY
    *AC-FT*    *AC-FT*    *AC-FT*  *MG/L*    *AC-FT*  *AC-FT*    *AC-FT*   *AC-FT*       *FT*   *MG/L*

1982
   1   472.      1543.        20.     3083.        0.        0.         0.    47597.    2189.4       822.
   2   279.      1648.        10.     3174.        0.        0.         0.    45680.    2188.1       827.
   3   191.      1835.       100.     1836.        0.        0.         0.    43754.    2186.9       833.
   4   494.      2105.       190.     1451.        0.        0.         0.    41345.    2185.3       845.
   5   -16.      2168.      9490.      747.        0.        0.         0.    48683.    2190.1       826.
   6   281.      2670.     21890.      656.        0.        0.         0.    67622.    2200.3       776.
   7  1213.      3973.      1690.      976.        0.        0.         0.    64126.    2198.5       795.
   8  1262.      4057.       600.     1146.        0.        0.         0.    59407.    2196.1       815.
   9  1247.      2273.         0.        0.        0.        0.         0.    55887.    2194.2       833.
  10   828.      1835.        30.     2856.        0.        0.         0.    53254.    2192.7       847.
  11   456.      1585.         0.        0.        0.        0.         0.    51213.    2191.5       854.
  12   326.      1602.        10.     3174.        0.        0.         0.    49295.    2190.5       860.

      7033.     27294.     34030.                  0.        0.         0.

1983
   1    68.      1543.       600.     1146.        0.        0.         0.    48284.    2189.9       865.
   2   182.      1648.        20.     3083.        0.        0.         0.    46474.    2188.7       869.
   3   450.      1835.         0.        0.        0.        0.         0.    44189.    2187.1       878.
   4   728.      2105.        40.     2570.        0.        0.         0.    41396.    2185.3       894.
   5   787.      2168.       280.     1290.        0.        0.         0.    38721.    2183.5       915.
   6   468.      2670.        50.     2368.        0.        0.         0.    35633.    2181.5       928.
   7   781.      2838.       540.     1165.        0.        0.         0.    32554.    2179.3       953.
   8   948.      2898.        10.     3174.        0.        0.         0.    28718.    2176.0       984.
   9   845.      1818.       360.     1241.        0.        0.         0.    26415.    2174.1      1018.
  10   251.      1468.     21320.      659.        0.        0.         0.    46016.    2188.4       860.
  11   325.      1585.      1810.      966.        0.        0.         0.    45916.    2188.3       870.
  12   463.      1602.        30.     2856.        0.        0.         0.    43881.    2186.9       880.

      6296.     24178.     25060.                  0.        0.         0.

1984
   1    47.      1543.        20.     3083.        0.        0.         0.    42311.    2185.9       882.
   2   544.      1648.        10.     3174.        0.        0.         0.    40129.    2184.5       894.
   3   424.      1835.         0.        0.        0.        0.         0.    37870.    2183.0       904.
   4   840.      2105.         0.        0.        0.        0.         0.    34925.    2181.0       925.
   5   853.      2168.       260.     1305.        0.        0.         0.    32164.    2178.9       952.
   6   774.      2670.       860.     1084.        0.        0.         0.    29580.    2176.8       979.
   7   939.      2270.       330.     1258.        0.        0.         0.    26701.    2174.3      1016.
   8   856.      2318.      2160.      940.        0.        0.         0.    25687.    2173.5      1042.
   9   531.      1818.      1040.     1053.        0.        0.         0.    24378.    2172.4      1064.
  10     0.      1468.      2840.      901.        0.        0.         0.    25750.    2173.5      1047.
  11   209.      1268.      2680.      909.        0.        0.         0.    26953.    2174.6      1041.
  12   -84.      1284.      3060.      891.        0.        0.         0.    28813.    2176.1      1022.

      5933.     22395.     13260.                  0.        0.         0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107  TLS
VARIABLE DEMAND


DATE  EVAP.     DEMAND     INFLOW   INFLOW   SHORT-    D/S      SPILLS   -------END OF MONTH-------
       LOSS                         QUALITY   AGE    RELEASE            CONTENT     ELEV.  QUALITY
     *AC-FT*   *AC-FT*   *AC-FT*  *MG/L*  *AC-FT*  *AC-FT*   *AC-FT*  *AC-FT*      *FT*  *MG/L*

1985
   1    157.     1234.      310.    1270.      0.       0.        0.   27732.   2175.2    1031.
   2    236.     1318.      500.    1179.      0.       0.        0.   26678.   2174.3    1042.
   3    209.     1468.     1010.    1058.      0.       0.        0.   26011.   2173.8    1051.
   4    576.     1684.     6220.     798.      0.       0.        0.   29971.   2177.1    1020.
   5    448.     1734.     2010.     951.      0.       0.        0.   29799.   2177.0    1030.
   6    363.     2136.     3050.     891.      0.       0.        0.   30350.   2177.4    1028.
   7    762.     2838.    10350.     737.      0.       0.        0.   37100.   2182.4     970.
   8   1177.     2898.       10.    3174.      0.       0.        0.   33035.   2179.7    1004.
   9    465.     2273.      270.    1297.      0.       0.        0.   30567.   2177.6    1021.
  10    249.     1835.    27400.     634.      0.       0.        0.   55883.   2194.2     839.
  11    344.     1585.      350.    1246.      0.       0.        0.   54304.   2193.3     847.
  12    444.     1602.       30.    2856.      0.       0.        0.   52288.   2192.2     855.

       5430.    22605.    51510.               0.       0.        0.

1986
   1    538.     1543.        0.       0.      0.       0.        0.   50207.   2191.0     864.
   2    441.     1648.        0.       0.      0.       0.        0.   48118.   2189.8     872.
   3    756.     1835.        0.       0.      0.       0.        0.   45527.   2188.0     886.
   4    807.     2105.      290.    1283.      0.       0.        0.   42905.   2186.3     905.
   5    250.     2168.     3600.     868.      0.       0.        0.   44087.   2187.1     907.
   6    408.     2670.     2240.     935.      0.       0.        0.   43249.   2186.5     917.
   7   1125.     2838.      640.    1135.      0.       0.        0.   39926.   2184.3     945.
   8    888.     2898.     5810.     806.      0.       0.        0.   41950.   2185.7     946.
   9     53.     2273.    22400.     654.      0.       0.        0.   62024.   2197.4     843.
  10   -394.     2569.     4370.     843.      0.       0.        0.   64219.   2198.5     838.
  11    199.     2219.     2400.     925.      0.       0.        0.   64201.   2198.5     844.
  12    -79.     2244.      500.    1179.      0.       0.        0.   62536.   2197.7     845.

       4992.    27010.    42250.               0.       0.        0.

1987
   1    367.     2160.      130.    1668.      0.       0.        0.   60139.   2196.4     852.
   2   -285.     2307.      750.    1107.      0.       0.        0.   58867.   2195.8     851.
   3    168.     1835.      180.    1480.      0.       0.        0.   57044.   2194.8     856.
   4    638.     2105.       10.    3174.      0.       0.        0.   54311.   2193.3     866.
   5   -198.     2168.    20630.     663.      0.       0.        0.   72971.   2202.8     807.
   6    236.     3738.     3310.     880.      0.       0.        0.   72307.   2202.5     813.
   7   1311.     3973.     2690.     909.      0.       0.        0.   69713.   2201.2     831.
   8   1207.     4057.        0.       0.      0.       0.        0.   64449.   2198.7     846.
   9   -138.     3182.      570.    1156.      0.       0.        0.   61975.   2197.4     847.
  10    708.     2569.        0.       0.      0.       0.        0.   58698.   2195.7     857.
  11    484.     1585.        0.       0.      0.       0.        0.   56629.   2194.6     864.
  12    128.     1602.        0.       0.      0.       0.        0.   54899.   2193.6     866.

       4626.    31281.    28270.               0.       0.        0.
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LAKE ALAN HENRY TDS SIMULATION   BRA90107   TLS
VARIABLE DEMAND

DATE  EVAP.      DEMAND      INFLOW   INFLOW    SHORT-     D/S       SPILLS   -------END OF MONTH-------
       LOSS                           QUALITY    AGE     RELEASE              CONTENT      ELEV.   QUALITY
     *AC-FT*    *AC-FT*     *AC-FT*  *MG/L*   *AC-FT*   *AC-FT*     *AC-FT*   *AC-FT*      *FT*   *MG/L*

1988
   1    429.      1543.          0.        0.        0.        0.         0.    52927.    2192.5       873.
   2    402.      1648.          0.        0.        0.        0.         0.    50877.    2191.4       880.
   3    783.      1835.          0.        0.        0.        0.         0.    48259.    2189.9       894.
   4    675.      2105.        100.     1836.        0.        0.         0.    45579.    2188.1       909.
   5    539.      2168.        250.     1312.        0.        0.         0.    43122.    2186.4       922.
   6    733.      2670.        830.     1090.        0.        0.         0.    40549.    2184.7       942.
   7    533.      2838.       1890.      960.        0.        0.         0.    39068.    2183.8       955.
   8    963.      2898.          0.        0.        0.        0.         0.    35207.    2181.2       980.
   9    525.      2273.       3580.      869.        0.        0.         0.    35989.    2181.7       983.
  10    667.      1835.          0.        0.        0.        0.         0.    33487.    2180.0      1002.
  11    601.      1585.          0.        0.        0.        0.         0.    31301.    2178.2      1021.
  12    214.      1602.          0.        0.        0.        0.         0.    29485.    2176.7      1028.

       7064.     25000.       6650.                  0.        0.         0.

CRITICAL PERIOD IS FROM  7/1963 THROUGH  4/1978.   MINIMUM CONTENT =       3100.
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APPENDIX C

EMERGENCY RESPONSE TELEPHONE NUMBERS AND INCIDENT RESPONSE FORM

Table C.1

PHONE LIST FOR REPORTING SPILLS OF HAZARDOUS MATERIAL

LAKE ALAN HENRY WATER QUALITY PROTECTION PLAN

AGENCY	LOCATION	PHONE NUMBER	24 HR
National Response Center	Wash. D.C.	(800)424-8802	*
Environmental Protection Agency	Dallas	(214)655-2222	*
Texas Emergency Response Commission	Austin	(512)465-2000	*
Texas Water Commission	Austin	(512)463-7727	*
Texas Water Commission, District	Lubbock	(806)796-7902	
Texas Railroad Commission	Austin	(512)463-6832	*
Texas Railroad Commission, District	Lubbock	(806)744-6944	
Texas Air Quality Control Board	Austin	(512)908-1876	*
Texas Air Quality Control Board, District	Lubbock	(806)744-0090	
CHEMTREC	Wash. D.C.	(800)424-9300	*
Local Emergency Planning Committee, Garza County	Lubbock	(806)495-3750	
Local Emergency Planning Committee, Kent County	Jayton	(806)237-3373	
Local Emergency Planning Committee, Borden County	Gail	(806)756-4391	
Local Emergency Planning Committee, Lynn County	Tahoka	(806)998-4211	
Local Emergency Planning Committee, Scurry County	Snyder	(915)573-8576	

Table C.2

PHONE LIST FOR REPORTING SPILLS OF HAZARDOUS MATERIAL

TEMPLATE

AGENCY	LOCATION	PHONE NUMBER	24 HR
National Response Center	Wash. D.C.	(800)424-8802	*
Environmental Protection Agency	Dallas	(214)655-2222	*
Texas Emergency Response Commission	Austin	(512)465-2000	*
Texas Water Commission	Austin	(512)463-7727	*
Texas Water Commission, District			
Texas Railroad Commission	Austin	(512)463-6832	*
Texas Railroad Commission, District			
Texas Air Control Board	Austin	(512)908-1876	*
Texas Air Control Board, District			
CHEMTREC	Wash. D.C.	(800)424-9300	*
Local Emergency Planning Committee			

Table C.3

INCIDENT RESPONSE FORM

The following information is necessary when reporting emergency spills:

NAME OF CALLER	
CALLBACK NUMBER	
CARRIER NAME	
RESPONSIBLE PARTY	
DATE AND TIME OF INCIDENT	
EXACT LOCATION OF INCIDENT AND DIRECTIONS	
NATURE OF INCIDENT	
EXTENT OF PERSONAL INJURIES	
EXTENT OF DAMAGE	
EXTENT OF FIRE	
WIND DIRECTION AND VELOCITY	
MATERIAL INVOLVED/WARNING LABELS	
CONTAINER TYPE	
RAILCAR OR TRUCK NUMBER	