

FRESNO / CLOVIS METROPOLITAN

Water Resources

MANAGEMENT PLAN

Phase I Report

Existing Water Supply System Assessment

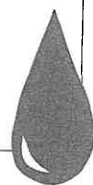
Volume II of II
Appendixes A-D

CH2M HILL

January 1992



Appendix B
Hydrogeologic
Conditions in the FCMA



**HYDROGEOLOGIC CONDITIONS IN THE
FRESNO-CLOVIS METROPOLITAN AREA**

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Re: Hydrogeologic Conditions

Dear 

Submitted herewith is our report on the hydrogeologic conditions in the Fresno-Clovis Metropolitan Area.

Sincerely yours,


Kenneth D. Schmidt

KDS/d

TABLE OF CONTENTS

	<u>Page</u>
LIST OF TABLES	v
LIST OF ILLUSTRATIONS	vi
INTRODUCTION	1
Acknowledgments	2
WELLS AND WATER PURVEYORS	2
SUBSURFACE GEOLOGIC CONDITIONS	3
Subsurface Geologic Cross Sections	4
Previous Sections	4
Expanded Sections	6
Summary	7
WATER LEVELS	8
Depth to Water	8
Water-Level Elevations	9
Groundwater Flow Direction	9
Vertical Head Differences	10
Northwest Fresno Area	10
North Fresno Growth Area	11
Southeast Fresno Area	11
Time Trends	12
Downtown Fresno	13
Leaky Acres and Downgradient	13
Southeast Fresno Sub-Area	13
Northwest Fresno	13
North Fresno	14
East Clovis	14
Summary	14
PUMPAGE	15
AQUIFER CHARACTERISTICS	15
Transmissivity	17
Permeability	17
Specific Yield	22
INTENTIONAL RECHARGE	22
GROUNDWATER QUALITY	24

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
Inorganic Chemical Constituents	25
Areal Distribution	25
Total Dissolved Solids	25
Nitrate	26
Hardness	27
Manganese	28
Vertical Distribution	28
Time Trends	29
Statistical Evaluation	30
Nitrate (1950-70)	30
Update Through 1978	31
Update Through 1991	31
Trace Organic Chemical Constituents	33
DBCP	34
Previous Reports and Sampling	34
Areal Distribution	34
Ethylene Dibromide	36
Volatile Halocarbons	37
Radiological Constituents	38
 MAJOR KNOWN POINT SOURCE GROUNDWATER CONTAMINATION SITES	 39
Fresno Railroad Yard	39
Fresno Meat Co.	40
Pinedale TCE Plume	40
Thompson-Hayward Agricultural and Nutrition Co., Inc. Site	41
Purity Oil Sales Superfund Site	41
Fresno Air Terminal	42
FMC Superfund Site	43
Wilbur-Ellis	44
Other Superfund Sites	44
Gasoline Leak Sites	44
 IMPACT OF UPGRADIENT IRRIGATION ON THE MIGRATION OF DBCP-CONTAMINATED GROUNDWATER	 44
 THE RELATION BETWEEN WELL DRAWDOWN AND THE DISTRIBUTION OF CONTAMINANTS IN THE GROUNDWATER	 46
 POTENTIAL FOR SEALING OF SHALLOW CONTAMINATED GROUNDWATER IN PUBLIC-SUPPLY WELLS	 47

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
ADEQUACY OF AVAILABLE DATA	49
Pumpage	50
Water Levels	50
Pesticide Contents in Adjacent Areas	50
Data Management	50
GROUNDWATER CONDITIONS IN THE NORTHWEST	
FRESNO SUB-AREA	50
Subsurface Geologic Conditions	51
Water Levels	52
Well Production and Aquifer Characteristics	52
Potential for Intentional Recharge	52
Groundwater Quality	53
Summary	54
GROUNDWATER LIMITATIONS IN THE NORTH FRESNO	
GROWTH AREA, HERNDON-SHEPHERD PLAN AREA,	
AND EAST CLOVIS SUB-AREA	54
Subsurface Geologic Conditions	54
Shallow Bedrock	55
Alluvial Deposits	56
Subsurface Geologic Cross Sections	56
Water Levels	58
Well Production and Aquifer Characteristics	59
Potential for Intentional Recharge	60
Groundwater Quality	60
Groundwater in the Reduced Deposits	60
Manganese in East Clovis Area	61
DBCP	61
Summary	62
PESTICIDE CONTAMINATION IN THE SOUTHEAST	
FRESNO SUB-AREA	63
DBCP	63
Areal Distribution	64
Early 1980's	64
1990-91	64
Vertical Distribution	65
Canterbury Station Test Wells	66
Sunnyside Test Holes	66
Time Trends	67
Summary	69

TABLE OF CONTENTS
(Continued)

	<u>Page</u>
Ethylene Dibromide	69
Aquifer Tests	70
Rate and Amount of Groundwater Underflow	71
The Need for Recharge Downgradient of the DBCP Plume	72
The Case for Extraction of High-DBCP Groundwater	72
REFERENCES	73
EXHIBIT A - WELLS AND TEST HOLES WITH GEOLOGIC AND/OR ELECTRIC LOGS	
EXHIBIT B - RECENT SPECIFIC CAPACITY DATA FOR PUBLIC-SUPPLY WELLS	

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
1	Annual Pumpage by Public Water Suppliers in Fresno-Clovis Metropolitan Area (1980-90)	16
2	Summary of Aquifer Tests for City of Fresno Wells	18
3	Summary of Aquifer Tests for City of Clovis Wells	20
4	Summary of Aquifer Tests for Other Wells	21
5	Canal Water Diverted for Intentional Recharge in the Urban Area (1979-90)	23

LIST OF ILLUSTRATIONS
(In Pocket)

Figure No.	Title
1	Location of Public Supply Wells in the Urban Area
2	Location of Test Holes and Wells with Geologic Logs and/or Electric Logs
3	Subsurface Geologic Cross Section A-A'
4	Subsurface Geologic Cross Section B-B'
5	Subsurface Geologic Cross Section C-C'
6	Subsurface Geologic Cross Section D-D'
7	Subsurface Geologic Cross Section E-E'
8	Subsurface Geologic Cross Section F-F'
9	Subsurface Geologic Cross Section G-G'
10	Depth to Water (Spring 1991)
11	Water-level Elevations (Spring 1991)
12	Flownet (Spring 1991)
13	Water-level Hydrographs for the City of Fresno Wells PS-3, PS-47 & PS-64
14	Water-level Hydrographs for the City of Fresno Wells PS-86, PS-79 & PS-77
15	Total Dissolved Solids Content in Groundwater (1989-91)
16	Nitrate Content in Groundwater (1989-91)
17	Hardness Content in Groundwater (1989-91)
18	Manganese Content in Groundwater (1989-91)
19	Typical Long-Term Trends in Salinity of Well Water in the Urban Area

LIST OF ILLUSTRATIONS
(In Pocket)
(Continued)

Figure No.	Title
20	Typical Long-Term trends in Nitrate Content of Well Water in the Urban Area
21	DBCP Content in Groundwater (1989-91)
22	Ethylene Dibromide Content in Groundwater (1989-91)
23	Volatile Organic Chemicals Content in Groundwater (1988-91)
24	Location of Known Major Point Source Groundwater Contamination Sites in and near the Urban Area
25	Depth to Bedrock Beneath Clovis Vicinity
26	DBCP Hydrograph for Well GFV-S
27	DBCP Hydrograph for Well PS-82
28	DBCP Hydrographs for Well D5-1, D5-2, D5-3, and D5-4
29	DBCP Hydrograph for Well D24-1
30	DBCP Hydrograph for Well D24-2
31	DBCP Hydrograph for Well D24-3
32	DBCP Hydrograph for Well D24-4
33	DBCP Hydrographs for Well D29-1 and D29-2

HYDROGEOLOGIC CONDITIONS IN THE FRESNO-CLOVIS METROPOLITAN AREA

INTRODUCTION

This report was prepared under sub-contract to CM₂M-Hill, a contractor to the City of Fresno, to provide information on groundwater for development of the Fresno-Clovis Metropolitan Water Resources Management Plan (WRMP). The main focus of this report is on the existing and planned urban areas for the Cities of Fresno and Clovis (termed herein the "urban area"). The urban area is located within a larger area, termed the Fresno County Water Management Plan Area, which was evaluated previously as part of EPA-funded 208 and 205J Water Quality Management programs. The original County of Fresno Water Management Plan Area was bounded approximately by the San Joaquin River on the north, the Friant-Kern Canal on the east, the Fowler Switch Canal on the southeast, American Avenue on the south, and Chateau Fresno Avenue on the west. For purposes of the present study, the western boundary of this larger area was extended westerly to Dickerson Avenue. The larger area is important because 1) groundwater flows into the urban area from beneath upgradient lands, 2) lands adjacent to the existing urban area may be urbanized in the future, and 3) it also includes the City of Fresno Wastewater Treatment Facility, located southwest of the urban area.

Previous studies of regional groundwater conditions in the Fresno area that provide information useful for this report include Page and LeBlanc (1969), John Carollo Engineers and Harshbarger & Associates (1969), and County of Fresno, et al (1979 and 1986). More site-specific studies have also been done at a number of groundwater contamination sites and in other parts of the urban area. A number of these are discussed in subsequent parts of this report.

A hydrologic base period extending from 1965-77 was used to represent long-term conditions in the studies for the 208 program. For the present evaluation, the period from 1980-89 has been selected, to provide more up to date information. Data through 1978 were previously compiled for the 208 program. Data on subsurface geology, municipal pumpage, water levels, aquifer characteristics, intentional recharge, and chemical quality were compiled and updated through Summer 1991 for this report.

This report is organized in the following manner. First, public-supply wells, subsurface geologic conditions, water levels, pumpage, aquifer characteristics, and intentional recharge are addressed. Next, groundwater quality and the most significant known groundwater contamination sites are addressed. The adequacy of the existing data base for the purpose of developing the WRMP is then addressed. This is followed by a more detailed discussion of

groundwater conditions in three sub-areas in the urban area. The first of these is Northwest Fresno, which is a rapidly urbanizing area with very favorable groundwater conditions. The sub-area is bounded by the San Joaquin River on the north, West Avenue on the east, Garfield Avenue on the west, and Dakota Avenue on the south. The next sub-area considered comprises the combined North Fresno Growth Area, Herndon-Shepherd Plan Area, and East Clovis area. The North Fresno Growth Area is bounded on the north by Copper Avenue, on the northwest by the San Joaquin River, on the west by Blackstone Avenue, on the south by Herndon Avenue, and on the east by Willow Avenue. The Herndon-Shepherd Plan Area is bounded on the north by Shepherd Avenue, on the west by Willow Avenue, on the south by Herndon Avenue, and on the east by Temperance Avenue. The East Clovis area is bounded by Herndon Avenue on the north, Clovis Avenue on the west, Dakota Avenue on the south, and Leonard Avenue on the east. The last sub-area comprises southeast Fresno (including Sunnyside and Calwa), where there is significant pesticide contamination of the shallow groundwater.

Acknowledgments

The substantial cooperation during this evaluation that was provided by the following agencies and entities is gratefully acknowledged:

City of Fresno Water Division
 City of Clovis Public Works Department
 Fresno Irrigation District
 Fresno Metropolitan Flood Control District
 County of Fresno Environmental Health Division
 California Department of Health Services
 Pinedale County Water District
 Malaga County Water District
 Bakman Water Company
 California State University, Fresno.

WELLS AND WATER PURVEYORS

Figure 1 shows the locations of public-supply wells in the Fresno Urban Area. Included are wells operated by the City of Fresno, City of Clovis, Bakman Water Company, Pinedale County Water District, and Malaga County Water District. Pinedale County Water District wells are abbreviated herein as P-series wells. City of Fresno wells are abbreviated by their pump station (PS) number, and City of Clovis wells as the C1-Series in this report. Prior to 1989, a number of wells in the Figarden, Mayfair, and Sunnyside areas were operated by a number of Fresno County Water Works Districts (FCWD). These wells are now operated by the City of Fresno, but are still numbered by the District number followed by the pump number (i.e., D4-2). Wells formerly in the Calwa County Water District are also now operated by the City of Fresno, and are abbreviated herein as the C-series. In addition, a number of other wells formerly operated by small private water companies

(such as the Kavanaugh Water Company) are also now operated by the City of Fresno, and their earlier letter designations are still used (i.e., KV-EN). Former FCWD No. 8 wells (Tarpey Village) are now operated by the City of Clovis, and are abbreviated as the T-series wells.

As of Summer 1991, there were 171 active City of Fresno wells, twenty active City of Clovis wells, eight active Bakman Water Company wells, five active Pinedale County Water Works District wells, and four active Malaga County Water Works District wells. About sixty public supply wells in the urban area have been shut down or their use limited because of contamination. Most of these are City of Fresno wells with the pesticides dibromodichloropropane (DBCP) or ethylene dibromide (EDB), or volatile halocarbons, primarily trichloroethylene (TCE). In addition, ten wells have been shut down or their use has been limited due to high nitrate contents. Groundwater quality is discussed in more detail in a subsequent part of this report.

Primarily because of urban development in recent years, a number of test holes and new public-supply wells have been drilled north of Shaw Avenue and in Southeast Fresno. These have provided a substantial amount of new information, particularly on subsurface geology.

There are a number of other large-capacity wells in the urban area besides public-supply wells, including an unknown number of irrigation wells. Included are wells for California State University, Fresno (CSUF), schools, mobile home parks, irrigation at golf courses (such as the Sunnyside and Fort Washington Country Clubs), lakes at the Woodward Lakes and Lake Van Ness developments, and for industrial use. These other wells in the urban area pump a significant amount of water, and are thus important in terms of the water budget.

SUBSURFACE GEOLOGIC CONDITIONS

Page and LeBlanc (1969) provided the regional subsurface geologic framework for the Fresno area. Information from drillers logs, electric logs, and geologic logs can be used to provide more detail on subsurface geologic conditions in specific parts of the area. Prior to the 1969 investigation of the urban area by John Carollo Engineers and Harshbarger and Associates (JCE and HA, 1969), no electric logs were known to be available for water wells in the area. However, electric logs were available for several oil or gas exploration holes, which extended to depths of several thousand feet. As part of the 1969 investigation, an electric log was obtained at a test well site (now City of Fresno Well PS 79) in northwest Fresno. Geologic logs were obtained from this and another test well site (now PS 44a) at that time. Commencing in the late 1970's, a number of geologic and electric logs were obtained from dozens of test holes that were drilled in the North Fresno Growth Area. Subsequently the same type of information was ob-

tained for numerous test holes drilled during 1989-91 in the City of Clovis Herndon-Shepherd Plan Area. In 1990, the City of Fresno contracted with Bradley & Sons, Inc. of Madera to install several dozen test holes and observation wells, many of which are north of Shaw Avenue. In addition, it has become standard practice in the past decade to electric log the holes for new public-supply wells.

Figure 2 shows the locations of test holes and wells in the urban area for which electric logs and geologic logs are available, as of October 1991. Exhibit A is a list of these holes and wells by State well location (township, range, section, and forty-acre part of the section). At the time of the 1969 investigation of the urban area, data on subsurface geologic conditions in the urban area were largely limited to drillers logs for existing wells, most of which were less than 300 feet deep. Presently available data now extend to a depth of about 500 to 600 feet throughout much of the area, particularly in northwest Fresno, the North Fresno Growth Area, in Clovis, and in southeast Fresno. In addition, information is available in some parts of the urban area to depths ranging from 800 to 900 feet.

Subsurface Geologic Cross Sections

Previous Sections

As part of the 1969 investigation, seven detailed subsurface geologic cross sections were developed (JCE & HA, 1969, Plate VI-7). The study focused only on lands within the City of Fresno at that time, and thus these sections generally did not cover the North Fresno Growth Area, the City of Clovis, or the Sunnyside area. These sections demonstrated the predominance of coarse-grained deposits above a depth of several hundred feet in the urban area. These deposits were termed the Quaternary older alluvium by Page and LeBlanc (1969). Another feature demonstrated in the 1969 investigation was the predominance of cobbles in the area south of the San Joaquin River, extending as far south as McKinley Avenue (JCE & HA, 1969, Plate VI-8f). These coarse-grained, highly permeable deposits in the older alluvium were found to coincide with areas of high specific capacities. Finer-grained deposits below a depth of several hundred feet in the urban area were termed the Tertiary-Quaternary continental deposits, also following the terminology of Page and LeBlanc (1969). Most of the public-supply wells in the urban area in 1969 tapped only the Quaternary older alluvium.

Another group of subsurface geologic cross sections were developed in the North Fresno Growth Area by Kenneth D. Schmidt and Associates (1987a). Five cross sections were developed, based on information from 32 wells or test holes for which electric logs were available as of January 1987. The depths of most of these wells or test holes ranged from 500 to 700 feet. The sections illustrated the predominance of thick clay strata in the continental deposits beneath part of the North Fresno Growth Area, which limited the ability to drill deep wells in that area. In addition,

deposits of a blue-green color were identified beneath most of the North Fresno Growth Area, at depths ranging from about 200 to more than 600 feet. These deposits are important in terms of groundwater quality, particularly with respect to iron, manganese, and hydrogen sulfide contents. Also, these sections indicated that fine-grained deposits were extensive above the water table in part of the area, which could limit the effectiveness of basins for intentional recharge of canal water.

As part of an evaluation of DBCP contamination in southeast Fresno for the City of Fresno, Schmidt (1984) developed three subsurface geologic cross sections in the Sunnyside Area. In 1991, some of these cross sections were revised and updated, and a new section was developed, based on additional information available by that time. These cross sections were developed as part of a hydrogeologic evaluation for a feasibility study, conducted on behalf of the City of Fresno and the Fresno Irrigation District. Two of the major findings from these cross sections in the Sunnyside area are: 1) the predominance of fine-grained strata below a depth of several hundred feet in the area east of Clovis Avenue, which limits the potential to drill deeper wells, and 2) the discovery of a widespread shallow clay layer above the water table in the area west of Minnewawa Avenue, extending west to near downtown Fresno. This restricting layer limits the effectiveness of basins for intentional recharge in part of this area.

Lastly, two subsurface geologic cross sections were developed by Kenneth D. Schmidt and Associates (1988), as part of a preliminary evaluation of the Pinedale TCE plume. These sections covered the area between Alluvial Avenue on the north, Shaw Avenue on the south, West Avenue on the west, and Maroa Avenue on the east.

The alluvial deposits of the sub-area have been subdivided into several types, based primarily on particle size and interpretation of the electric logs. One unit comprises deposits primarily coarser than sand, usually cobbles, gravel, and sometimes boulders. Deposits of this unit tend to have the highest resistivities on the electric logs and are generally the most permeable of the deposits except when inter-mixed with clay. A second type comprises deposits that are primarily sand in texture. Deposits of this type tend to have the next highest resistivities on the electric logs, and are also generally highly permeable. These two coarse-grained strata comprise the major water-producing deposits of the urban area. A third type comprises deposits that are primarily clay. Deposits of this type tend to have the lowest resistivities on the electric logs and are generally of the lowest permeability of all the deposits. If a sufficient thickness of these strata is present, then they may act as a confining bed, to partly separate groundwater in the overlying and underlying coarse-grained deposits. The fourth type comprises fine-grained deposits of an intermediate texture between sand and clay. These deposits have resistivities intermediate between sand and clay. Included in this type are silt, sandy clay, clayey sand, and silty clay deposits. Deposits of this type are believed to have a low to moderate permeabil-

ity, can contribute some water to wells, and probably do not act as significant confining beds. As in most alluvial basins in the southwest, these deposits are variable in thickness and extent, and sometimes individual units cannot be correlated for great distances laterally.

Subsurface geologic cross sections have been developed in relatively small parts of the urban area as a result of site-specific groundwater contamination investigations. Included are the Thompson-Hayward Facility (near McKinley and Temperance Avenues), the FMC facility near Calwa, and the Purity Oil facility near Malaga.

Expanded Sections

The most important parts of the urban area where additional subsurface geologic cross sections are necessary for development of the WRMP are: 1) Northwest Fresno, and 2) Clovis. A substantial number of deep test holes and wells has been drilled in both of these areas in recent years. Therefore, as part of this investigation, two new subsurface geologic cross sections were developed in Northwest Fresno. Also, a new cross section was developed, extending through the Herndon-Shepherd Plan Area and the East Clovis Area.

Figure 2 also shows the locations of seven subsurface geologic sections that are presented in this report. Cross Sections A-A' and B-B' extend through the North Fresno Growth Area. Cross Section C-C' extends through Clovis. Cross Sections D-D' and E-E' extend through the Southeast Fresno sub-area. Cross Sections F-F' and G-G' extend through the Northwest Fresno sub-area.

Cross Section A-A' (Figure 3) extends from Well PS 93 on the southwest near Herndon and Fruit Avenues to Well PS 133 on the northeast near Friant Road and Copper Avenue. This cross section is located northwest of the area of where the thick clay is present in the continental deposits. This section demonstrates the predominance of coarse-grained strata near the San Joaquin River, even in the continental deposits. Cross Section B-B' (Figure 4) extends from near Rice Road and Friant Road near the San Joaquin River, southeast to City of Fresno Well No. 95, near Sierra and Willow Avenues. This section illustrates the predominance of clay beneath part of the North Fresno Growth Area, and the presence of coarse-grained permeable deposits at considerable depth near the San Joaquin River, and northeast of CSUF. The top of the blue-green deposits are shown on both sections. These deposits are present throughout most of the North Fresno Growth Area.

Cross Section C-C' (Figure 5) extends from City of Clovis Well No. 25 on the north, near Nees Avenue and Minnewawa, southeast to Well No. 20, near Barstow and Armstrong Avenues, thence south to City Well No. 16, near Gettysburg and Armstrong, then southwest to a test well near Ashlan and Fowler Avenues. This section shows the shallow depth to bedrock in part of the Shepherd-Herndon Plan Area and the overwhelming predominance of clay at depth along the south-

ern part of this section. Shallow bedrock is a constraint to drilling new public-supply wells in the east part of the Herndon-Shepherd Plan area and near Tollhouse Road and Herndon Avenue, where there is an area of very shallow bedrock.

Cross Section D-D' (Figure 6) extends from near the east edge of the Fresno Air Terminal on the north, through Sunnyside, to PS 107 at Greenfield Village on the south (Clovis and Jensen Avenues). This section shows the overwhelming predominance of clay at depth along parts of the section, for example at TH-145B near Clinton and Clovis Avenues and TH-145 near Butler and Clovis Avenues.

Cross Section E-E' (Figure 7) extends from west to east through part of the Sunnyside Area. The west end of the section is at PS 30a near Belmont and Jackson Avenues and the east end at PS 147, near Armstrong and Huntington Avenues. This cross section illustrates the presence of a widespread restricting clay layer above the water table in much of the area west of Minnewawa Avenue, which is an important limitation for intentional recharge by basins in this area.

Cross Section F-F' (Figure 8) extends from near City of Fresno Well PS 160 on the west (near the Riverside Municipal Golf Course, northeast of Herndon) easterly, along Herndon Avenue to PS 93, at Fruit and Herndon Avenues. This cross section extends through one of the most productive parts of the aquifer in the urban area. Some coarse-grained, highly permeable strata extend to a depth of at least 900 feet along this section. Coarse-grained deposits also predominate above the water table, a condition conclusive to intentional recharge in basins. A nearly impermeable iron-silica cemented hardpan is also present throughout much of this area which has afforded some protection to the quality of groundwater in the area. Although blue-green deposits have been encountered at depth in northwest Fresno, they are generally beyond the depth to which new public-supply wells would be constructed.

Cross Section G-G' (Figure 9) extends for new City of Fresno Well PS 139 on the north (near Polk and Alluvial Avenues) south through Highway City to PS 138 on the south (near Clinton and Blythe Avenues). This section also passes through one of the most productive parts of the aquifer in the Fresno urban, although to the south, some clays are again predominant at depth. Some permeable strata are present to depths exceeding 800 feet along this section, and also predominate above the water table. A more detailed discussion of these sections is provided in subsequent parts of this report.

Summary

In terms of future development of groundwater in the urban area, the most favorable subsurface geologic conditions are in the Northwest Fresno Sub-area, where highly permeable deposits are present to depths of at least 900 feet. Subsurface geologic conditions are a limitation for development of new public-supply wells

in parts of the North Fresno Growth Area, the Herndon-Shepherd Plan Area, the East Clovis Area, and in part of the Southeast Fresno sub-area. This is primarily due to the presence of shallow bedrock north and northeast of Clovis, and the predominance of fine-grained deposits at depth beneath part of the North Fresno Growth Area and beneath the eastern part of the urban area. At least three areas underlain by relatively thick clay strata have been delineated. One is a southwest-northeast oriented zone in the central part of the North Fresno Growth Area. Another is east of Clovis Avenue, extending from east of the Fresno Air Terminal to California Avenue. The third is smaller than the other two, and is between Calwa and Greenfield Village, primarily south of Kings Canyon Avenue.

In terms of intentional recharge in basins, subsurface geological conditions are the most favorable beneath the Northwest Fresno Sub-area. Restricting layers above the water table are uncommon, and the shallow alluvium is usually coarse-grained and highly permeable in this sub-area. Beneath part of the Southeast Fresno sub-area, conditions are much less favorable, because of the presence of a widespread restricting layer above the water table. In large parts of the North Fresno Growth Area and the Herndon-Shepherd Plan Area, relatively thick fine-grained deposits predominate above the water table.

WATER LEVELS

Water-level measurements were obtained from the City of Fresno, City of Clovis, and Fresno Irrigation District. Measurements for the former County of Fresno Northeast Network were obtained from the California Department of Water Resources. To supplement measurements in the area near the San Joaquin River, measurements were collected for wells north of the river that are measured by the Madera Irrigation District. To supplement measurements in the southwest part of the urban area, water-level measurements were obtained from the City of Fresno for a monitoring program associated with the Fresno Metropolitan Wastewater Treatment Facility. As part of the cooperative City of Fresno and Fresno Irrigation District program in southeast Fresno, water levels were measured in several dozen private wells south and east of the urban area in March 1991. Combined, these measurements form a comprehensive data base for Spring 1991. This allowed detailed depth to water and water-level elevation contour maps to be prepared for that period.

Depth to Water

Figure 10 indicates that depth to water ranged from about 50 to 60 feet beneath adjacent rural areas to more than 140 feet in part of the urban area in Spring 1991. Some of the shallowest water levels were in the southeast part of the urban area, and the deepest water levels were in parts of the North Fresno Growth Area. In most of the urban area, depth to water was between 80 and 110 feet. In general, depth to water is greater to the north beneath topographically higher areas.

Water-Level Elevations

Figure 11 is a water-level elevation contour map for Spring 1991. In Spring 1991, the water table was relatively flat in the northwest part of the urban area, in downtown Fresno, and to the southwest. In Spring 1991, water-level elevations ranged from more than 280 feet above mean sea level in northeast Clovis and east of Sunnyside, to less than 200 feet in downtown Fresno.

Groundwater Flow Direction

Figure 12 shows flowlines for Spring 1991, based on the water-level elevation contour map (Figure 11). The direction of groundwater flow and hydraulic gradient are important in terms of determining rates and amounts of groundwater inflow into the urban area and between subareas within the urban area. They are also important in evaluating changes in groundwater quality than can be expected in the future. Flowlines are constructed perpendicular to the water-level elevation contours and show the direction of groundwater flow. Flowlines are drawn so that the network of contours and flow lines (the flownet) approximates squares as much as possible. An important assumption in the use of a flownet is that the groundwater will flow perpendicular to the water-level contours only in an isotropic, homogenous aquifer. This means that if the permeability of the aquifer materials varies with direction, then the groundwater flow will follow the direction of highest permeability. Groundwater will still flow downgradient, but at some direction other than perpendicular to the water-level contours. Thus the flownet should be interpreted with care and consideration given to subsurface geologic conditions. Subsurface geologic information in and near the urban area indicates that the highest horizontal permeability is often oriented in the northeast-southwest direction.

On the flownet, there are a number of places where flow lines converge and effectively terminate. These are locations of groundwater discharge, which are areas of concentrated pumping. Similarly, there are a number of places where flow lines diverge or begin, which are locations of groundwater recharge. For the Northwest Fresno sub-area, seepage from the San Joaquin River is an important source of recharge. Seepage from the river is also an important source of recharge to groundwater in Madera County north of the river. Recharge to the North Fresno Growth Area and Herndon-Shepherd Plan Area appears to be primarily from Dry Creek. A major source of recharge to the part of the urban area south of Ashlan Avenue and north of Kings Canyon Avenue is from intentional recharge at the City of Fresno Leaky Acres facility (operated since 1970) and the nearby City of Clovis recharge facility. In southeast Fresno, inflow of groundwater from upgradient irrigated lands appears to be the major source of recharge. Throughout much of the urban area there is some additional recharge from storm runoff basins and canal seepage. Also, lands where surface water is used for irrigation southwest of the Enterprise Canal are sources of recharge, particularly where soils are highly permeable.

Historically the urban cone of depression has gradually expanded to the north and south. Historical boundaries of abstraction were shown through 1968 by JCE and HA (1969), through 1978 by the County of Fresno, et al. (1979), and through 1984 by the County of Fresno, et al. (1986). Groundwater within this boundary of abstraction flows into the urban area, while groundwater to the north and south does not. Prior to about 1970, the boundary of extraction did not extend north to the San Joaquin River. Since at least 1978, the boundary of abstraction has expanded to extend north of the river, particularly in the vicinity of Pinedale and along the western boundary of the North Fresno Growth Area. By 1970, the urban depression cone extended south to at least Central Avenue. The approximate boundary of abstraction as of Spring 1991 is shown on Figure 12.

Vertical Head Differences

Substantial information on vertical differences in hydraulic head has become available during the past year or so, from the City of Fresno observation well installation and monitoring program. In general, each of these observation wells has several piezometers, each tapping different water-producing strata at the same site. First, a hole was drilled and electric logged and the drill cuttings were logged by a geologist. The specific depth intervals to be monitored were then selected. The depth zone tapped by each piezometer was then carefully isolated from other water-bearing strata, by installing annular seals. Most of these observation wells are in three geographic areas:

1. The Northwest Fresno Area
2. The North Fresno Growth Area
3. The Southeast Fresno Area.

Water-level measurements for these wells extend in many cases for six months to more than a year. Water-level hydrographs for these were provided by the City of Fresno Water Division. These hydrographs and the associated measurements were examined, and apparent trends noted. It was clear that measurements for some wells showed little variation in hydraulic head with depth (i.e., the water-level elevations for various depth intervals were almost identical), whereas others showed substantial variation. In areas where there is little variation in hydraulic head with depth, it is inferred that the primary direction of groundwater flow is horizontal. The lack of head differences alone does not mean that there are no significant confining beds at such sites. In most such areas, either there is insignificant pumping of deeper groundwater (such as historically in part of Northwest Fresno Area), or there is a lack of well developed confining beds, or both.

Northwest Fresno Area

Records for six observation wells in this area indicated no significant differences in hydraulic head with depth. These wells were generally south of Shaw Avenue or east of Fruit Avenue.

Records for other four observation wells (TH-139, TH-146, TH-158, and TH-160) indicated significant differences in head, particularly below a depth of about 300 feet. These head differences ranged from about 10 to 35 feet and averaged about 15 feet. All of these wells were north of Shaw Avenue and west of Marks Avenue. Because of the lack of active deep wells south of the San Joaquin River in this area at the time of these records, and other evidence, these head differences appear to be due to pumping of deep irrigation wells on the north side of the San Joaquin River. Although a recharge ridge (i.e., higher water level) is present beneath the river, this does not preclude drawdown in wells on the south side of the river, due to pumping of deep wells on the north side of the river. There are a number of deep irrigation wells north of the river, and pumpage has been significant during recent drought years.

North Fresno Growth Area

Three observation wells in this area had essentially no differences in hydraulic head with depth. These wells were 400 feet deep or less, and were not near relatively deep wells. Records for five wells (TH-131, TH-132, TH-148, TH-150, and TH-168) indicated differences in head of at least five feet. Records for two of these wells (TH-131 and TH-150) that were near deep public-supply wells indicated head differences ranging from 30 to almost 40 feet. These head differences are primarily between groundwater in the older alluvium and groundwater in the under-lying continental deposits. The observation wells showing large head differences are in areas where a significant confining bed is located in the upper part of the continental deposits.

Southeast Fresno Area

Observation wells in this area can be grouped into two geographic areas. Measurements for three wells north of Kings Canyon Avenue (TH-55B, TH-142, and TH-145B) showed differences in hydraulic head with depth ranging from 18 to 33 feet and averaging about 25 feet. In this same area, Bakman Water Co. Well No. 13A was recently drilled, and a similar difference in water levels was observed between this new deep well and an adjacent old shallow well. These differences are attributed to pumpage from some deep public-supply wells in the vicinity (such as PS 102 and 13A) and also due to substantial clay layers in the upper part of the continental deposits. The head differences are again largely between shallow groundwater in the older alluvium and deeper groundwater in the continental deposits.

Measurements for two wells south of Kings Canyon Avenue (TH-153 and TH-164) showed smaller differences in hydraulic head, averaging about five feet. This is attributed to the lack of pumping of deep wells in that vicinity during the period of record that was available. Pumping of new deep wells in this area that have been recently drilled is expected to increase vertical head gradients in this area significantly in the future.

Time Trends

Water-level hydrographs were prepared for the period 1959-69 for about fifty City of Fresno wells as part of the 1969 study (JCE and HA, 1969). These hydrographs were updated through 1978 as part of the 208 program studies (County of Fresno, et al. 1979). At that time, a number of new water-level hydrographs were prepared for the north part of the urban area, where a number of wells were drilled after the mid-1960's. As part of this investigation, these water-level hydrographs were updated through 1991. In addition, new water-level hydrographs were prepared for about one dozen wells, most of which are north of Herndon Avenue and were drilled after the mid-1970's. The large areas where wells were formerly operated by the Fresno County Water Works Districts (Figarden, Mayfair, and Sunnyside) and the Calwa County Water District are not necessarily well represented by these hydrographs. Thus about one dozen additional water-level hydrographs were prepared for the period 1980-91 for wells in these areas.

Water-level hydrographs for the urban area from 1959-78 were examined as part of the 208 study and three wells were selected to show long-term water level trends in the urban area. PS 3 (T14S/R20E-10M2) is located in downtown Fresno. PS 47 (T13S/R20E-19C1) is located near the south end of Figarden (near Ashlan and Van Ness Avenues). PS 64 (T13S/R20E-11L) is located near Barstow and Millbrook Avenues, west of CSUF. Each of these hydrographs was extended through 1991 for purposes of this investigation (Figure 13). Three additional water-level hydrographs are shown for purposes of this report (Figure 14). One is for PS 86, located near Clovis West High School. Another is Well PS 79, near Valentine and Herndon Avenues. Another is for Well PS 77, near Adler Avenue, north of Kings Canyon Avenue. Hydrographs for these wells extend from the late 1960's or early 1970's to the present.

The hydrologic base period used for evaluations in the 208 study extended from 1965-77, which represented close to average long-term surface water deliveries. For the present evaluation, a base period extending from 1980-89 has been selected, which is also representative of long-term conditions, and portrays more up-to-date conditions than the earlier period. In order to determine long-term water-level trends from the hydrographs, the entire period from Spring 1965 to Spring 1990 was evaluated in cases where hydrographs for that period were available.

For purposes of evaluating historical water-level changes, six parts of the urban area were evaluated. These are:

Downtown Fresno
Leaky Acres and Downgradient
Southeast Fresno Sub-area
Northwest Fresno Sub-area
North Fresno
East Clovis

Downtown Fresno

Water-level hydrographs were available for 22 wells in and near the downtown Fresno area. The average water-level change during 1967-78 was a decline of 0.2 foot per year. For 1980-88, the average water-level decline was 0.1 foot per year. For the entire period from 1965 to 1988, the average water-level decline was less than 0.1 foot per year. Overall, this has been an area of very stable water levels since 1965.

Leaky Acres and Downgradient

Water-level hydrographs were available for sixteen wells in this area, which is bounded approximately by Shaw Avenue on the north, Blackstone Avenue on the west, Belmont Avenue on the south, and Peach Avenue on the east. The average water-level decline during 1965-78 was 0.6 foot per year, and during 1980-90 was 0.1 foot per year. For the entire period from 1965-90, the average decline was 0.4 foot per year. These hydrographs indicate a substantial reduction in the rate of water-level decline since 1978, and this is attributed to increased amounts of recharged water in the groundwater as time has progressed. By the 1980's, water levels in the entire area between Leaky Acres and downtown Fresno were almost stable.

Southeast Fresno Sub-Area

Hydrographs were available for ten wells in the Southeast Fresno Sub-area. Most of these wells were downgradient of the high DBCP area. The average water-level decline during 1965-78 was 0.7 foot per year, and during 1980-90 was about 0.9 foot per year. For the entire period 1965-90, the average water-level decline was 0.9 foot per year. Essentially, this area appears unaffected by recharge at Leaky Acres. In addition, upgradient irrigated lands have relied extensively on groundwater pumpage, as opposed to canal deliveries. Lastly, intentional recharge in this area has been limited due to the size of the distribution system and subsurface geologic conditions beneath many of the basins that are used. An almost uniform water-level decline has occurred over the years, and there has been no obvious effect of intentional recharge.

Northwest Fresno

The area considered in Northwest Fresno for the water-level hydrograph evaluation is generally bounded by Blackstone Avenue on the east, Belmont on the south, Highway 99 on the southwest, and the San Joaquin River on the north. Hydrographs were available for 30 wells in this area. Average water-level declines during 1965-78 were 0.7 foot per year and during 1980-90 were about 0.1 foot per year. For the entire period 1965-90, the average decline was 0.5 foot per year. The substantial reduction in the rate of water-level decline is similar to that experienced in the area affected by Leaky Acres. The primary reason for this is attributed to in-

creased intentional recharge in storm basins in this area since 1978. Prior to 1978, such recharge had been small.

North Fresno

The North Fresno Area considered for the hydrograph evaluation was bounded on the north by Shepherd Avenue, on the west by Ingram Avenue, on the south by Shaw Avenue, and on the east by Willow Avenue. Hydrographs were available for 14 wells in this area. The average water-level decline during 1965-78 was 1.1 feet per year and during 1980-90 was about 0.7 foot per year. For this earlier period, the only hydrographs available were for wells south of Herndon Avenue. Records for these wells indicated a substantial reduction in the rate of water-level decline after 1978, which is also attributed to increased intentional recharge in flood basins. For the entire period 1965-90, the average rate of decline was 0.7 foot per year. Overall the rate of water-level decline in the part of this area north of Herndon Avenue during 1980-90 was similar to that observed in Southeast Fresno. This is attributed to increased urban pumping after 1978, and to the small amount of intentional recharge in this part of the urban area. Limitations on such recharge include the following:

1. Part of this area is outside of the F.I.D.
2. Storm water from part of the area drains to the San Joaquin River, and flood basins aren't present in some parts of the area.
3. The lack of distribution facilities to allow intentional recharge in parts of the area.

Historical water-level records for wells in the County of Fresno northeast network, which were available through the mid-1980's and after mid-1990, generally indicated a long-term stability of water levels in the part of the area east of Millbrook Avenue through the mid-1980's. However, measurements in 1990-91, after significant urbanization occurred, indicate a decline averaging about one foot per year.

East Clovis

Hydrographs were available for 1980-88 for three wells near the East Clovis Area. Water-level declines averaging about 0.7 foot per year occurred, similar to those observed in the Southeast Fresno sub-area. This area is largely upgradient of where intentional recharge was being practiced, and urban pumpage has increased since 1980. Measurements for the Northeast Network, which comprises many wells upgradient of the East Clovis Area, indicate average declines of about one foot per year between Spring 1980 and Spring 1991.

Summary

For the base period of 1980-89, the average water-level decline in downtown Fresno, the area influenced by Leaky Acres, and

Northwest Fresno was about 0.1 foot per year. The combined size of the areas considered was about 37,000 acres. In the Southeast Fresno Sub-area, in North Fresno, and in Clovis the average rate of decline was about 0.7 foot per year. The combined size of the areas considered was about 26,000 acres. Using an average specific yield of 0.13 (JCE and HA, 1969) in the urban area, the change in storage averaged about 3,000 acre-feet per year during 1980-89.

PUMPAGE

Information provided by JCE & HA (1969) indicated a municipal pumpage of 95,000 acre-feet in 1968. There was an estimated annual pumpage of 5,000 acre-feet for other uses (excluding crop irrigation) in the urban area (industries, golf courses, etc.) at that time. Information on public water suppliers in the urban area was compiled for the period 1931-80 by Guay and Milten (1986). These records indicated a total pumpage of 105,400 acre-feet (excluding Malaga County Water District and some small private water companies) in 1980. Pumpage for public supply in the urban area is provided primarily by the City of Fresno, City of Clovis, Bakman Water Company, Pinedale County Water District, and Malaga County Water District. Records of annual pumpage were obtained from each of these entities. The annual pumpage for the period 1980-91 by entity is provided in Table 1.

Total pumpage for public supply in the urban area was about 140,000 acre-feet as of 1990. This value exceeds that for 1968 by about 45,000 acre-feet, or an increase of almost fifty percent. There was another estimated 15,000 acre-feet pumped for CSUF, industrial use, golf courses, mobile home parks, schools, lakes, and other uses in the urban area in 1990.

AQUIFER CHARACTERISTICS

Recent specific capacity data for wells were collected from municipal public supply pumpers in the urban area. These data are summarized in Exhibit B. JCE and HA (1969, Plate VI-11) provided a map showing the distribution of specific capacity in and near the urban area. Specific capacities were lowest west of Highway 99 and in the east part of the urban area, and highest in Northwest Fresno. A conversion factor of 1,850 was developed at that time, based on two aquifer tests, to multiply times the specific capacity to estimate transmissivity.

Aquifer tests are available for 25 large-capacity wells in and near the urban area. Aquifer tests were conducted on two test wells (PS 44a and PS 79) in northwest Fresno in August 1969 (JCE & HA, 1969). Two wells in FCWD 42 (northeast of Clovis) were tested in October 1978 (Schmidt, 1979), as part of a water-supply evaluation for the County of Fresno. As part of studies of the Sunnyside DBCP contamination, Kenneth D. Schmidt and Associates (1987b) conducted aquifer tests on four wells in southeast Fresno (PS 63, D5-

TABLE 1 - ANNUAL PUMPAGE BY PUBLIC WATER SUPPLIERS
IN FRESNO-CLOVIS METROPOLITAN AREA (1980-90)

Year	City of Fresno	City of Clovis	Bakman Water Co.	Pumpage (Acre-feet)					Total
				Pinedale CWD	Fresno CWD	Calwa CWD	Malaga CWD		
1980	73,320	7,863	2,838	1,473	16,595	2,287	961	105,337	
1981	77,454	8,499	3,007	1,860	19,400 E		901	111,100E	
1982	74,118	8,426	3,007	1,989	19,920 E		746	108,200 E	
1983	75,352	8,160	3,000	1,890	20,440 E		812	109,700 E	
1984	87,187	9,468	3,710	2,411	20,960 E		899	124,600 E	
1985	85,792	9,454	3,730	1,607	21,480 E		886	122,900 E	
1986	89,494	9,843	3,826	1,975	23,000 E		1,009	129,100 E	
1987	92,459	10,070	3,682	1,920	23,520 E		979	132,700	
1988	101,076	10,830	3,670	1,900	24,040 E		1,167	142,700	
1989	114,218 (92,174)	12,519 (10,966)	3,528	1,881	23,577		1,531	133,677	
1990	118,802 (92,903)	13,566 (11,953)	3,743	1,840	27,062		1,534	139,485	

Values after 1988 for City of Fresno include pumpage formerly done by Fresno CWD and Calwa CWD. Values in parentheses for City of Fresno in 1989-90 exclude this other pumpage. Values for Fresno CWD and Calwa CWD combined with E are estimates. Values after 1988 for City of Clovis include pumpage for former FCWD No. 8, and values in parentheses exclude this pumpage.

4, D24-1, and Bakman No. 9) in Spring 1987. As part of studies of the TCE plume south of Pinedale, an aquifer test was conducted on D19-3 in August 1988 (Kenneth D. Schmidt and Associates, 1988). Aquifer tests have also been conducted on eight new City of Fresno wells and six new City of Clovis wells in recent years. Aquifer tests are also available for four other large-capacity wells in or near the urban area. The duration of these tests ranged from 7 to 24 hours. Tables 2, 3, and 4 summarize the results of these tests.

Transmissivity

Transmissivity is an indication of the capability of the aquifer to transmit water through a specific width of the aquifer. Aquifer tests are available for five wells in the North Fresno Growth Area. Except for one well, these wells ranged from about 400 to 600 feet in depth. Transmissivities ranged from 39,000 to 100,000 and averaged 60,000 gpd per foot in this area. Aquifer tests are available for five wells in the Herndon-Shepherd Plan area. Depth of these wells ranged from about 350 to 520 feet. Transmissivities ranged from 13,000 to 75,000 and averaged 41,000 gpd per foot in this area. Aquifer tests are available for four wells in the Southeast Fresno Sub-area. Depth of these wells ranged from about 140 to 290 feet. Transmissivities ranged from about 65,000 to 155,000 and averaged 110,000 gpd per foot. Aquifer tests are available for five wells in Northwest Fresno. Depths of these wells ranged from about 300 to 750 feet. Transmissivities ranged from 112,000 to 253,000 and averaged 190,000 gpd per foot.

The range in transmissivity in the primary urban growth areas is a good indication of the relative well production capacity of these areas. Transmissivity is highest in Northwest Fresno, and next highest in the Southeast Fresno Sub-area. Transmissivity is lowest in the Herndon-Shepherd Plan area and northeast of Clovis, and next lowest in the North Fresno Growth Area. For comparison purposes, the average transmissivity in Northwest Fresno is about three times higher than that in the North Fresno Growth Area. The average transmissivity in Northwest Fresno is almost five times higher than that in the Herndon-Shepherd Plan Area.

Permeability

Horizontal permeability values for coarse-grained (sand or coarser) strata in the older alluvium tapped by large-capacity wells have been determined for six of the aquifer tests. Following is a summary of these values:

<u>Well</u>	<u>Date</u>	<u>Permeability (gpd/ft²)</u>
PS 63	3/19/87	1,600
PS 79	8/16/69	1,900
D5-4	3/15/87	1,700
D19-3	8/5/88	2,300
D24-1	3/18/87	2,400
B-9	4/7/87	2,600

TABLE 2 - SUMMARY OF AQUIFER TESTS
FOR CITY OF FRESNO WELLS

Well No.	Date	Duration (hours)	Perforated Interval (feet)	Pumping Rate (gpm)	Static Level (feet)	Specific Capacity (gpm/ft)	Transmissivity (gpd/ft)
PS44a	08/13/69	24	120-520	1,850	84.8	134	250,000
PS63	03/19/87	7	146-287	905	82.1	38	109,000
PS79	08/06/69	24	120-380	1,750	92.7	125	220,000
PS96	10/22/79	24	220-280 440-510	1,250	113.2	26	76,000
PS132	06/07/90	20	195-510	2,030	126.9	53	100,000
PS133	02/26/90	24	140-190 265-575	2,100	112.4	43	62,000
PS134	06/25/90		170-260 320-410	1,835		64	55,000
PS139	11/13/90	22	190-350 380-620	1,915	100.0	69	113,000
PS140	11/20/90	24	145-205 240-300	960	114.5	15	39,000

Continued: 18

TABLE 2 - SUMMARY OF AQUIFER TESTS
FOR CITY OF FRESNO WELLS (CONTINUED)

<u>Well No.</u>	<u>Date</u>	<u>Duration (hours)</u>	<u>Perforated Interval (feet)</u>	<u>Pumping Rate (gpm)</u>	<u>Static Level (feet)</u>	<u>Specific Capacity (gpm/ft)</u>	<u>Transmissivity (gpd/ft)</u>
PS160	08/09/91	22	190-390 420-760	2,145	85.4	125	253,000
D5-4	03/05/87	7	144 O.B.	995	53.7	48	66,000
D19-3	08/05/88	8	132 O.B.	570	112.6	43	66,000
D24-1	03/18/87	7	142 O.B.	480	40.8	54	109,000

**TABLE 3 - SUMMARY OF AQUIFER TESTS
FOR CITY OF CLOVIS WELLS**

<u>Well No.</u>	<u>Date</u>	<u>Duration (hours)</u>	<u>Perforated Interval (feet)</u>	<u>Pumping Rate (gpm)</u>	<u>Static Level (feet)</u>	<u>Specific Capacity (gpm/ft)</u>	<u>Transmissivity (gpd/ft)</u>
8-A	10/12/91	10	315-510	1,800	110.8	39	68,000
21	06/29/89	24	230-520	1,300	98.5	13	35,000
22	08/17/90	23	190-345	1,135	101.1	14	16,000
23	10/03/90	24	170-367	770	96.3	10	13,000
24	04/24/91		160-380	1,475	86.4	38	75,000

TABLE 4 - SUMMARY OF AQUIFER TESTS
FOR OTHER WELLS

<u>Well No.</u>	<u>Date</u>	<u>Duration (hours)</u>	<u>Perforated Interval (feet)</u>	<u>Pumping Rate (gpm)</u>	<u>Static Level (feet)</u>	<u>Specific Capacity (gpm/ft)</u>	<u>Transmissivity (gpd/ft)</u>
T12S/R19E-36K	03/08/91	7	150-270	995	117	136	112,000
T12S/R21E-27P	03/19/90	7.5	130 T.D.	615	56.4	36	42,000
T12S/R21E-28A	03/21/90	8	-	400	53.9	26	59,000
T12S/R21E-28B	03/20/90	8	80-100 & O.B.	515	58.2	42	97,000
D42-7	10/10/78	24		415	62.8	16	35,000
D42-8	10/26/78	24		140	55.8	3	3,000
Bakman No. 9	04/07/87	7.5	144 O.B.	253	62.5	49	155,000

These permeability values are for relatively clean sand, gravel, and cobbles. Four of the tests are for wells in the Sunnyside area, whereas the other two (PS 79 and D19-3) are for wells in the Northwest Fresno area. These values are typical of those found in similar deposits elsewhere in the southwestern U.S.

Vertical permeabilities of confining beds in the urban area have not been determined by aquifer tests. However, comparing the nature of these beds to that observed elsewhere in alluvial deposits, it is estimated that vertical permeabilities of these beds range from about 0.01 to 2 gpd per square foot.

Specific Yield

Page and LeBlanc (1969) presented estimates of specific yield for the Fresno area. JCE and HA (1969) utilized an average specific yield of 0.13 for the aquifer in the urban area. Exact values of specific yield for the deeper alluvium aren't available. However, average values for the older alluvium (generally above a depth of several hundred feet), in Northwest Fresno and in the Southeast Fresno sub-area probably range from 0.15 to 0.20, based on the coarse-grained nature of these deposits. Average values for the under-lying continental deposits probably range from about 0.07 to 0.12, based on the predominant fine-grained texture of these deposits.

INTENTIONAL RECHARGE

Intentional recharge of canal water has been practiced at Leaky Acres by the City of Fresno since 1971, west of Tarpey Village by the City of Clovis since 1974, and by the FCWD, City of Fresno, and City of Clovis in Fresno Metropolitan Flood Control District storm runoff basins since 1978. The County of Fresno, et al. (1979) summarized amounts of intentional recharge through 1978. By the end of 1978, almost 80,000 acre-feet of canal water had been recharged at Leaky Acres, and a total of almost 100,000 acre-feet in the urban area. In 1978, almost 24,000 acre-feet were recharged, about half of which was at Leaky Acres. Table 5 summarizes amounts diverted for recharge since 1978. Values shown for the City of Clovis include both the City facility and storm basins. Recharge had increased to over 40,000 acre-feet per year by 1984, but decreased substantially during 1985-88. However, recharge had increased by 1989 to almost 50,000 acre-feet per year. During 1980-89, the average intentional recharge was about 29,000 acre-feet per year. This was about 23,000 acre-feet per year greater than for 1965-77. The impact of this recharge on groundwater quality is discussed in a subsequent part of this report. Some water is diverted by F.I.D. for irrigation and lake filling at Woodward Park. This could be considered in-lieu recharge, because it replaced groundwater pumpage. Diversions to Woodward Park averaged about 400 acre-feet during 1980-89.

TABLE 5 - CANAL WATER DIVERTED FOR INTENTIONAL
RECHARGE IN THE URBAN AREA (1979-90)

<u>Year</u>	<u>Leaky Acres</u>	<u>City of Clovis</u>	<u>Storm Basins</u>		<u>Total</u>
			<u>FCWD</u>	<u>City of Fresno</u>	
1979	15,587	6,952		3,068	25,607
1980	14,865	6,751		5,727	27,343
1981	16,864	4,930		3,957	25,751
1982	16,361	6,127	4,060	5,570	32,118
1983	17,017	4,811	4,776	6,856	33,460
1984	18,132	4,918	8,105	10,430	41,585
1985	12,202	2,679	6,014	7,939	28,834
1986	1,527	4,398	9,261	8,682	23,868
1987	7,823	2,383	2,687	3,497	16,390
1988	7,893	2,620	3,467	5,985	19,965
1989	17,589	5,222	8,246	16,404	47,461
1990	20,317	3,169	0	25,323	48,809
Total					

The values are uncorrected for evaporation. Evaporation is estimated to average about two percent. After 1989, FCWD recharge is accounted for under City of Fresno (storm basins).

GROUNDWATER QUALITY

There have been numerous investigations of groundwater quality in the urban area, including Page and LeBlanc (1969), JCE and HA (1969), and Engineering-Science, Inc. (1970). The first of these reports was regional and covered most of the valley portion of Fresno County, whereas the second dealt specifically with the urban area. The third of these reports dealt with central Fresno County, including most of the Water Management Plan Area. Nightingale (1970) made one of the first evaluations of changes in the quality of well water over time in the Fresno area.

A number of groundwater quality studies have been conducted in the area northeast of the urban area (termed the "Northeast Area"). These include evaluations of the effect of irrigation on groundwater quality (Nightingale, 1972 and 1974, and Nightingale and Bianchi, 1974), regional groundwater quality in the Northeast Area (County of Fresno, 1976), and an evaluation of high nitrate areas in groundwater of the Northeast Area (Day and others, 1977).

Investigations of the quality of groundwater in the urban area have included those by the California Division of Water Resources (1952 and 1953), the California Department of Water Resources (1957 and 1965), Behnke and Haskell (1968), and Schmidt (1971). These studies focused on the effect of man's activities on groundwater quality, including disposal of industrial wastes, sewage effluent, septic tanks, cooling water, and urban storm runoff. The latter Department of Water Resources (DWR) study and the Schmidt dissertation of 1971 focused on nitrate contents. Nightingale and Bianchi (1977) reported on the groundwater quality aspects of recharge of canal water at the Leaky Acres Project.

Extensive groundwater quality investigations of the urban area and adjacent lands were completed as part of the 208 Water Quality Management Program (County of Fresno, et al. 1979) and 205J Water Quality Management Program (County of Fresno, et al, 1986). Whereas the 208 program studies focused on inorganic chemical constituents in groundwater, by the time that the 205J program studies were undertaken, the pesticide dibromodichloropropane (DBCP) had been found in groundwater in part of the urban area. The report on the results of the 205J program thus included a discussion of DBCP in groundwater beneath the Water Management Plan Area, including the urban area.

Water from numerous large-capacity wells in the urban area has been sampled for analysis of inorganic chemical constituents for several decades. Although relatively few water samples were collected and analyzed prior to the early 1960's (when the DWR nitrate study was done), numerous samples have been collected and analyzed since that time. Historical chemical analyses for water from public-supply wells in the urban area were originally tabulated as part of the "701 Study" (Engineering-Science, Inc., 1970). This tabulation was updated and expanded during Schmidt's (1971) nitrate study in the Fresno-Clovis Metropolitan Area. This tabulation was

again updated and expanded through 1978 as part of the 208 program. The results of chemical analyses of water from City of Fresno wells since 1977 have been computerized, a printout of the results is available, and this was used in this evaluation. The results of chemical analyses, including trace organics, and alpha activity, for samples collected in recent years were also obtained from the California Department of Health Services (DOHS) and other water purveyors in the urban area.

Inorganic Chemical Constituents

Areal Distribution

Four inorganic chemical constituents were selected for detailed discussion, based on their occurrence in groundwater and their importance to water use in the urban area. Total dissolved solids (TDS) was chosen primarily due to its importance for public supply, and also because it can be used to provide information on the major sources of recharge in the area. Nitrate has been one of the most important inorganic chemical constituents in groundwater of the urban area for decades. It is the only inorganic chemical constituent in the Primary Drinking Water Standards that is known to have been found in water from some large-capacity wells, in amounts exceeding the maximum contaminant level (MCL). Hardness was selected because hard groundwater is common in shallow groundwater in parts of the urban area, particularly near Sunnyside. Manganese was selected because manganese contents exceeding the recommended MCL are common in east Clovis, near Dry Creek, and near the City of Clovis recharge facility.

The discussion in this part of the report largely concerns public-supply wells in the urban area. The quality of groundwater in a local area (i.e., near a source of contamination) may be different than shown by the results of public-supply well sampling. The quality of water pumped from a well also depends on well construction, because there are usually significant vertical variations in groundwater quality. Thus the quality of water from shallow wells often is not the same as that of water from deep wells.

Total Dissolved Solids. Figure 15 shows TDS contents in water from wells in the urban area in 1989-91. TDS contents of less than 100 mg/l were present only beneath and downgradient of Leaky Acres and the City of Clovis recharge facility. The relatively low salinity of groundwater in these parts of the urban area is due to the intentional recharge of low salinity canal water for two decades. Although the low salinity groundwater is generally considered beneficial, it has a higher corrosiveness than other groundwater in the urban area. TDS contents in groundwater beneath the northern half of the urban area normally ranged from about 100 to 250 mg/l, except in two formerly unsewered areas (Figarden and former FCWD 11 and 14, near Hoover High School). In these two areas, TDS contents ranged from about 250 to 400 mg/l. South of McKinley Avenue, TDS contents in water from most wells exceeded 250 mg/l. South of McKinley Avenue, TDS contents exceeded 250 mg/l in water from most

wells, except in part of downtown Fresno and west and northeast of Sunnyside. The relatively low TDS contents in groundwater west and northeast of Sunnyside appears to be due to seepage from the Fancher Creek, Briggs, and Washington Canals.

There are several known plumes of high salinity groundwater in or near the urban area which are not shown on this figure, because no public-supply wells are located near them. One of these extends southwest from the Southern Pacific Railroad Yard (near Shields Avenue and Highway 99). This plume has been extensively evaluated, including during the 208 and 205J programs, based on sampling of small-capacity domestic wells. TDS contents in shallow groundwater within this plume have exceeded 650 mg/l. Another plume of high salinity groundwater extends northwest from the Fresno Meat Company, near North and Fig Avenues. A TDS content exceeding 2,000 mg/l was found in water from a well in that area in 1972. Both of these plumes are discussed in more detail in a subsequent section in this report. There is another area of relatively high TDS content near Church and West Avenues (PS 88), where TDS contents exceeded 500 mg/l.

Nitrate. Figure 16 shows nitrate content in water from wells in the urban area in 1989-91. Nitrate contents were less than 25 mg/l in most of the urban area, and less than 15 mg/l in the north and northwest parts. The areas of lowest nitrate contents correspond to those with low salinity, and this is due to recharge of stream-flow and canal water with low nitrate content and salinity.

Nitrate contents have exceeded the MCL of 45 mg/l in water from only a few public-supply wells in the urban area. One of the largest areas of high nitrate contents in 1989-91 was west of Clovis Avenue, between Olive and Belmont Avenues. Nitrate contents in water from three Bakman Water Company wells in this area ranged from 47 to 55 mg/l in 1990. Nitrate contents in water from two other wells (D17-2 and D22-1) have been near the MCL in recent years. This area is located immediately downgradient of former waste disposal fields at the Gallo Winery. The area is also down-gradient of a large area of nitrate contents exceeding 45 mg/l, that extends to the northeast east of Clovis Avenue, along the floodplain of Fancher Creek. The nitrate content was 65 mg/l in 1989 in water from a City of Fresno well near West and Church Avenues (PS 88) and this well was closed. This well is located in a northeast trending area of high nitrate that extends southwest from downtown Fresno. Both of these high nitrate areas adjacent to the urban area were discussed in detail in the 208 program report (County of Fresno, et al, 1979).

Another area where nitrate contents exceeded the MCL in 1989-91 was in the southernmost part of the former unsewered Figarden area. Three wells in former FCWD 1 and 2 had nitrate contents ranging from 50 to 57 mg/l in 1989-90, and these wells are closed. A nitrate content of 68 mg/l was present in water from an unused public supply well at Greenfield Village (Jensen and Clovis Avenues) in 1989. Several wells in the unsewered part of the Sunny-

side area had nitrate contents approaching the MCL. Another area of high nitrate, that was not delineated based on public-supply well sampling, was one of the brine plumes previously discussed. Nitrate contents commonly exceeded 45 mg/l in the northwest trending plume from the Fresno Meat Company (near North and Fig Avenues) in 1979.

Figure 16 also clearly indicates the impact of septic tanks that were formerly used in parts of the urban area. One of the best examples is in Figarden, where the former unsewered area is essentially defined by the area where nitrate contents exceeded 15 mg/l in the well water. Nitrate contents exceeded 25 mg/l beneath much of the former unsewered area, and exceeded 45 mg/l beneath the oldest developed part of this area (to the south) in 1989-91. Nitrate contents exceeding 25 mg/l were also common in the Mayfair Area (southwest of the Fresno Air Terminal), which was also formerly unsewered, in 1989-91. This area had some of the smallest lots where septic tanks were formerly used in the urban area. Nitrate contents in water from some wells in this area historically exceeded the MCL. However the combination of sewerage and recharge at Leaky Acres and the City of Clovis facility to the northeast since 1970 has reduced nitrate contents in the north part of this area and stabilized them in the south part. The Sunnyside area has also been on septic tanks, and nitrate contents also exceeded 25 mg/l in groundwater beneath most of this area in 1989-91.

Nitrate contents in water from most of the wells downgradient of Leaky Acres and the City of Clovis recharge facility were less than 5 mg/l in 1989-91, except for the Mayfair Area. The lowest nitrate contents in water from wells in the urban area were in shallow groundwater near the San Joaquin River and downgradient of facilities for intentional recharge.

Although high nitrate contents have caused five City of Fresno wells to be closed, and the use of three Bakman Water Co. wells to be affected, construction of deeper wells with adequate annular seals has been demonstrated to be very effective in mitigating the problem. Such mitigation has been successfully practiced for more than two decades. Vertical trends in groundwater quality are discussed in a subsequent part of this report.

Hardness. Figure 17 shows total hardness, expressed as calcium carbonate, for water from wells in the urban area in 1989-91. Hardness was less than 100 mg/l (which is considered low in this area) in two large areas. The first was in North Fresno, within several miles of the San Joaquin River. The second generally extended from near Leaky Acres and the City of Clovis recharge facility westerly to near Highway 99. The lowest hardness contents (less than 50 mg/l) were present at and immediately downgradient of these major recharge facilities.

Total hardness exceeded 300 mg/l only in several areas, the largest of which was beneath the southeastern part of the Sunnyside area. Two smaller areas were near PS 55, east of Clovis Avenue

along Shields Avenue, and at PS 88. Water from both of these wells also had high nitrate contents. Experience has shown that proper well construction techniques (i.e., deeper wells) can also mitigate the high hardness contents in most parts of the San Joaquin Valley.

Manganese. The recommended MCL for manganese in public water supplies is 0.05 mg/l. Historically, few public-supply wells in the urban area have produced water exceeding the MCL. However, a former City of Fresno well (PS 83) near Fowler and Dakota Avenues was abandoned in the early 1970's because the manganese content exceeding the MCL. Manganese problems have become more common with expansion of the urban area to the east. Figure 18 shows areas where manganese contents in water from wells have exceeded 0.01 mg/l. Besides the results from public-supply wells, this figure also shows contours of manganese content in the East Clovis area, based on sampling of many private domestic wells in this area in 1990. The largest known area of high manganese content is in East Clovis. Two City of Clovis wells (No. 13 and No. 16) produced water with manganese contents ranging from 0.13 to 0.27 mg/l, exceeding the recommended MCL of 0.05 mg/l, in 1990. In addition, water from City of Clovis Well No. 20 (near Barstow and Armstrong) had a manganese content of 0.04 mg/l, just below the MCL, in 1989. A test well drilled near Ashlan and Fowler Avenues (one-half mile north of former City well PS 83) also encountered high manganese contents in the shallow groundwater.

Relatively high manganese contents have been found in well water at and northeast of Highway City. Manganese contents in water from two City of Fresno wells (PS 44a and PS 104) ranged from 0.04 to 0.06 mg/l in 1989-90. Test wells in the Herndon-Shepherd Plan area have indicated high manganese in shallow groundwater in part of that area, particularly near Dry Creek. A test well near the City of Clovis recharge facility (near Well 4-AA) indicated high manganese contents in shallow groundwater.

Vertical Distribution

The vertical distribution of constituents in the groundwater can be determined in several ways. First, water samples can be collected from specially designed and constructed test wells or the pilot holes for new wells. Second, wells are sometimes deepened or replaced by adjacent deeper wells. The quality of water pumped from the well can be compared before and after deepening. Sometimes there are adjacent wells of different depth that can be compared. Open-bottomed, or unperforated wells provide extremely useful information related to vertical differences in groundwater quality, since they produce water from specific strata, as opposed to gravel packed wells with perforations extending over several hundred feet in depth. Third, specially designed monitor wells tapping groundwater in discrete depth intervals can be installed and monitored. Dozens of observation wells have been installed for the City of Fresno in recent years, and each generally has several monitor wells tapping different depth zones. In general, data indicate that the quality of groundwater in the urban area usually

improves with depth to at least about 500 feet. An exception is in the North Fresno Growth Area and part of the East Clovis Area, where reduced (blue-green) deposits are encountered above that depth. Groundwater in these deposits is present under anaerobic or reduced conditions, and can have high contents of iron, manganese, arsenic, and hydrogen sulfide.

Schmidt (1971) determined the vertical distribution of nitrate in two unsewered parts of the urban area (Figarden and Mayfair). This was based on water samples collected primarily from open-bottomed wells in 1970. The highest nitrate contents were present in the upper 50 to 60 feet of the aquifer.

Groundwater of high salinity (connate water) underlies the usable aquifer in the Fresno area, except near the east edge of the San Joaquin Valley. Page and LeBlanc (1969, Plate 17) contoured the base of the fresh groundwater (top of the connate water). Fresh groundwater was defined as having a TDS content of less than 2,000 mg/l. The information that they used was primarily derived from interpretation of electric logs for deep oil or gas exploration wells. More recent data from water wells and test holes have shown that the eastern edge of this body of connate water is near Pinedale. Test wells extending through the alluvium and down to bedrock in the Herndon-Shepherd Plan area have not encountered connate water. Deep exploration holes in Northwest Fresno and near Calwa have encountered connate water above a depth of 2,000 feet. Fresh groundwater extends to a depth of about 1,300 feet beneath downtown Fresno, and to about 1,700 feet northwest of Figarden.

In recent years, numerous test well, pilot hole sampling, and monitor well installation programs have been undertaken in the urban area. The results of these programs have confirmed that TDS, nitrate, and hardness contents normally decrease with increasing depth, particularly beneath areas that were formerly unsewered or were irrigated. Groundwater in the older alluvium is normally aerobic or oxidized. Groundwater in the reduced, deeper underlying continental deposits, on the other hand, is reduced. The quality of groundwater below a depth of about 250 feet has normally not been affected by man's activities. TDS, nitrate, and hardness contents in this water are normally low, but significant contents of iron, manganese, hydrogen sulfide, and sometimes arsenic can be present, particularly in deposits that are blue or green in color. The blue-green deposits are particularly important where they are present above a depth of about 500 feet, such as in the North Fresno Growth Area, and parts of the East Clovis area. At greater depths, they may be too deep to be tapped by water wells.

Time Trends

Sufficient data are available to indicate long-term time trends in the inorganic chemical quality of well water in the urban area.

Statistical Evaluation. One of the first determinations of changes of the quality of well water with time was by Nightingale (1970), who evaluated salinity and nitrate in the urban area and surrounding agricultural area. He used records for 1950-67 and found that the salinity of well water increased linearly with time and the mean nitrate content increased from 10 to 16 mg/l in the urban area during that period. One of the limitations of data available at that time was that few specific wells had been regularly sampled prior to 1967. The trends that were observed were for a period prior to the commencement of intentional recharge in the urban area and prior to the sewerage of the previously unsewered areas such as Figarden and Mayfair.

Nitrate (1950-70). Schmidt (1971) determined long-term time trends for nitrate content in well water in specific parts of the urban area from the 1950's through 1970. The specific areas investigated included unsewered tracts near Figarden, the Mayfair District, and the west part of Tarpey Village. Long-term trends were also evaluated in the downtown Fresno area, which has been sewerage by that time for many decades.

The predominant time trend through 1970 in the northern part of the unsewered area near Figarden was a constancy of nitrate. In the southern part of the area, where there was a greater density of septic tanks that had been there for a longer period of time, nitrate contents in water from about one-half of the wells increased with time, whereas contents in water from the remainder usually were relatively constant. Nitrate contents in water from most wells in the Tarpey Village Area increased with time, particularly between 1958 and 1963. This was probably associated with the development of septic tanks in Tarpey Village and possibly disposal of sewage effluent from a nearby sewage treatment plant (the former City of Clovis facility). Nitrate contents in water from wells tapping the deeper parts of the aquifer (i.e., more than about 60 feet below the water level) were relatively constant.

The greatest densities of septic tanks that were formerly in the urban area were in the Mayfair area. Water from all wells that were sampled in this area in 1951 had less than 15 mg/l nitrate. By 1963, nitrate contents in about one-half of the sampled wells exceeded 25 mg/l. The overall pattern was increasing nitrate contents in water from shallow wells and relatively constant nitrate contents with time in water from deep wells. By 1970, nitrate contents in water from some wells exceeded 45 mg/l, or the drinking water limit. In the downtown Fresno area, which had been sewerage for many decades, nitrate contents in water from most wells either decreased or were constant with time. The exception was for shallow wells, most of which had been replaced by deeper wells by the 1960's. Nitrate contents in water from some of these shallow wells increased until their abandonment, and the source of nitrate was unknown.

In summary, the predominant time trend in water from deep wells in the urban area through 1970 was a constancy of nitrate

content. In unsewered urban areas, nitrate contents in water from shallow wells frequently increased for a period of about ten years after commencement of septic tank use. Thereafter, nitrate contents increased at a more gradual rate. Water from deep wells in or near unsewered areas showed little or no change in nitrate content with time.

Update Through 1978. Several significant events occurred in the early 1970's related to potential sources of nitrate in groundwater in the urban area. Sewering began in 1970 in the Mayfair area, and most of the urban area is now sewered, except for part of the Sunnyside Area. The City of Clovis Sewage Treatment Plant (formerly located west of Tarpey Village) was closed down in 1972. All of the smaller sewage treatment plants other than the one at Malaga were closed down as part of a regional sewerage program. Most large areas of septic tanks and many small sewage treatment plants were thus eliminated as potential sources of nitrate in groundwater in the urban area. Also, intentional recharge of excellent quality (low salinity and nitrate content) canal water began at Leaky Acres, upgradient of the northern part of the Mayfair area, in 1971. Additional recharge of canal water by the City of Clovis at a site west of Tarpey Village commenced in 1974. Nightingale and Bianchi (1977) discussed decreases in salinity and chloride content of groundwater near and downgradient of Leaky Acres. Because of the low salinity of the canal water which had been recharged, the salinity of groundwater had already markedly decreased over a distance of at least one mile downgradient of Leaky Acres by 1975.

Hydrographs for electrical conductivity, nitrate, chloride, and hardness content for water from about 120 large-capacity wells in the Fresno-Clovis Urban Area were prepared as part of the 208 Water Quality Management Program. Personnel of the County of Fresno Environmental Health Division collected, tabulated, and plotted data extending through 1978. Data were collected and tabulated to update a previous compilation, which extended through 1970.

Salinity and chloride content in water from wells within the influence of Leaky Acres and the Clovis recharge facility decreased with time after 1970. Beyond the influence of Leaky Acres and the City of Clovis recharge facility, there was little difference in time trends observed from 1971 to 1978, compared to those observed prior to 1971. That is, nitrate contents were continuing to gradually increase in water from shallow wells in unsewered areas, and remaining relatively constant in deep wells. Electrical conductivity and chloride time trends often were similar to nitrate time trends.

Update Through 1991. As part of this investigation, many of the water quality hydrographs prepared for City of Fresno wells as part of the 208 program were updated through 1991. Figure 19 shows typical trends for electrical conductivity in water from three public-supply wells in the urban area.

Well D19-2 is located northwest of the Figarden Shopping Center. This well was drilled to 190 feet and cased to 152 feet (open-bottomed). Electrical conductivity increased significantly from the late 1950's through the early 1980's, then appeared to stabilize. Electrical conductivity was about 250 micromhos in 1959 and about 550 micromhos in 1990. This trend is considered typical of the influence of septic tanks in formerly unsewered areas. Within about ten years after the area was sewered, the previous increases in salinity essentially stopped. Well D10-4 is located in the northeast part of the Mayfair District, downgradient and within about one-third of a mile of Leaky Acres. This well was drilled to a depth of 225 feet and cased to 185 feet (open-bottomed). Electrical conductivity decreased from about 250 micromhos in 1958 to about 100 micromhos in 1978, and appeared to stabilize after that time. The salinity of the water pumped from this well indicates that the majority of pumped water is derived from recharge at Leaky Acres. Although recharge of low salinity canal water is considered beneficial in most aspects, one disadvantage is an increased corrosiveness, which is important in terms of regulations such as the new lead rule. Well PS 37 is located south of the Mayfair District, and is perforated from 141 to 290 feet in depth. Electrical conductivity increased from about 250 micromhos in 1955 to almost 400 micromhos in 1974, and has been relatively constant since that time. A review of electrical conductivity hydrographs for other wells in the urban area indicate that constant trends have predominated, except for some increases in formerly unsewered areas and decreases due to intentional recharge.

Hydrographs for wells in downtown Fresno generally indicate relatively constant electrical conductivities after the early 1970's. The electrical conductivity of water from some wells increased in the late 1960's. In Tarpey Village, the electrical conductivity of water from most wells has been relatively constant during the past several decades. For most wells in the Sunnyside area, the electrical conductivity has been constant or has slightly decreased since the early 1970's. In the area south of the Fresno Air Terminal, the electrical conductivity of water from several wells (in former FCWD No. 17 and 22) has increased in the recent decade, whereas the electrical conductivity has remained essentially the same in water from other wells. In the south part of the Mayfair District, which has been unaffected from recharge at Leaky Acres, electrical conductivities normally rose through the late 1970's, and have remained relatively constant since that time.

Figure 20 shows typical trends for nitrate contents in water from three public-supply wells in the urban area. Well D1-5 is located near Gettysburg and Thorne Avenues, in the formerly unsewered Figarden area. The well was drilled to a depth of 225 feet and cased to 142 feet (open-bottomed). Nitrate contents in water from this well increased from less than 3 mg/l in 1957 to 25 mg/l in 1983. Since 1983, nitrate contents have been relatively constant. This pattern in nitrate content in water from this well is similar to electrical conductivity. The nitrate contents indicate that within about ten years after sewerage of the area, nitrate

contents stabilized. Well D1-3 is located near Wilson and Dakota Avenues, also in the formerly unsewered Figarden area. This was in an older part of Figarden with larger lots than the previously discussed area. The well was drilled to a depth of 185 feet and cased to 154 feet (open-bottomed). The nitrate content was 15 mg/l in 1955 and remained near that value through the early 1970's. After the early 1970's, the nitrate content rose to between 20 and 25 mg/l and stayed at that level thereafter. The cause for the increase could have been partly related to historical water-level declines in the area.

PS 17 is located near Van Ness and Shields Avenues. The well was drilled to a depth of 226 feet and cased to 169 feet (open-bottomed). This well is located south and downgradient of the formerly unsewered Figarden area. Nitrate content increased gradually, from 5 mg/l in 1952 to 13 mg/l in 1976. After 1976, the nitrate content stabilized, normally ranging from about 12 to 16 mg/l. The pattern in this well follows that shown by Well D1-3.

Nitrate contents in water from wells in downtown Fresno have been relatively constant since the early 1970's. However, nitrate contents in water from several wells on the fringe of the downtown area increased in the 1950's to 1970's. Nitrate contents in water from wells in Tarpey Village generally increased through about 1970, and have either stabilized or decreased since that time. This is due primarily to sewerage of the previously unsewered part of Tarpey Village, closure of the former City of Clovis Wastewater Treatment facility, and intentional recharge to the west of Leaky Acres since 1974. In Sunnyside, nitrate contents in water from some wells have increased since 1960, and these coincide with where nitrate contents are presently just below the MCL. These increases are attributed primarily to septic tank effluent. Nitrate contents in water from other wells have remained relatively constant.

South of the Fresno Air Terminal, nitrate contents have increased since the 1950's in water from several wells in District 17 and 22 and in some Bakman Water Company wells. This is in the same area where several wells have had nitrate contents near or exceeding the MCL in recent years. The increasing salinity and nitrate content indicate a source of degradation to the northeast. In the Mayfair District, south of the influence of recharge from Leaky Acres, nitrate contents have been relatively constant since the late 1970's, following sewerage of the area. However, within the influence of Leaky Acres recharge, nitrate contents have decreased since the late 1970's.

Trace Organic Chemical Constituents

The primary trace organic chemical constituents that have been found in water from some public-supply wells in the urban area are DBCP, ethylene dibromide (EDB), and several volatile halocarbons. The most common volatile halocarbons are trichloroethylene (TCE) and tetrachloroethylene (PCE). In terms of amount of contaminated groundwater, the largest problem by far is due to DBCP.

DBCP

Previous Reports and Sampling. Two reports have been prepared for the City of Fresno on DBCP in groundwater in the Southeast Fresno Sub-area (Schmidt, 1984 and Kenneth D. Schmidt and Associates, 1987b). A map was prepared in the first of these reports showing the areal distribution of DBCP in groundwater as of 1982-84. In the second of these reports, both the vertical distribution and time trends for DBCP were discussed in detail. As part of a more recent study of groundwater in this sub-area (a joint feasibility study by the Fresno Irrigation District and City of Fresno), a DBCP map was prepared for 1990-91. This map included data from 35 private wells that were sampled in January 1991 and another 18 private wells that were sampled during May 1991 in the adjacent upgradient rural area.

Another report was prepared for the City of Fresno on the North Fresno Growth Area (Kenneth D. Schmidt and Associates, 1987a) that included a map of DBCP contents in groundwater. This map included data from nineteen private domestic wells that were sampled in Spring 1987. These wells were sampled because of the absence of public-supply wells in most of the east part of that area at that time. In May 1991, J. H. Kleinfelder and Associates, under contract to the City of Fresno, sampled 21 private wells in and near the north part of the North Fresno Growth Area for DBCP analyses.

For a number of years, a private well monitoring program and monitor well sampling program (for which DBCP is routinely analyzed) has been conducted in and near the Thompson-Hayward facility, east of the Fresno Air Terminal. Analyses were available for 72 wells that were sampled in December 1989.

About 30 private domestic wells in the Herndon-Shepherd Plan area were sampled in Spring 1989, and about three dozen private wells in the East Clovis area were sampled in June 1990 by Kenneth D. Schmidt and Associates, as part of studies for the City of Clovis. Information on sampling of private domestic wells and small water systems was also available from the County of Fresno Environmental Health.

Areal Distribution. Figure 21 shows the range in DBCP contents found in water from public supply wells in the urban area during 1989-91. Actual values are shown for water from public supply wells, where the contents exceeded 0.02 ppb. Only contours are shown in rural areas where private wells were sampled, for confidentiality. The largest areas of DBCP contamination were present in two localities:

1. In the northeast part of the urban area, generally northeast of a line extending from near Cedar and Teague Avenues south to near Cedar and Bullard Avenues, thence southeast to the northeast part of the Fresno Air Terminal.

2. In southeast Fresno, generally southeast of a line extending from Calwa on the west to near Greenfield Village, thence northerly to near Clovis Avenue and Belmont Avenue.

The first of these two areas includes the northernmost and southeastern parts of the North Fresno Growth Area, the western part of the Herndon-Shepherd Plan Area, and parts of the City of Clovis, Tarpey Village, and the East Clovis area. In 1990-91 DBCP contents exceeding the MCL were present in seven City of Clovis wells in this area, in three City of Fresno wells, and in two additional Fresno Air Terminal wells operated by the City of Fresno. The highest DBCP contents were present in a northeast trending zone, extending from City of Fresno PS 85 (near Maple and Palo Alto Avenues) on the southwest to near Shepherd Avenue, between Peach and Minnewawa Avenues, on the northeast. DBCP contents exceeded 2.0 ppb in groundwater in this area in 1990-91. The area of DBCP contents exceeding 0.5 ppb was more than four miles long and averaged about one and one-half miles wide. There were two areas in or near the north part of the North Fresno Growth Area where DBCP contents also exceeded 2.0 ppb. There were two other local areas where DBCP contents exceeded 1.0 ppb (near Herndon and Minnewawa Avenues and in the north part of Tarpey Village). Another fairly large area of DBCP contents exceeding 1.0 ppb extended northeast from the northeast part of the Fresno Air Terminal to near Ashlan and Locan Avenues.

Water from 18 wells in the Southeast Fresno Sub-Area at least periodically had water with DBCP contents exceeding the MCL in 1989-91. This included four wells in Calwa, two wells in Greenfield Village, three Bakman Water District wells, and nine other City of Fresno wells in the Sunnyside area. DBCP contents in groundwater in much of this area exceeded 1.0 ppb in 1990-91. Because of the large extent of contamination, this area is discussed in more detail in a subsequent part of this report.

Elsewhere in the urban area, DBCP contamination was generally at much lower contents and more localized than in the two large areas previously discussed. Two wells in the Figarden area (D19-3 and D25-5) had DBCP contents ranging from less than 0.02 to 0.09 ppb. Water from four wells west or southwest of CSUF had DBCP contents ranging from 0.02 to 0.07 ppb (PS 53, PS 64, PS 65, and D14-2). The northerly three of these wells appeared to be down-gradient of PS 85 and the northeast trending lobe of high DBCP content previously described, as of Spring 1991. Seventeen wells in an area near the Mayfair area had DBCP contents periodically exceeding 0.02 ppb. In water from most of these wells, the DBCP contents were less than 0.10 ppb. There were six other wells south of Huntington Boulevard and north of California Avenue where DBCP contents were also normally in the range of 0.02 to 0.10 ppb.

An apparently relatively isolated case of DBCP content exceeding the MCL is in water from D32-3, located at the San Joaquin Country Club, near the San Joaquin River. Another case is D17-2,

northwest of Kings Canyon Junior High School, where DBCP contents ranged from 0.49 to 1.2 ppb.

As of Summer 1991, there were 15 City of Fresno wells, three City of Clovis wells, and three Bakman Water Company wells closed because of DBCP contamination. In addition, water from one City of Fresno well with DBCP contamination (D24-4) was being treated. The vertical distribution and time trends for DBCP content in the two largest areas of contamination are discussed in subsequent parts of this report.

Ethylene Dibromide

Figure 22 shows the distribution of ethylene dibromide (EDB) in groundwater in an near the urban area in 1990-91. The locations of public supply wells for which analyses are available are shown, and for wells where EDB contents exceeded the MCL of 0.02 ppb, the range in EDB content is provided. There are three areas outside of the present urban area where there has been extensive sampling of private wells for EDB analyses. These are the Herndon-Shepherd Plan Area, the East Clovis Area, and southeast Fresno. For these areas, the locations of the private wells that were sampled are not shown, but several zones are delineated, within which the private wells sampled had EDB contents exceeding the MCL.

Water from two wells (D25-5 and KV-ES) north of Figarden Village had EDB contents ranging from less than 0.02 ppb to 0.07 ppb, periodically exceeding the MCL. Water from the first of these wells also has also had detectable DBCP. The source of the EDB in groundwater in this area is unknown. EDB contents ranging from less than 0.02 to 0.08 ppb were found in water from two wells in the Mayfair area (NEG-2W and NEG-2E). The source of the EDB in this area is also presently unknown.

Two areas of EDB contents exceeding the MCL have been found in the Herndon-Shepherd Plan area. One is in water from City of Clovis Well No. 21, east of Willow Avenue and south of Alluvial Avenue. This well is in an area of high DBCP contents in the shallow groundwater. Another is in a triangular shaped area between Herndon and Nees Avenues and Marion and Fowler Avenues. A new City of Clovis well (No. 23) was recently drilled in this area, but was sealed off opposite shallow strata and has been free of EDB. Based on sampling of numerous other wells in the plan area, the occurrence of EDB appears to be highly localized. The source appears to be pesticide applications to agricultural lands in close proximity to the sampled wells.

In the East Clovis area, a zone of EDB contents in groundwater exceeding the MCL was found between Barstow and Gettysburg and Fowler and Temperance Avenues. Three City of Clovis wells are located in this area, and EDB concentrations in water from them have ranged from less than 0.02 ppb to 0.10 ppb. Groundwater in this area also contains relatively high DBCP contents. The source of the EDB in this area is also believed to be pesticide applica-

tions on agricultural lands in close proximity to the sampled wells.

The highest EDB contents known in groundwater in the urban area are present in the eastern part of the Sunnyside area. Water from four wells (D24-1, D24-2, D24-4, and D29-1) had EDB contents periodically exceeding the MCL. The highest contents, ranging from 0.1 to 1.1 ppb, were found in water from D29-1. The source of the EDB also appears to be pesticide applications to agricultural lands in close proximity to the sampled wells. This is also the part of the urban area where some of the highest DBCP contents are present in the groundwater.

Apparently more localized zones of EDB contamination have been found at two other wells in the southern part of the urban area (C-3 and PS 82). EDB contents in water from PS 82, near the Internal Revenue Service Center, ranged from less than 0.02 to 0.04 ppb. An EDB content of 0.11 ppb was found in water from C-3 in Calwa.

In summary, water from 13 public-supply wells in the urban area had EDB contents at least periodically exceeding the MCL of 0.02 ppb in 1989-91. Six of these wells were in southeast Fresno (including Calwa), and three were in East Clovis. In addition, water from two other public-supply wells had EDB contents at least periodically equal to the MCL. As of Summer 1991, ten City of Fresno wells and two City of Clovis wells were closed due to EDB contamination.

Volatile Halocarbons

Figure 23 shows contents of volatile halocarbons found in water from public-supply wells in the urban area in recent years. More information on volatile halocarbon contamination of groundwater in the urban area at and near specific sources is provided in a subsequent part of this report. At least three significant plumes of volatile halocarbons have been indicated by sampling of public-supply wells in the urban area.

1. A TCE plume extending from west of Pinedale south to about Barstow Avenue
2. A TCE plume extending southwest from the south part of the Fresno Air Terminal
3. A PCE plume near the northeast corner of the Fresno Air Terminal

The first plume appears to be the largest and to have the highest contents, based on existing information. TCE contents exceeding 300 ppb were present in water from two public-supply wells (Pinedale CWD No. 3 and D25-2) in Summer 1988. TCE contents in water from three other public-supply wells (D19-3, D25-4, and D25-8) have exceeded the MCL of 5 ppb. The contamination apparently

originated in the Pinedale industrial area and the contaminated zone appears to be about two miles long and about one-half mile wide. This plume is discussed in more detail in a subsequent part of this report.

Volatile halocarbon contamination has been found in two locations at the Fresno Air Terminal. Water from three public-supply wells south of the airport (PS 70, D22-1, and D22-2) had TCE contents ranging from 13 to 55 during 1988-91. Water from PS 70 also contained PCE contents near or at the MCL of 5 ppb, and low contents of cis-1,2-dichloroethylene (DCE), 1,2,3-trichloropropane, 1,2-dichloropropane, and carbon tetrachloride. A PCE content of 30 ppb, exceeding the MCL of 5 ppb, was found in water from Fresno Air Terminal Well No. 1, west of Clovis Avenue and south of Shields Avenue. Water from PS 59 had PCE contents ranging from 1.1 to 14 ppb during 1989. Water from D17-2 had PCE contents ranging from <0.5 to 0.5 ppb during 1989-90. Water from other sampled public-supply wells in this vicinity has not had detectable PCE contents. This plume is discussed in more detail in a subsequent part of this report.

Water from Well C-5 in Calwa contained several volatile halocarbons at contents exceeding detection limits, however only the TCE content (ranging from 2 to 11 ppb) periodically exceeded the MCL. Most of the rest of the cases of detectable volatile halocarbons in public-supply wells in the urban area in 1989-91 were limited to PCE and occasionally dichloroethylene (DCE). The source of these constituents in these cases has not been determined. Water from two wells (PS 15a and PS 37) between downtown Fresno and the Fresno Air Terminal periodically had PCE contents exceeding the MCL. PCE contents in water from PS 37 ranged from 1 to 7 ppb, and contents in water from PS 15 ranged from 3 to 14 ppb.

As of Summer 1991, seven City of Fresno wells were closed and another was on standby due to TCE contamination. Two City of Fresno wells were closed and another was on standby due to PCE contamination.

Radiological Constituents

Public-supply wells are routinely tested for alpha activity. There are no known public-supply wells which have produced water with an alpha activity exceeding the MCL of 15 picocuries per liter. Water from four wells (PS 29, PS 37, GFV-N, and D7-1) had alpha activities ranging from about 11 to 13 picocuries per liter in 1989. These all are essentially relatively shallow, older wells. These are among the highest values known to be present in public-supply wells in the urban area. The EPA proposed a limit for radon of 200 picocuries per liter in the July Federal Register. In July 1991, samples were collected from fifty geographically distributed City of Fresno wells for radon analyses. Values ranged from about 300 to 2,400 picocuries per liter. Highest values were generally in the northern part of the area, near the San Joaquin River. The average radon activity in water from these wells was

about 860 picocuries per liter, and all values exceeded the proposed limit (excluding possible counting errors). A blank water sample sent in with the well samples contained 200 ± 200 picocuries per liter. If EPA adopts such a standard, it appears that most of the public-supply wells in the urban area would not meet the standard. The radon limit could thus have a significant economic impact on the water supply in the urban area. These radiological constituents are believed to be related primarily to natural factors.

MAJOR KNOWN POINT SOURCE GROUNDWATER CONTAMINATION SITES

In this section of the report, known major incidences of groundwater contamination or near the urban area due to point sources are discussed. Contamination from nonpoint or diffuse sources, such as agricultural practices, are considered elsewhere. Included in the point source sites are two brine plumes, a number of sites where gasoline derived constituents have reached the groundwater, several pesticide manufacturing or handling plant sites, and several significant plumes of volatile halocarbons. Of these sites, only two of the volatile halocarbon plumes are known to have affected public-supply wells. The extent of groundwater contamination at some of these sites has been at least partially determined through installation and sampling of monitor wells. At several of these sites, the extent of contamination has been partly determined based on sampling of private domestic and/or irrigation wells. Figure 24 shows these sites and the extent of contamination in cases where it has been delineated.

Fresno Railroad Yard

Brine contamination of groundwater southwest of the Fresno Railroad Yard (between Clinton and Dakota Avenues) has been evaluated since the 1950's. Wastewater from an ice plant and water softening plant were formerly disposed into pits in this area. Chloride contents exceeded 800 mg/l in water from one well in this area in 1953 (California Division of Water Resources, 1953). Chloride contents in water from about one dozen wells exceeded 200 mg/l at this time. A distinct plume of high chloride extended about one-half mile southwest of the Fresno Railroad Yard. The plume in later years was described in both the 208 and 205J Water Quality Management Program Studies (County of Fresno, et al, 1979 and 1986).

In Spring 1979 personnel of the County of Fresno, Environmental Health Division re-sampled numerous wells in this vicinity. The direction of groundwater flow in this area is to the west or southwest. Water from three wells had chloride contents exceeding 200 mg/l. Apparently the high salinity contaminated groundwater followed at least two high permeability zones. Electrical conductivity of water from wells in this area followed a similar areal distribution to that for chloride content. Recharged wastewater

apparently moved a distance of one mile in 25 years or at a rate of about 200 feet per year (Schmidt, Krancher, and Bisel, 1981). As of 1984, the plume extended to near Belmont and Cornelia Avenues (County of Fresno, et al, 1986). The length of the plume was almost three miles by that time.

Fresno Meat Co.

High chloride contents and salinity have been found in groundwater near and downgradient of brine ponds at the Fresno Meat Company, between Fruit and Fig Avenues, near North Avenue. The direction of groundwater flow in this area is to the northwest. Chloride contents exceeded 1,200 mg/l in water from one well near the plant in 1972. The County of Fresno performed more detailed sampling in November 1974, and water from one downgradient well had an electrical conductivity of 3,500 micromhos and a chloride content of 690 mg/l. In Spring 1979, the County of Fresno Environmental Health Division sampled numerous wells in this area. A plume of high chloride content and salinity was clearly delineated, extending a distance of about one mile to the northwest from the Fresno Meat Company plant. Chloride contents exceeded 90 mg/l in water from nine wells within the plume. Electrical conductivity exceeded 1,000 micromhos in water from six wells within this plume. Nitrate contents commonly exceeded 45 mg/l in water from wells within this plume (County of Fresno, et al, 1979).

Pinedale TCE Plume

A plume of high TCE contents in groundwater in the Pinedale vicinity was discussed previously (Figure 23). The plume extends from the Pinedale industrial area south to near the Gibson School. TCE contents exceeding 300 ppb have been found in two wells formerly used for public supply. The California Department of Health Services (DOHS) has installed monitor wells at four sites, one of which is at the former IWP site in the industrial area, and three of which are between Herndon and Bullard Avenues. Two monitor wells were installed at each of the last three sites, and these indicate that most of the contamination was above a depth of 200 feet. The City of Fresno installed a cluster monitor well near Well D25-2, which had produced water with TCE contents exceeding 300 ppb. Information from this monitor well indicated that Well D25-2 is a conduit for the downward migration of TCE from above a depth of 200 feet to near the bottom of the well. At least two sources of the TCE have been identified. One is the abandoned IWP site, and the other is the Vendo Company Facility, on North Ingram Avenue, east of the IWP site. A monitor well at the IWP site indicated TCE contents of about 100 ppb in the shallow groundwater. Monitor wells have been installed at the Vendo Company Facility, and TCE contents in the thousands of ppb have been found in the shallow groundwater (Geomatrix Consultants, 1991).

Kenneth D. Schmidt and Associates (1988) conducted an aquifer test in August 1988 at Well D19-3, near the TCE plume. The average permeability of coarse-grained strata above a depth of 170 feet was

determined to be 2,300 gpd per square foot. The estimated rate of groundwater flow in these deposits was about 340 feet per year in 1988. It was estimated that there was about 8,000 acre-feet of contaminated groundwater in 1988. The amount of downgradient flow of the TCE-contaminated groundwater in the plume was estimated to range for about 200 to 400 gpm.

Six public-supply wells in this plume have been closed due to TCE contents exceeding the MCL of 5 ppb. Included are one Pinedale County Water District well north of Herndon Avenue, and five City of Fresno wells south of Herndon Avenue. On-going studies of the Pinedale plume are being undertaken by DOHS, the City of Fresno, and the Vendo Company.

Thompson-Hayward Agricultural and Nutrition Co., Inc. Site

The THAN Superfund site is located southeast of Temperance and McKinley Avenues, east of the Fresno Air Terminal. The site was formerly used for the manufacturing and handling of a number of pesticides. Kennedy/Jenks/Chilton (1991) reported on the Phase II/III Groundwater Investigation at the site. The primary groundwater contaminants are several volatile halocarbons (chloroform and 1,2-dichloroethane) and several pesticides (DBCP, dieldrin, and 1,2,3-trichloropropane). A chloroform plume extending about 6,000 feet southwest from the site has been delineated. The plume is about 1,200 feet wide, and extends to near Harvey Avenue, midway between Olive and Belmont Avenues. Sampling of over 70 private domestic wells and dozens of monitor wells has allowed excellent definition of the extent of the plume. As in the Pinedale TCE plume, most of the contamination is present above a depth of about 200 feet. A DBCP plume, where contents exceed 1.0 ppb, also appears to extend about one mile to the southwest from the facility, and this plume is slightly east of the chloroform plume. However, the DBCP may also be due to historical pesticide applications to agricultural areas. Contaminants other than chloroform and DBCP are present only within about one quarter mile of the site.

The nearest downgradient public-supply wells to the chloroform plume are PS 102 (about one-half mile distant) and Bakman Water Co. No. 13A (about one mile downgradient). However, these wells are also sealed off opposite shallow strata most likely to become contaminated. These two wells are some of the only public-supply wells in the urban area that have continuous annular seals extending more than 250 feet in depth. Even though these wells have deep annular seals, DBCP has been detected in water from both of them in recent years at contents less than the MCL. The DOHS is overseeing further studies at the THAN site, and cleanup alternatives for the groundwater are being considered.

Purity Oil Sales Superfund Site

This seven-acre site is located west of Maple Avenue and north of Muscat Avenue in Malaga, and was used for refining used oil from

1934 to 1975. A number of waste pits were used to store and dispose wastes, such as oily acidic sludge. By the early 1980's, the site was abandoned, and groundwater contamination had been found. In 1982 the site was included on the National Priorities List (NPL), and since 1984 both the DOHS and EPA have investigated the site (EPA, 1989).

The groundwater beneath the site is contaminated by several volatile halocarbons. The contaminated zone extends about 3,000 feet northwest of the site, and is about 800 feet wide. Beneath and near the site, contaminant levels in water from monitor wells exceed MCLs, and the highest levels have been found for 1,2-dichloroethane. Most of the contamination is only in the shallow groundwater, and this groundwater is not currently being used for public supply or private water supplies. Volatile halocarbon levels have exceeded recommended state action levels for 1,2-dichloroethane in water from private industrial wells located between the site and North Avenue. Also, iron and manganese are present in the groundwater at contents exceeding the secondary MCLs.

The nearest public-supply wells to this site are PS 40-a, about one mile northwest of the edge of the plume, and former Calwa County Water District Well No. 1, about one mile to the north. The latter of these wells is located within the large DBCP plume of the Southeast Fresno sub-area.

EPAs preferred remedial alternative for the groundwater is to extract about 700 gpm from about seven wells, and to treat the volatile halocarbons with air stripping.

Fresno Air Terminal

The California Air National Guard base is located in the southeast part of the Fresno Air Terminal. The 140-acre site was investigated as part of the Installation Restoration Program, the military's version of the EPA Superfund Program. In 1988, the Air National Guard identified four spill or disposal sites that could contain contaminants (California Air National Guard, 1991).

Eighteen monitor wells were subsequently installed to an average depth of about 90 feet. Water samples were tested for a variety of suspected contaminants, including byproducts of fuels, waste lubricants, and cleaning solvents. TCE contents ranging from 0.7 ppb to 140 ppb were found in monitor wells in the north, western, and southwestern parts of the base. PCE contents ranging from 1.7 ppb to 110 ppb were found in monitor wells located in the western and southwestern parts of the base. Contents of both of these volatile halocarbons exceeded the MCL of 5 ppb in water from some wells. The PCE-contaminated groundwater appears to have originated at the base and to be leaving the property to the southwest. The highest PCE contents and moderate TCE contents were found beneath the petroleum, oil, and lubricant area at the base. Four monitor wells were installed along the northern perimeter of the base to evaluate upgradient conditions. Near the northern edge of the

base, water from four monitor wells had TCE contents ranging from 3.3 to 140 ppb. Since the direction of groundwater flow was to the southwest, it was believed that TCE in groundwater was entering the base from an upgradient source and leaving the base to the southwest. The Air National Guard, DOHS, EPA, City of Fresno, and Fresno County Environmental Health are evaluating remedial actions, additional investigative requirements, and the contamination sources.

The contamination from the Fresno Air Terminal may have affected five public-supply wells (D17-1, D22-1, D22-2, PS 59, and PS 70). Three of these wells (D22-1, D22-2, and PS 70) have been closed due to TCE contents exceeding the MCL. No off-site monitor wells have been drilled yet.

FMC Superfund Site

The FMC Superfund site is located south of Church Avenue and northeast of the Southern Pacific Railroad in Calwa. Sunland Sulfur Company began processing sulfur for agricultural uses at the site in 1931. In 1946, Sunland started formulating fertilizers and dry pesticides in addition to sulfur products. FMC bought the facility in 1959, and began formulating liquid pesticides. During the 1960's and 1970's, FMC discharged liquid wastes and rinse waters to an unpaved, vacant five-acre lot adjacent to the formulation facilities. Also from 1963 to 1974, rinse water from a drum washing operation was sprayed onto a cement evaporation pad. During the early 1970's, FMC used an on-site clay-lined waste pond to collect wastes from plant operations, on-site spills and rainfall runoff. In 1979, the California Regional Water Quality Control Board (Regional Board) requested that FMC initiate a groundwater monitoring program. Several pesticides, volatile halocarbons, volatile aromatics, and pentachlorophenol were subsequently found in the groundwater (EPA, 1990). The waste pond was drained in 1983 as FMC began to meet regulatory requirements for closure of the pond.

In 1984, the site was proposed for inclusion on the National Priorities List, and in 1985, DOHS turned over the regulatory lead for the site to EPA. In December 1986, EPA and FMC signed a Consent Order, requiring FMC to perform a Remedial Investigation and Feasibility Study for the site. The Remedial Investigation was conducted in two phases. The Phase I investigation provided an overview of contamination at the site, defined target contaminants, and identified areas of high levels of contamination. The Phase II investigation provided a more detailed analysis of the contaminated areas.

Numerous contaminants have been detected in groundwater in two shallow sand strata beneath the site. These two sand strata are separated by a less permeable zone that apparently allows some groundwater and contaminants from the shallow sand strata to migrate to the deeper sand strata. The following contaminants were detected most often in both sand strata: dieldrin, casoran, di-

methoate, ethylene dibromide, xylene, carbon tetrachloride, DNBP, chloroform, pentachlorophenol, dibromochloropropane, bromodichloromethane, toluene, tetrachloroethylene, trichloroethylene, and DNOC. Monuron and 1,1-dichloroethane were detected only in groundwater from the shallowest sand zone.

The direction of groundwater flow at the site is toward the north and the northwest. Groundwater contamination beneath and downgradient from the site is believed to have originated from wastewater discharged to various portions of the site.

The nearest public-supply wells to the plume are PS 36, located near Church and Orange, about one-quarter mile from the plume, and PS 33-a, located near California and 4th Street, about one half mile north. The most mobile constituents in the plume are DBCP, EDB, PCE, TCE, and pentachlorophenol. Low levels of PCE have been found in water from PS 3, about one mile northwest of the facility and low levels of 1,1-DCE have been found in water from PS 33-a. However, the source of these volatile halocarbons is unknown. EPA is to select a preferred remedy for cleanup of the FMC site after the Feasibility Study is completed.

Wilbur-Ellis

Groundwater contamination due to several pesticides has been found at the Wilbur-Ellis facility, south of Annadale Avenue and west of Cedar Avenue, northwest of the Purity Oil site. Phosphamidon, lindane, endosulfan, and malathion were reportedly detected in water from an on-site well (County of Fresno, et al, 1986). The current status of this site has not been determined.

Other Superfund Sites

At least three other Superfund sites are known. Included are the Fruit and Church Junkyard, the Fresno County Credit Union in downtown Fresno, and Commercial Electroplaters, near Highway 41 and North Avenue. No information is available on the extent of groundwater contamination at these sites.

Gasoline Leak Sites

There are seven sites in the urban area where gasoline-derived constituents are known to have reached the groundwater. A number of other site investigations are underway where it has not been determined yet if such constituents have reached the groundwater.

IMPACT OF UPGRADIENT IRRIGATION ON THE MIGRATION OF DBCP-CONTAMINATED GROUNDWATER

Irrigation of farm lands upgradient of the DBCP-contaminated groundwater in and near the Fresno area can exert a significant effect on the migration of DBCP. DBCP is a mobile constituent, and available evidence indicates that it travels almost as fast as the

groundwater itself. According to Darcy's Law, the rate of groundwater flow is dependent on the permeability and effective porosity of the alluvial deposits and on the hydraulic gradient, or slope of the water table. The slope of the water table along the fringes of the urban area is dependent on two factors. First, is the extent of pumpage and recharge (both incidental and intentional) in the urban area. Second, is the pumpage, the use of surface water, and recharge in the upgradient rural area.

The Southeast Fresno Area is used as an example in considering the effect of irrigation on contaminant migration. The average water-level slope in this area was about 30 feet per mile in Spring 1991. Upslope irrigation in part of this area (south of Kings Canyon Avenue, north of Jensen Avenue, and east of Clovis Avenue) depends highly on well water, whereas adjacent irrigated areas to the north, south, and east tend to use more canal water. If groundwater alone was used for irrigation, a long-term water-level decline would result. Based on experience elsewhere in the Fresno area, this decline would average at least several feet per year. On the contrary, if canal water alone was used for irrigation over a large area, water levels would rise at least several feet per year, and water-logging would eventually result. This happened in the late 1800's and early 1990's in the Fresno area.

The key to minimizing the downgradient migration of DBCP is to flatten the hydraulic gradient near the front of the DBCP-contaminated groundwater. This can be done by increasing intentional recharge in the urban area, downgradient of this front, and by increasing the relative amount of pumped water that is used for irrigation in the upgradient area. Also, pumping of contaminated wells will slow the downgradient migration of DBCP. All three of these management practices would tend to decrease the hydraulic gradient, and thus significantly slow the downgradient migration of DBCP into previously uncontaminated areas.

Irrigation based on groundwater pumpage has another positive impact on the migration of DBCP. Every time that some DBCP-contaminated groundwater is pumped to the surface and applied for irrigation, more biodegradation of DBCP results. Soil column tests conducted in the Plant Sciences Department at CSUF have indicated that for DBCP contents typically found in well water (i.e., less than 5 ppb), no detectable contents would be found in deep percolation water. This is consistent with the observation that since the use of DBCP was banned in 1977, DBCP contents have decreased in shallow groundwater beneath irrigated areas in the Fresno-Dinuba area. Also, test holes and test wells in recent years in the Fresno-Dinuba area have usually indicated low contents of DBCP in groundwater near the water table beneath irrigated areas. Thus the more cycles of irrigation pumping and irrigation that can be done with groundwater in areas upgradient of the urban well field, the more degradation of DBCP that will occur before it reaches the urban well field.

In summary, intentional recharge of high quality canal water in parts of the urban area with good quality groundwater, coupled with increased use of DBCP-contaminated groundwater for irrigation of upgradient lands and pumping of urban wells contaminated with DBCP can have a highly beneficial impact on decreasing the rate of downgradient migration of DBCP to previously uncontaminated areas.

THE RELATION BETWEEN WELL DRAWDOWN AND THE DISTRIBUTION OF CONTAMINANTS IN THE GROUNDWATER

Well drawdown can effect the distribution of contaminants in several ways. First, lowered water levels can induce migration of contaminants to a pumping well. Second, pumping of a well can reduce contaminant levels in water from other wells, due to plume migration. Also, well drawdown can alter the vertical distribution of contaminants and induce downward movement of shallow contaminated groundwater to deeper levels. The last of these phenomena is addressed in another section of this report that concerns the development and testing of new deep public-supply wells.

Well drawdown influences the rate of migration of contaminants by affecting the hydraulic gradient. The water-level drawdown at any distance from a well can be calculated from the transmissivity and storage coefficient for an unconfined or confined aquifer. For leaky aquifers, which are present at depth in parts of the North Fresno Growth and Herndon-Shepherd Specific Plan Areas, and in the eastern part of the urban area, drawdowns are slightly less than for totally confined aquifers, due to downward leakage through the confining bed. This leakage can be determined from the vertical permeability of the confining bed and the vertical head gradient. Leaky aquifer tests can provide actual values for the vertical permeability of confining beds. Such tests usually require from at least several days to a week or more of pumping. However, such tests are not known to have been conducted in the Fresno area. In the absence of such data, information on vertical permeability can be indirectly derived, based on information from water quality depth sampling programs, and by monitoring the quality of water pumped from new wells that only tap strata below the confining bed. In this regard, substantial data is available on DBCP contents in the Herndon-Shepherd Plan Area of Clovis and also in the Southeast Fresno Area.

In considering the effects of well drawdown in the Fresno urban area, groups of pumping wells must normally be considered, as opposed to individual wells. This is particularly true for extensive contaminated groundwater bodies, such as DBCP in the Southeast Fresno Area. Historical drawdowns in most individual public-supply wells in most of the Fresno urban area were relatively small, normally in the range of 10 to 20 feet or less for pumping rates ranging from about 1,000 to 2,000 gpm. This was because only the shallow, highly permeable, older alluvium was tapped by these wells, and the unconfined nature of the shallow groundwater also minimized drawdowns. However, in recent years, more wells have tended to be

drilled deeper (due to contamination of the shallow groundwater and water-level declines). The deeper groundwater tends to be more confined, particularly where thick confining beds are present. Also, more wells are now being drilled in areas where even the shallow groundwater is present in less permeable deposits. The combination of these factors has resulted in greater drawdowns in newer public-supply wells. For example, in the North Fresno Growth Area and the Herndon-Shepherd Plan Area, drawdowns in the range of 40 to 80 feet for pumping rates of 700 to 1,500 gpm are common. In such areas, seasonal water-level fluctuations (spring to fall) have also tended to be significantly greater than were observed historically in shallow City of Fresno wells. This is a commonly observed pattern for confined and unconfined aquifers in the San Joaquin Valley.

One of the greatest threats due to migration of contaminated groundwater into areas that are now uncontaminated in the urban area is in the Northwest Fresno Area. Large-scale urban pumping in future decades, without adequate recharge, could cause substantial water-level declines (estimated to be at least one foot per year). Historical irrigation pumping in this area, particularly in summer months, was relatively small. This was due to the predominance of fig orchards, which were normally irrigated in the winter, and with canal water. This area could become the center of the urban depression cone in the future, and contaminated groundwater could move toward it from several directions, including from the southeast, where extensive DBCP contamination is present in the groundwater. To avoid such water-level declines, adequate intentional recharge is necessary, to counter-balance the effects of the increased pumping.

POTENTIAL FOR SEALING OFF SHALLOW CONTAMINATED GROUNDWATER IN PUBLIC-SUPPLY WELLS

It has been well established in many parts of the San Joaquin Valley, that the deeper groundwater, beneath one or more clay strata or confining beds, is generally not contaminated due to man's activities. This has been determined from hundreds of test holes and test wells, and construction of hundreds of deeper public-supply wells, particularly during the past 12 years. Examples of this are at Delano and McFarland, where groundwater with high nitrate contents above a depth of about 700 feet have been successfully sealed off. High DBCP contents, normally above a depth of about 250 feet in the groundwater, have been successfully sealed off in new public-supply wells in Dinuba, Reedley, Kingsburg, Atwater, Parlier, Selma, Bakersfield, Delano, and Richgrove. High EDB contents have been successfully sealed off in Atwater and in Bakersfield.

In the Fresno Urban Area, several deep wells have been drilled to seal off a shallow groundwater. Examples are Bakman Water Co. Well No. 13A and City of Fresno PS 102. Also, successful well rehabilitation, whereby shallow perforations in existing wells have

been plugged, has been completed at three City of Fresno Wells (PS-2A, PS-59, and PS-61). Contamination in the first of these three wells involved volatile halocarbons, and the others involved DBCP.

A number of wells with deep annular seals have been in operation for up to about ten years in the San Joaquin Valley. There is little question that small-capacity (i.e., 200 gpm or less) wells can be developed to produce good quality water over the long term (i.e., decades). The difference between large-capacity wells and small-capacity wells is that at pumping rates in the range of 500 to 2,000 gpm, significant downward head gradients can be developed near the large-capacity wells. These downward head gradients, if large enough, can induce downward flow of contaminated groundwater through the confining beds (clay strata) themselves, that separate the contaminated groundwater from under-lying uncontaminated groundwater.

There are three key aspects to developing deeper groundwater of good quality. The first is to conduct specially designed test holes or test wells, to carefully delineate the quality of water in each major water-producing layer at the site. In this manner, the exact vertical extent of contamination, and of good quality groundwater can be determined. Such a program also clearly identifies which confining layers are the most important ones, in separating the contaminated groundwater from good quality water. Second, when a production well is constructed, it is designed to tap only good quality groundwater, if possible. Perforated and gravel packed intervals are limited to those intervals containing good quality water. An annular seal is placed between the blank casing and the wall of the hole, in the space above the gravel pack. This seal is continuous up to the land surface, and optimally extends through more than one confining layer. Once the new well is developed, it is pump tested at various pumping rates, which allows the drawdown at each pumping rate to be determined. Experience has shown that for most confining beds encountered to date in the San Joaquin Valley, drawdowns of less than 30 to 40 feet are advisable, and greater drawdowns are to be avoided if possible. Such a limitation on drawdown, of course, causes a limitation in the acceptable pumping rate. As opposed to several thousands of gallons per minute that were pumped historically from shallow wells tapping permeable deposits, the yields of deep wells producing good quality water more commonly range from about 700 to 1,500 gpm.

One of the key factors enabling the construction of such deep wells is that the vertical permeabilities of significant confining beds are often only a very small part (typically less than one thousandth) of the horizontal permeabilities of the water-producing strata. Thus placing annular seals opposite confining beds restores the original subsurface geologic conditions and makes it difficult for water to move downward. Also, in most parts of the Fresno area where contamination is present, few existing wells tap groundwater in the deep strata, and the total amount of uncontaminated groundwater is very large. Because the amount of deeper

groundwater is large, and there is little competition for it, this source is considerable, particularly over the next several decades.

Because the shallow groundwater in the recharge areas for the deeper groundwater may also be contaminated, it is important on the long-term to consider recharging the deeper groundwater in urban areas where such deep wells are developed and pumped. Because the overlying groundwater is likely to still be contaminated even in future decades, recharge will most likely be necessary through injection wells, or the supply wells themselves during periods of minimal pumpage. Injection of water into deep zones appears practical, particularly if a municipal water treatment plant is available, so that the water to be recharged can first be filtered and sterilized.

The most difficult areas to successfully develop new deeper public-supply wells are in areas where bedrock is shallow, clay strata are predominant at depth, or the deeper groundwater is not of good quality. In the Fresno urban area, such areas are primarily limited to part of northeast Fresno and north Clovis, and east of Clovis Avenue.

With the present maximum contaminant level (MCL) of 0.2 ppb for DBCP, drilling deeper wells appears highly feasible in most parts of the Fresno urban area. If the MCL were to be reduced to 0.1 ppb or lower in the future, it is expected, based on experience elsewhere, that it would be difficult to develop new wells to produce DBCP levels below this level. With the existing MCL for EDB of 0.02 ppb, it is expected that drilling of new wells to produce good quality groundwater in areas where EDB contents in groundwater exceed about 0.2 ppb could be difficult. Fortunately, there are few locations in and near the Fresno urban area where such high contents of EDB are found. In terms of nitrate, chloride, and other major inorganic chemical constituents, development of deeper wells has been a proven approach for decades in the Fresno urban area.

In summary, construction of deeper wells to produce potable water over a number of years is a proven technology, although there are some parts of the Fresno urban area where this may not be possible. The most difficult locations to drill such wells will generally be in northeast Fresno, north Clovis, and east of Clovis Avenue. The locations where this can most readily be done are in the Northwest Fresno Area, and in most of the rest of the City of Fresno that is south of Herndon Avenue and west of Clovis Avenue.

ADEQUACY OF AVAILABLE DATA

There are several data gaps that should be addressed in terms of the WRMP. Several of these are recommended for the next several months, before a final plan is developed. Others are more long-term in nature. Essentially, these gaps include non-public supply well pumpage in the urban area, water-level records, pesticide contents in parts of the surrounding area, and data management.

Pumpage

Pumpage from non-public water supply providers in the urban area has not been compiled or summarized. Included are industrial users, schools, irrigators, CSUF, lake filling, gravel processing, golf courses, parks, and cemeteries. Because the total pumpage from these wells is believed to be significant, an effort should be undertaken to determine this. First, all active large-capacity, non-public supply wells in the urban area should be identified. Next, pumpage should be estimated, either from metered measurements, power records, irrigated acreage and crop type, or other factors.

Water Levels

Presently, most water-level measurements in the urban area are from pumped wells. These data are of limited value because of the variable pumping patterns of wells in the area. It is recommended that at least seven continuous float-type water-level recorders be installed. Two would be in the Northwest Fresno Sub-area, two in the North Fresno Growth Area, one in the Herndon-Shepherd Plan Area, one in East Clovis, and one in the Southeast Fresno Sub-area. The recorders should be installed in unused wells or monitor wells that are not located near pumped wells.

Pesticide Contents in Adjacent Areas

There are two areas where little information is available on DBCP and EDB contents in groundwater. One is beneath the rural part of the Northwest Fresno Area (i.e., southwest of Highway 99). The second is north of, and adjacent to, the San Joaquin River. The second area is of concern, particularly near the San Joaquin County Club, where DBCP has been found in a City of Fresno well. Also, triazine herbicides should be sampled in well water at or near citrus orchards or former citrus orchards northeast of Clovis. Triazine herbicides are widespread in groundwater beneath citrus orchards on the east side of the valley. The citrus area northeast of Clovis is upgradient of a number of new public-supply wells that have been installed during the past several years.

Data Management

Although most chemical quality data for water from City of Fresno wells are computerized, there needs to be a data management program established for pumpage, geologic data, water levels, specific capacities, and intentional recharge in the urban area. This would enhance interpretive efforts in the future.

GROUNDWATER CONDITIONS IN THE NORTHWEST FRESNO SUB-AREA

The northwest part of the urban area was selected as a sub-area in this report because of its unique hydrogeologic conditions

and groundwater quality compared to other parts of the urban area. As used herein, the Northwest Fresno Sub-Area is bounded on the north by the San Joaquin River, on the west by Garfield Avenue, on the east by West Avenue, and on the south by Dakota Avenue. First, a nearly impermeable hardpan overlies much of this area, which has afforded some protection to groundwater quality. Second, figs were historically the predominant crop in this area. These figs have been irrigated primarily in the winter with canal water, and pump-age in the sub-area was minimal prior to urban development. Third, coarse-grained deposits predominate in this area and high well capacities are obtainable. Fourth, there is substantial recharge due to the sub-area from seepage of streamflow from the San Joaquin River to the north. Lastly, the chemical quality of the groundwater in this sub-area, based on available information, is highly superior to that elsewhere in the urban area. Because of these conditions, this part of the urban area has considerable potential in terms of alternative future water management plans.

Subsurface Geologic Conditions

Two deep oil or gas exploration holes were drilled in this sub-area (T13S/R19E-2G, near Sierra and Blythe Avenues, and T13S/R19E-20C, near Ashlan and Garfield Avenues). The first of these holes (KCL Minier No. 1) was drilled to a depth of 3,692 feet in 1967. The second (J.C. Forkner No. 1) was drilled to a depth of 5,614 feet in 1959. Electric logs are available for both of these holes. In recent years, about a dozen relatively deep water well test holes have been drilled in this sub-area by the City of Fresno. Both geologic logs and electric logs are available for these holes. Electric logs are also available for six City production wells that were drilled prior to 1980 in this sub-area. Together this information provides substantial information on subsurface geologic conditions in the Northwest Fresno Sub-Area.

Two cross sections extending through this sub-area were previously presented. Cross Section F-F' (Figure 8) extends from PS 160 on the west (south of the Riverside Municipal Golf Course), easterly along Herndon Avenue, to PS 93 (at Herndon and Fruit Avenues). Three of the holes along this section are more than 700 feet deep. Coarse-grained deposits of the older alluvium are present above a depth of about 300 feet along this section. All of the holes along this section encountered substantial permeable strata in the under-lying continental deposits. The electric log for Hole T13S/R19E-2G, located about one-half mile south of this section, indicates that some coarse-grained strata containing fresh groundwater (less than 2,000 mg/l TDS) are present to a depth of 1,700 feet. The reduced (blue-green) deposits were encountered by three of the test holes, below depths ranging from about 700 to 730 feet along this section. In general, clay strata are discontinuous, and highly permeable sand, gravel, and cobbles predominate above the water table.

Cross Section G-G' (Figure 9) extends from PS 139 on the north (near Alluvial and Polk Avenues) south through Biola Junction to PS

138 (at Clinton and Blythe Avenues). Four of the holes along this section are more than 600 feet deep. The base of the older alluvium also averages about 300 feet deep along this section. In general, clay strata predominate in the under-lying continental deposits, particularly south of Ashlan Avenue. However, the deeper test holes along this section have encountered several relatively thick coarse-grained strata in the continental deposits. Only one hole along this section (PS 139) encountered the reduced deposits, at a depth of about 700 feet. Information from this section indicates that the top of the reduced deposits deepens to the south. Coarse-grained deposits predominate above the water table along the part of this section north of Gettysburg Avenue. However, substantial fine-grained strata are present above the water table along this section at PS 35-A and PS 99.

Water Levels

In Spring 1991, depth to water decreased to the southwest in the sub-area (Figure 10). Depth to water ranged from less than 70 feet beneath the southwest part to more than 110 feet beneath the northeast part. The boundary of urban extraction (Figure 11) bisected this sub-area in Spring 1991. Groundwater east of near Highway City moved south from the San Joaquin River and into the urban depression cone. Groundwater west of near Highway City moved southwesterly from the San Joaquin River, past the urban depression cone. Water-level elevations in Spring 1991 ranged from about 220 feet near the San Joaquin Country Club to less than 210 feet beneath the southeast part of the sub-area. In Spring 1991, the slope of the water table was flatter in the Northwest Fresno Sub-Area than in all of the other parts of the urban area. In part this is due to the presence of highly permeable deposits beneath the sub-area.

Well Production and Aquifer Characteristics

In general, well yields exceeding 2,000 gpm are possible throughout most of the Northwest Fresno Sub-area. Aquifer tests for four City wells in the sub-area (Table 2) indicate specific capacities ranging from 69 to 134 gpm per foot, and averaging 105 gpm per foot. These tests indicated that transmissivities ranged from 113,000 to 253,000 gpd per foot, and averaged 209,000 gpd per foot. Depths of the tested wells ranged from about 400 to 750 feet. This information, compared to that for other parts of the urban area, indicates that the Northwest Fresno Sub-Area has excellent well production and aquifer characteristics for groundwater development.

Potential for Intentional Recharge

Because of the predominance of coarse-grained, highly permeable deposits above the water table throughout much of this sub-area, subsurface geologic conditions are very favorable for intentional recharge by basins. There are fourteen existing storm water basins within this subarea, and at least four more are proposed.

With the increased urban pumping that is projected when new public-supply wells are put on line, particularly west of Brawley Avenue, all of these existing ponds are projected to be within the future urban depression cone. The potential for recharge could be increased even farther by constructing an intentional recharge facility in this area, if feasible.

Groundwater Quality

TDS contents in well water in this sub-area ranged from about 110 to 220 mg/l in Spring 1991. However, a brine plume (high TDS and chloride content), extending southwest from the Fresno Railroad Yard, is located about one-half mile south of this sub-area. Nitrate contents in well water ranged from about 5 to 20 mg/l, and were less than 15 mg/l in Spring 1991 throughout most of the sub-area. Nitrate contents exceeding 15 mg/l were generally in or near formerly unsewered areas. Manganese contents in water from public-supply wells were less than 0.02 mg/l, except for two wells (PS 44a and PS 104) near Highway City.

The only detectable DBCP content in water from a public-supply well in recent years was at D32-3 (ranging from less than 0.02 ppb to 0.09 ppb). This well is located near the San Joaquin Country Club. However, few wells in the area southwest of Highway 99 have been sampled for DBCP analyses. Ethylene dibromide has not been detected in water from public supply wells in this sub-area in recent years. However, water from two wells (D25-5 and KV-ES) about one mile east of the sub-area had detectable contents of EDB, sometimes exceeding the MCL of 0.02 ppb. Also, there has been no known sampling for EDB analyses of water from most wells in the part of the sub-area southwest of Highway 99.

Volatile halocarbons in water from public-supply wells in the sub-area have been less than detection limits in recent years. However, east of the study area, between Alluvial and Gettysburg Avenues and West and Maroa Avenues (the Pinedale plume), several volatile halocarbons have been found. However, only contents of TCE have exceeded the MCL. Water from two wells formerly used for public-supply had TCE contents exceeding 300 ppb in 1989. This TCE plume is presently moving to the south, following the direction of groundwater flow.

Urban development of the Northwest Fresno Sub-Area without adequate recharge could produce a more westerly direction of groundwater flow, and some westerly migration of the TCE plume. Both adequate recharge (equal to or slightly exceeding the urban pumpage) in the sub-area, and control of the TCE plume are necessary to protect the future quality of groundwater in the sub-area. Adequate recharge is also needed in the Northwest Fresno Sub-Area on the long-term in order to prevent DBCP from the southeast part of the urban area from migrating into this sub-area.

Summary

Subsurface geologic conditions in the Northwest Fresno Sub-Area are the most favorable for groundwater development in or near the urban area. Highly permeable deposits predominate above and below the water table. The presently unurbanized part of this sub-area is located entirely within the Fresno Irrigation District, and intentional recharge can be practiced by basins. The chemical quality of the groundwater is excellent for public supply, based on available data. This sub-area has considerable potential for increased intentional recharge and export of pumped water to other parts of the urban area.

GROUNDWATER LIMITATIONS IN THE NORTH FRESNO GROWTH AREA, HERNDON-SHEPHERD PLAN AREA, AND EAST CLOVIS SUB-AREA

The Fresno North Growth Area is bounded on the north by Copper Avenue, on the west by Blackstone Avenue, on the south by Herndon Avenue, and on the east by Willow Avenue. The Herndon-Shepherd Plan area is bounded by Shepherd Avenue on the north, Willow Avenue on the west, Herndon Avenue on the south, and Temperance Avenue on the east. The East Clovis area, as used herein, is bounded by Herndon Avenue on the north, Clovis Avenue on the west, Dakota Avenue on the south, and Leonard Avenue on the east. These three areas have been combined herein into one sub-area for purposes of this evaluation.

Drilling of wells and test holes in this sub-area during the past decade has indicated that well yields are not as favorable as in much of the rest of the urban area to the south and southwest. Problems encountered have included shallow bedrock and substantial thicknesses of clay strata at some locations, and deeper water levels than elsewhere. In addition, the part of the sub-area northeast of the Enterprise Canal is outside of the Fresno Irrigation District (FID), where canal water and/or distribution facilities for this water are not available. Concerns were expressed about the long-term adequacy of groundwater for urban development in parts of this sub-area in the 208 Water Management Plan (County of Fresno et al, 1979).

DBCP was found in groundwater in parts of this sub-area in the early 1980's, and EDB was found in 1989, although beneath a much smaller part of the sub-area. Manganese and arsenic are other groundwater quality problems in part of the sub-area.

Subsurface Geologic Conditions

Previous groundwater studies that have included the sub-area include the Northeast Fresno Groundwater Study (County of Fresno, 1976), and the 208 Water Management Plan report (County of Fresno, et al, 1979). These studies were completed before much information was available on groundwater conditions below a depth of several hundred feet in the sub-area. Historically, almost all irrigation

wells in or near the sub-area were only drilled to a depth of several hundred feet, and there were few public-supply wells.

Since the late 1970's, substantial information has been obtained on groundwater conditions to a depth of 600 to 700 feet, as part of exploration drilling programs and development of new public-supply wells. Kenneth D. Schmidt and Associates (1987a) described groundwater conditions in the North Fresno Growth Area based on data available through early 1987. As part of that investigation, six new deep test holes were drilled and logged in the east part of the Fresno North Growth Area. In addition, an 800-foot deep test well was completed at Woodward Park for collecting water samples at selected depths. Results from this well provided one of the first indications of the quality of water that was present in the deeper, reduced continental deposits in the urban area. More than fifty test holes or pilot holes for production wells have been drilled and logged in or near the sub-area since the mid-1970's. Twenty City of Fresno and seventeen City of Clovis public-supply wells had been constructed in this sub-area by Fall 1991.

Shallow Bedrock

Shallow bedrock is a constraint to development groundwater in the Herndon-Shepherd Plan Area and in the north part of the East Clovis Area. Shallow bedrock northeast of the urban area was mapped as part of the 208 program (County of Fresno, 1979, Figure 7). Contours of thickness of alluvium (depth to bedrock) were developed primarily based on drillers logs that were available as of 1978. Thickness contours were shown at fifty-foot intervals, from 50 to 200 feet. Part of this coverage extended into the northeast part of the Herndon-Shepherd Plan Area and into the north part of the East Clovis Area. Depth to bedrock gradually decreases to the northeast toward the Friant-Kern Canal. However, a bedrock high was delineated near Herndon Avenue, between Temperance and Leonard Avenues, where the depth to bedrock is less than 100 feet.

Since 1989, about one dozen test wells have been drilled in the western part of the Herndon-Shepherd Area and a number of these encountered bedrock (metamorphic rock) above a depth of 500 feet. In addition, several deep test holes or wells have been drilled in the East Clovis Area. Together, this information allows preparation of a depth to bedrock map (Figure 25). Depth to bedrock generally exceeds 600 feet in most of the North Fresno Growth Area, in the southwest part of the Herndon-Shepherd Plan Area, and in most of the East Clovis Area south of Shaw Avenue. Within the Herndon-Shepherd Plan Area, depth to bedrock increases gradually to the southwest. Depth to bedrock ranges from less than 100 feet near Dry Creek and Shepherd Avenue and near Herndon and Tollhouse Avenues, to more than 600 feet near Willow and Herndon Avenues. In the East Clovis Area, depth to bedrock is less than 300 feet north of Bullard Avenue and east of Clovis Avenue.

Alluvial Deposits

Evaluation of both geologic logs and electric logs for test holes and wells in the sub-area indicates that the uppermost 100 to 300 feet of alluvium are normally more coarse-grained than the underlying deposits, and can be classified as the older alluvium. The most favorable geologic location for developing groundwater from the older alluvium in the North Fresno Growth Area is to the southwest, where 150 feet or more of saturated deposits are present. The least favorable geologic locations for developing groundwater are generally to the north near Copper Avenue, where less than 100 feet of saturated deposits are present. At depth in the North Fresno Growth Area and in part of the East Clovis Area, the continental deposits are usually blue, green, or gray in color, indicative of reducing conditions. The presence of several hundred feet or more of reduced deposits beneath the Fresno North Growth Area and part of the East Clovis Area has important implications on the potential development of groundwater for public supply.

Kenneth D. Schmidt and Associates (1987a, Figure 3) mapped the top of the reduced continental deposits in the North Fresno Growth Area. The top of the reduced deposits is less than 350 feet deep beneath the north part of the Fresno North Growth Area and is more than 600 feet deep near Pinedale and near the southeast corner of the area (near Willow and Herndon Avenues). The most favorable locations for production of groundwater from the continental deposits are to the northwest near the San Joaquin River or in the southeastern part of the area. Near Pinedale and the southeast corner of the Fresno North Growth Area, the oxidized continental deposits are more than 300 feet thick, whereas in some parts of the northern part of the area, they are less than 100 feet thick. All of the continental deposits in the Fresno North Growth Area are below the water table.

In the Herndon-Shepherd Plan Area, the most geologically favorable locations for well production are in the southwestern and western parts, where depth to bedrock exceeds about 400 feet. The reduced deposits are not known to have been encountered east of Willow Avenue and north of Herndon Avenue. In the East Clovis Area, the most geologically favorable areas for well production are south of Shaw Avenue and west of Fowler Avenue. However, reduced deposits are known to be present at depth, south of Shaw Avenue, between Clovis and Fowler Avenues.

Subsurface Geologic Cross Sections

Three of the previously referenced subsurface geologic cross sections for the urban area extend through this sub-area. Cross Section A-A' (Figure 3) extends from near Fruit and Herndon Avenues (PS 93), past Pinedale and along the river bluff, through Woodward Park and the Woodward Lakes project, to near Copper Avenue (PS 133). This figure illustrates the thickening of the coarse-grained deposits of the older alluvium to the southwest. Although coarse-grained deposits are predominant in the older alluvium, at some

sites (PS 6B, WPW-1, WL-4, and WL-1) fine-grained deposits are also significant. Deposits that are above the water level along this section are often fine-grained and of low permeability and could hinder intentional recharge by basins. Substantial clay strata are often present in the underlying continental deposits along this section. Some of the thickest clay strata in the continental deposits were found at WPW-2, PS 6b, 21J, WL-4, WL-2, and WL-1. Some of the thickest permeable strata in the continental deposits were found at WPW-2, PS 6b, WPW-1, PFW-1, and WL-3.

The undulating top of the reduced deposits along this section is shallowest at WPW-1, WL-4, and WL-3, where less than 100 feet of oxidized continental deposits are present. The deepest test holes and wells drilled to date in the Fresno North Growth Area have apparently not penetrated the base of the reduced deposits. The reduced deposits are more than 500 feet thick at PFW-1 (near Friant and Fort Washington Roads) and more than 430 feet thick at Woodward Park (T12S/R20E-21J).

Cross Section B-B' (Figure 4) extends from the Woodward Lake Project southeast through Park Fort Washington, to near Sierra and Willow Avenues (PS 95). This section is perpendicular to the San Joaquin River, and most of the test holes or wells along this section are 640 feet or more deep. The thickness of the older alluvium is relatively constant along this cross section. However, fine-grained strata are thicker and more predominant to the southeast along this section. Deposits above the water table southeast of PC-4 are primarily fine-grained. The top of the reduced deposits becomes progressively deeper to the southeast along this section. At WL-2, the oxidized continental deposits are about 140 feet thick, whereas at TH-1 they are about 370 feet thick. PFW-2 is the only test hole or well along this section where clay is predominant in the continental deposits. However, City of Fresno Well PS 86 (about one-half mile southwest of the section) is also in the zone where clay is predominant. More coarse-grained deposits are present in the continental deposits both to the northwest and southeast of PFW-2 and PS 86.

Cross Section C-C' extends from City of Clovis Well 25 (Nees and Minnewawa Avenues) southeast to City of Clovis Well 20 (Barstow and Armstrong Avenues), thence south to test hole T13S/R21E-22D (near Ashlan and Fowler Avenues). The northernmost four wells are in the Herndon-Shepherd Plan Area, and the southern three are in or near the East Clovis area. The three southernmost holes or wells ranged from 514 to 855 feet in depth. Five test holes or wells along this cross section encountered bedrock (metamorphic rocks), at depths ranging from about 360 to 440 feet. Depth to bedrock increases to the southeast along this section. Coarse-grained deposits of the older alluvium generally thicken to the southeast. At City Well No. 25 these deposits are only about 110 feet thick, at Test Well 89-B they are about 170 feet thick, and at City Well No. 16 they are about 250 feet thick. The underlying continental deposits are predominantly fine-grained, although there are some relatively thin coarse-grained strata present.

The reduced (blue-green) deposits are present beneath the southernmost part of this section. At Test Well 22D, they were encountered below a depth of 300 feet. Reduced deposits were also reportedly encountered west of this site at City Well No. 12, near Clovis and Gettysburg Avenues. Below a depth of 440 feet at Test Well 22D, siltstone was predominant. Although not considered bedrock, this deposit is generally non-water producing. The shallow bedrock, thin older alluvium, predominance of clay in the continental deposits, relatively shallow reduced deposits, and siltstone unit in parts of the area are constraints to development of public-supply wells.

Water Levels

Water-levels were measured by the County of Fresno in a number of wells in the Northeast Network on a quarterly basis from 1975 to the mid-1980's. These measurements were normally for relatively shallow (100 to 200-feet deep) domestic wells, which tapped the older alluvium. Measurements in these wells generally showed a constancy in depth to water over the long term. The first City of Fresno wells in the North Fresno Growth Area (PS 86, PS 92, PS 94, and PS 96) became operational during the mid 1970's through the early 1980's. Their use has affected water-level trends since that time.

In Fall 1990, the California Department of Water Resources re-activated the Northeast Network water-level measurement program. Measurements for Spring 1980 and Spring 1991 were evaluated. In general, there were average water-level declines of at least 1.0 foot per year during this period.

There are five City of Fresno public-supply wells in or near the Fresno North Growth Area for which monthly water-level measurements are available since the late 1970's. Figure 14 shows a water-level hydrograph for Well PS 86. Well PS 86 is located near Teague and Millbrook Avenues, just west of the Clovis West High School. This well is located in the zone of high clay content in the continental deposits. Depth to water in this well is highly dependent on pumping patterns of the well itself. Spring measurements from 1980 through 1986 were relatively constant. After 1986, spring levels dropped markedly, at a rate of about three and one-half feet per year, partly due to increased pumping of the well itself.

Well PS 85 is located near Sierra and Maple Avenues, north of CSUF. Water levels in this well were relatively stable from 1977 to 1988, and fell about two feet per year from 1988-91.

Well PS 92 is located near Alluvial and First Avenues. This well is also located in the zone of high clay content in the continental deposits. No long-term change in depth to water is apparent prior to 1986. However, since 1985, spring water levels have fallen about nine feet, or an average of 1.5 feet per year.

PS 94 and PS 96 are located near Audobon Drive and the Southern Pacific Railroad tracks. Wells PS 94 and PS 96 are in a transition zone, from where clay is predominant in the continental deposits to the southeast, to where significant water-bearing strata are present in the continental deposits to the northwest. The water level declined an average of about 1.7 feet per year in PS 94 from 1979-85. After that time, the water levels rose to near the 1980-81 level and remained there through 1991. Well PS 96 is located near Fresno Street and the Southern Pacific Railroad tracks. Little long-term change in depth to water is apparent prior to 1989. From 1988 to 1991, the water level declined about three feet per year. This is significant, because of a number of new City wells were placed on line in this area by early 1991. The normal seasonal variation in depth to water in most of these wells has ranged from 10 to 15 feet. These variations partly reflect the presence of confined groundwater at depth in the area. The combined development of new public-supply wells by the City of Fresno and City of Clovis north of Herndon Avenue and east of Blackstone Avenue will likely result in significant water-level declines, unless more intentional recharge is practiced.

Well Production and Aquifer Characteristics

Excellent well production (pumping rate and specific capacity) is generally present south of Herndon Avenue (PS 85 and PS 93) and west of Blackstone Avenue (PS 98 and PS 6b), adjacent to the North Fresno Growth Area. In these areas, pumping rates of 2,000 gpm or more are possible and specific capacities usually exceed 60 gpm per foot. Most of the water pumped from wells in these areas is derived from the older alluvium.

Specific capacities of City of Fresno wells in the North Fresno Growth Area in 1988 ranged from about 20 to over 100 gpm per foot. Except for two flowpath wells (PS 6b and PS 89a), which tap shallow and deep strata, operating yields of most of these wells have not exceeded 1,000 gpm. The lowest pumping rates and specific capacities are for wells in the zone where significant clay is present in the continental deposits (at PS 86 and PS 92). In this area, specific capacities average about 20 gpm per foot and long-term pumping rates of less than about 900 gpm can be expected. Slightly higher specific capacities are present in the transition zone (PS 94 and PS 96) between the zone of high clay content and the San Joaquin River. In this area, specific capacities range from about 20 to 35 gpm per foot, and long-term well yields range from about 900 to 1,000 gpm. Most of the water pumped from these wells is also derived from the older alluvium.

Based on aquifer tests on five City of Fresno wells in the North Fresno Growth Area, transmissivity ranged from 39,000 to 100,000 gpd per foot, and averaged 66,000 gpd per foot. Based on aquifer tests on five City of Clovis wells in the Herndon-Shepherd Plan Area, transmissivities ranged from 13,000 to 75,000 gpd per foot, and averaged 41,000 gpd per foot. No aquifer tests are available for the East Clovis Area.

Potential for Intentional Recharge

In terms of intentional recharge, the alluvial deposits beneath much of the eastern part of the North Fresno Growth Area contain substantial fine-grained strata below a depth of 30 feet and above the water table. Information on subsurface geologic conditions indicates that shallow fine-grained deposits are common in the area where the underlying continental deposits contain substantial clay. Present plans call for flood control basins only in the part of the area south of Shepherd Avenue, and lands to the north are to be drained to the San Joaquin River. South of Shepherd Avenue, there are apparently some locations where intentional recharge may be feasible, but many of these are in areas underlain by groundwater with a DBCP content exceeding 0.1 ppb. Similar limitations are present in much of the Herndon-Shepherd Plan Area.

Groundwater Quality

The inorganic chemical quality of groundwater in the older alluvium in the North Fresno Growth Area is generally excellent for drinking water. However, manganese contents exceeding the MCL have been found in shallow groundwater near Dry Creek and in part of East Clovis.

Groundwater in the Reduced Deposits

The chemical quality of groundwater in the reduced (blue or green) continental deposits has been of some concern since the completion of an 880-foot deep test well (T12S/R20E-9D) at the Rolling Hills subdivision in Madera County in January 1986. High iron (1.7 mg/l), manganese (0.29 mg/l), and moderate arsenic (0.03 mg/l) contents were found in a water sample pumped from a depth of about 500 feet in this test well.

A test well was drilled in December 1986 at Woodward Park to provide information on the chemical quality of water in the reduced deposits. The test well (T12S/R20E-21J) was drilled by the casing hammer method. The reduced continental deposits were encountered from a depth of 370 feet to the bottom of the hole at 800 feet. Water samples were collected from a total of eight depths in the reduced deposits. A moderate hydrogen sulfide odor was detected in water samples from 380 to 390 feet and 760 to 800 feet in depth. Iron and manganese contents exceeded the recommended MCLs of 0.3 and 0.05 mg/l, respectively, at all three depths where pumped samples were collected. The highest iron and manganese contents were found in groundwater from near the upper part of the reduced deposits. The arsenic content in water from a depth of 580 to 615 feet was 0.06 mg/l, exceeding the MCL of 0.05 mg/l. Arsenic contents in water from the other two depths were detectable, but less than the MCL.

An arsenic content of 0.12 mg/l was recently obtained in a water sample collected from a depth of about 500 feet in TH-168, near Maple and Behymer Avenues.

Water samples were also collected from the reduced deposits east of Tarpey Village in August 1989. A casing hammer test well was drilled near Ashlan and Fowler Avenues (T13S/R21E-22D) to a depth of 600 feet. Although high manganese contents were present in groundwater from some depth intervals, there was no hydrogen sulfide odor in this water, and contents of iron and arsenic were low.

Manganese in East Clovis Area

Figure 18 shows an area of high manganese contents in groundwater of East Clovis area, based on June 1990 sampling of numerous private wells. A zone of manganese contents exceeding the MCL of 0.05 mg/l extended northeasterly from near Fowler and Dakota Avenues (the site of the former City of Fresno Well PS 83 that was abandoned due to high manganese contents) northeasterly to near Temperance and Gettysburg Avenues, thence easterly to Leonard Avenue. Information from the casing hammer test hole that was drilled east of Fowler Avenue, and about one-quarter mile south of Ashlan Avenue delineated the vertical distribution of manganese at this location. The manganese content ranged from 0.06 to 0.19 mg/l and exceeded the recommended MCL above a depth of 270 feet at this location.

DBCP

The County of Fresno Environmental Health Division analyzed DBCP contents in water collected from about 30 domestic wells during 1981-84 in or near the Fresno North Growth Area. Nineteen private domestic wells in this area were sampled in Spring 1987 by Kenneth D. Schmidt and Associates under contract to the City of Fresno. These wells were sampled because of the absence of public-supply wells in most of the east part of that area at that time. In May 1991, J.H. Kleinfelder and Associates, under contract to the City of Fresno sampled 21 private wells in and near the north part of the North Fresno Growth Area for DBCP analyses. DBCP contents have also been analyzed for the public-supply wells in the area. DBCP has been detected in water from four public-supply wells in the vicinity (PS 85, PS 89-A, PS 133, and PS 134). Most of the other public-supply wells are generally farther west, and not near the most likely sources of DBCP (pesticides applied to vineyards or deciduous tree crops). Well PS 85 is near the southeast corner of the area and DBCP contents have increased markedly in water from this well in recent years. The results of private well sampling in this area were discussed previously. Figure 21 provides information on DBCP contents in water from wells in recent years.

DBCP contents have exceeded 1.0 ppb in two parts of the Fresno North Growth Area. One is east of Maple Avenue and south of Teague Avenue, and the second is north of Behymer Avenue, east of Maple Avenue. DBCP contents in water from four wells in the first of these areas ranged from 2.3 to 4.6 ppb in 1981-84. DBCP contents in water from most wells have usually exceeded 0.1 ppb in the part of the area that is east of Maple Avenue and south of Perrin Ave-

nue. This part of the area has historically been one with abundant deciduous tree crops. In the second part of the area with high DBCP contents, a content of 1.7 ppb was found in water from one well in 1984-84. In July 1991, a DBCP content of 6.1 ppb was found in water from another well in this area. Part of this area is downgradient of an extensive tract of vineyards north of Copper Avenue. The domestic wells with high DBCP contents in both of these parts of the area likely produce water only from the older alluvium.

Information on historical DBCP contents in well water in the Herndon-Shepherd Plan Area was obtained from the County of Fresno Environmental Health. In addition, a water sampling program for thirty private wells in the area was undertaken in Summer 1989, to supplement and update previously available data. DBCP contents exceeding the MCL of 0.2 ppb in groundwater of the Herndon-Shepherd Plan area are primarily west of Marion Avenue. DBCP contents generally increase to the west, to near a northeast trending line connecting Nees and Willow Avenues to Shepherd Avenue just east of Peach Avenue. Northwest of that line, DBCP contents decrease to less than the MCL, near Willow and Shepherd Avenues.

Ten casing hammer test wells were completed in this area during 1989-91, partly to determine the vertical distribution of DBCP at perspective sites for new City of Clovis' public-supply wells. Results of these test wells illustrated two predominant patterns. First, clay strata in part of this area aren't effective confining layers. At three test well sites, DBCP has migrated to depths exceeding 300 feet in this area, which is significantly deeper than normally found elsewhere in the Fresno-Dinuba Area. However, DBCP contents exceeding the MCL haven't been found in any of the test wells below a depth of 260 feet. The relatively shallow bedrock and the presence of DBCP in the area is a substantial constraint in developing new public-supply wells that produce water not requiring treatment. The results from the 1989 sampling of water from shallow private domestic wells indicated that the area near Dry Creek had low DBCP contents. However, the subsequent drilling of several test wells in this area indicated that high DBCP contents were present generally in groundwater below a depth of about 120 feet and above a depth of about 250 feet. Recent recharge from stream-flow in Dry Creek is apparently the source of the shallow groundwater in this area, which has low DBCP contents. This recharge probably originated after the use of DBCP was banned.

One casing hammer test well has been drilled in the East Clovis Area near Ashlan and Fowler Avenues (T13S/R21E-22D). No DBCP was detected at this site. Detectable DBCP in groundwater in the East Clovis area is primarily either west of Sunnyside Avenue, or between Gettysburg and Barstow Avenues and Clovis and Temperance Avenues.

Summary

The major known limitations in terms of development of groundwater for public supply in this sub-area are:

1. The shallow depth to bedrock in the northeastern part of the Herndon-Shepherd Plan Area and the northern part of the East Clovis Area.
2. Thick clay strata below a depth of several hundred feet in parts of the North Fresno Growth Area and east Clovis Area.
3. Unfavorable subsurface geologic conditions above the water table in many areas for intentional recharge by basins.
4. Lack of canal water and/or distribution facilities north of the Enterprise Canal.
5. Large areas of DBCP contamination in the groundwater and localized EDB contamination in at least three areas.
6. High manganese contents in shallow groundwater along Dry Creek and in part of the East Clovis Area.
7. The presence of reduced deposits (possibly associated with arsenic and hydrogen sulfide in the groundwater) at relatively shallow depth beneath the North Fresno Growth Area and part of the East Clovis Area.

PESTICIDE CONTAMINATION IN THE SOUTHEAST FRESNO SUB-AREA

DBCP

Numerous analyses are available for DBCP in water from public-supply wells in and near the sub-area since 1979. As part of the 1984 study, DBCP analysis for these wells were collected. Information on well construction is generally available for all public-supply wells in the sub-area. Water from about fifty private domestic wells in the sub-area had been analyzed by the Environmental Health Division of the County of Fresno. Information on well construction was available for about half of these wells. Most of the water samples from these domestic wells were collected during 1982-83. In addition, water from about sixty individual domestic wells was analyzed by the Bureau of Sanitary Engineering, California Department of Health Services. Most of these samples were collected during 1981-83, and many are for wells near the northeastern part of the study area. Most domestic wells in the study area are between about 80 and 150 feet in depth. Some irrigation wells sampled are about 200 feet in depth. Both of these types of wells generally tap only the older alluvium.

As part of a more recent study of groundwater in this sub-area (a joint feasibility study by the Fresno Irrigation District and City of Fresno), a DBCP map was prepared for 1990-91. This map included data from 35 private wells that were sampled in January

1991 and another 18 private wells that were sampled during May 1991 in the adjacent upgradient rural area.

Areal Distribution

Early 1980's. DBCP values for the period 1981-84 were plotted and contoured by Schmidt (1984, Plate 6). For private domestic wells, only one analysis was usually available, and for public-supply wells, an average DBCP value was used, if more than one analysis was available. Most values plotted for the public-supply wells were for late 1983 or early 1984. A distinct geographic pattern of DBCP content in well water was delineated. Except for an isolated area east of the Fresno Air Terminal (near Well PS 55), a major southwest trending boundary existed, with high DBCP contents to the southeast and low DBCP contents to the northwest. Water from wells northwest of this line generally had a DBCP content less than 0.1 ppb. The 1.0 ppb contour generally was about one-quarter to one-half mile southeast of the 0.1 ppb contour. Approximately half of the sub-area was underlain by shallow groundwater containing more than 1.0 ppb DBCP, or the state action level at that time. Most of the area where DBCP content exceeded 1.0 ppb was southeast of a line that extended from near McKinley and Temperance Avenue, southwest to near Belmont and Armstrong Avenues, thence south to near Butler and Armstrong Avenues, thence southwest to near Jensen and Clovis Avenues. In the area where DBCP contents exceeded 1.0 ppb, water from some wells contained more than 5.0 ppb of DBCP. Overall, DBCP contents in well water in the early 1980's corresponded fairly closely to the locations of existing or former vineyards, which were mapped as part of the 208 program. Relatively low or undetected contents of DBCP were usually present beneath urbanized areas and lands not developed to vineyards.

1990-91. The distribution of DBCP in groundwater in 1990-91 was shown in Figure 21. By this time, an MCL for DBCP had been established at 0.20 ppb, lower than the previous state action level of 1.0 ppb. Several trends are apparent in comparing the map for 1983-84 with that for 1990-91. First, DBCP contents in the hot-spots beneath parts of the upgradient rural area had generally decreased. This trend has been widely observed in rural parts of the Fresno-Dinuba area, and the main reasons for this are:

1. Pumping out of high DBCP water by irrigation wells and subsequent degradation of the DBCP.
2. Recharge of low-DBCP or DBCP-free water from canal seepage and deep percolation of excess applied irrigation water since the use of DBCP was banned.
3. Degradation of DBCP in the aquifer.

Another trend is that there has been downgradient migration of DBCP in certain areas, which would be expected, considering the relatively high permeability of the older alluvium in most of this sub-area.

One of the most noticeable patterns in Figure 21 is the clear relation between the location of several canals and the DBCP contents in the groundwater. An example is the Fancher Creek Canal. East of Clovis Avenue this canal traverses an area where DBCP contents were much lower than to the south. East of Temperance Avenue and in the vicinity of the canal, DBCP contents were less than 0.1 ppb, and often undetectable, whereas they were greater than 0.5 ppb in water from wells more distant from the canal, both to the north and south. An even more striking relation is along the Fancher Creek Canal from near E. Tulare Avenue and Clovis Avenue, south to near the Washington Canal and Jensen Avenue. DBCP contents exceeding 0.1 ppb were essentially only upgradient (east) of this canal. Significant seepage along the Fancher Creek Canal has been reported by the Fresno Irrigation District. Because the direction of groundwater flow is generally westerly in this area, the low DBCP contents in groundwater west of the canal are attributed to dilution due to canal seepage. There is some evidence that seepage from the Central Canal, between Willow Avenue and the junction with the Washington Canal, acts in a similar fashion.

Comparing the 1982-84 map (Schmidt, 1984, Plate 6) with Figure 21, it can be seen that the 1.0 ppb DBCP contour has shifted westerly an average of about a mile and a half between Tulare Avenue and California Avenue, east of Clovis Avenue. Assuming that an average of about seven years had elapsed, this is a rate of DBCP migration of about 1,100 feet per year. The 0.1 ppb DBCP contour has shifted westerly in this area an average of about one mile. The corresponding rate of DBCP migration would be about 750 feet per year. The average of these two rates, or about 900 feet per year, is in excellent agreement with the previous estimate of the rate of groundwater flow in the area (800 to 900 feet per year) by Kenneth D. Schmidt and Associates (1987b). This estimate was based on the results of four aquifer tests conducted in the vicinity in Spring 1987, and using the water-level elevation contour map for Spring 1987. These tests are discussed in more detail in a subsequent part of this report. The main intrusion of DBCP in the Southeast Fresno Sub-area between the early 1980's and about 1990, occurred in Sections 4 and 9 of T14S/R21E, and in Calwa.

Vertical Distribution

The vertical distribution of DBCP in the aquifer can be evaluated by several approaches, as discussed previously in this report. The results of depth sampling programs (where water samples are collected from specific strata in a test hole or well) are available at five sites in the sub-area. At the time of the 1984 report, minimal information for such programs was available. In that report, DBCP contents were compared with well construction information for specific wells. The high DBCP content in groundwater at PS 55 was primarily located in permeable strata between depths of about 120 and 200 feet. High DBCP contents in the old John Wash School well were primarily in strata between depths of about 220 and 250 feet. The new school well tapped DBCP-free water below a depth of about 350 feet. At D24-3, high DBCP contents were found

in strata between about 150 and 250 feet in depth. At PS 107, high DBCP contents were found in strata between about 110 and 200 feet in depth. DBCP contents in water from specific strata in the early 1980's were plotted on the subsurface geologic cross section (Schmidt, 1984, Plates 2, 3, and 4). Most of these values were determined from depth sampling programs, but some were determined from other information.

Since the 1984 report, additional hydrogeologic studies were completed for the proposed Canterbury Station project, located in (between California and Jensen Avenues and Clovis and Fowler Avenues). Two specially designed deep test wells for sampling groundwater at various depths were completed for that project in Summer 1985. As part of the 1987 study of DBCP in southeast Fresno, two additional similar test wells were drilled in the high-DBCP part of the study area, during December 1986-January 1987. All four holes were drilled by the casing hammer method to a depth of about 600 feet. The locations of these test wells are shown in Figure 2.

Canterbury Station Test Wells. CB-1 (T14S/R21E-16D) was drilled just south of California Avenue and one-quarter mile east of Clovis Avenue. CB-2 (T14S/R21E-16E) was drilled just east of Clovis Avenue, and one-half mile south of California Avenue. The two test wells indicated that deposits below a depth of 300 feet had significant potential for groundwater development, even though clay strata predominate. At CB-1, water samples were collected for determination of DBCP at 13 different depths. DBCP content in groundwater at this site was almost 2.0 ppb at a depth of about 100 feet, but was less than 0.01 ppb at all depths that were sampled below 140 feet. At CB-2, water samples were collected for determination of DBCP at 11 different depths. DBCP content ranged from 0.2 to 2.3 ppb at four depth intervals between 100 and 205 feet. DBCP in water at this site was not detected below a depth of 230 feet. Groundwater below a depth of 200 feet at the two Canterbury Station test well sites appeared to be of suitable inorganic chemical quality for drinking water, except possibly for iron at CB-1, which could require treatment.

Sunnyside Test Holes. Sunnyside Test Well No. 1 (SS-1) was drilled southeast of the intersection of Butler and Locan Avenues, in the eastern part of the sub-area (T14S/R21E-11K). Sunnyside Test Well No. 2 (SS-2) was drilled southwest of the intersection of Church and Temperance Avenues, in the southeast part of the sub-area (T14S/R21E-15J).

At SS-1, water samples were collected for determination of DBCP at eight different depths. DBCP content was 0.83 ppb at a depth of about 80 feet and 0.36 ppb at a depth of about 140 feet. Below a depth of 176 feet, no DBCP was detected at this site. At SS-2, water samples were collected for determination of DBCP at 11 different depths. DBCP content was 0.04 ppb at a depth of about 90 feet, 2.4 ppb at about 140 feet, and 0.4 ppb at about 180 feet. Below a depth of 275 feet, no DBCP was detected.

At SS-1, less than 40 feet of permeable water-bearing strata were found below the DBCP-containing groundwater. At SS-2, there were almost 160 feet of permeable water-bearing strata below the DBCP-containing water at this site. However iron contents in this deeper groundwater might require treatment for public supply.

Time Trends

The results of frequent sampling for DBCP analyses are available since about 1979 for the following wells where DBCP contents exceeding about 0.1 ppb have been found: PS 82, GVF-S, D5-1,2,3, and 4, D24-1,2,3, and 4, and D29-1 and 2. Plots of DBCP content versus time (DBCP hydrographs) were prepared for these wells.

Well GVF-S is located northeast of the intersection of Clovis and Jensen Avenues, at Greenfield Village, and is perforated from 72 to 110 feet in depth. Historical DBCP contents in water from this well are shown in Figure 26. From 1981 to 1986, DBCP contents in water from this well decreased almost linearly. DBCP contents at the time of sampling have been less than 1.0 ppb since 1983. At CB-2, the closest test well for which precise depth sampling has been conducted, the DBCP content was much lower in groundwater at a depth of 100 feet (0.2 ppb) than at a depth of 150 feet (2.3 ppb). This suggests the possibility that water low in DBCP content has been recharged in recent years. Another causative factor may be the lateral movement of low-DBCP groundwater from some up-gradient area. Such groundwater was present in a large area east of Fowler Avenue and south of Jensen Avenue in the early 1980's (County of Fresno, et al, 1986).

Well PS 82 is located near Peach and Butler Avenues and is perforated from 180 to 380 feet in depth. This well is located in an area where DBCP contents in well water have usually been less than 0.1 ppb in recent years, but were greater than 0.1 ppb in the early 1980's. Records of DBCP content are available for this well from 1979 to 1991 (Figure 27). DBCP contents exceeded 1.0 ppb in water from this well in early 1980. DBCP contents below 1.0 ppb were obtained by steadily pumping the well (i.e., eliminating on-off cycles). There has been an overall decrease in DBCP content during the period of record, and by 1990-91 contents were less than the MCL of 0.20 ppb. Pumping of this well appeared to be functioning as a groundwater cleanup mechanism, along with seepage from the Fancher Creek Canal, which is upgradient.

DBCP contents for four former FCWD wells are shown in Figure 28. Wells D5-1 and D5-2 are the shallowest of these wells and D5-3 is the deepest. DBCP contents in water from D5-4 increased almost linearly from 1979-86. By late 1986, DBCP content in water from this well exceeded 0.8 ppb, compared to about 0.1 ppb in 1979. This well is located adjacent to the Fancher Creek Canal. In 1990, this well was successfully deepened, and by 1990-91, produced water with a DBCP content below the MCL. However, DBCP contents in water from Wells D5-1 and D5-2 have increased dramatically. DBCP contents ranged from 0.4 to 0.6 ppb in 1986, compared to very low con-

tents in 1979. By 1990-91, contents as high as 2 to 3 ppb were found in water from these two wells. The primary reason for these increasing DBCP contents is the downgradient migration of high-DBCP groundwater from the southeast (i.e., primarily in the south half of Section 9 and in Section 16, of T14S/R21E). These two wells are located about one-quarter mile east and upgradient of the Fancher Creek Canal.

Figure 29 shows DBCP contents in water from D24-1. This well is located north of Butler Avenue and east of Fowler Avenue. This well is located in a transition zone between high DBCP groundwater (greater than 3.0 ppb) to the southwest and lower DBCP groundwater (less than 1.0 ppb) to the northwest. It was drilled to 153 feet in depth, cased to 142 feet, and is an open bottomed well. DBCP contents have remained relatively constant since 1979.

Figure 30 shows DBCP contents in water from D24-2. This well is located south of Kings Canyon Road and east of Fowler Avenue. The well was drilled to a depth of 250 feet, cased to 184 feet, and is open-bottomed. Since 1979, DBCP contents in water from this well have increased. DBCP contents in this well were below 1.0 ppb before 1986. However, during heavy pumping conditions in early 1986, DBCP contents in water from this well exceeded 1.4 ppb. By 1990-91, contents as high as 4.0 ppb had been found. This well is also in a transition area between high-DBCP groundwater to the southwest and low DBCP groundwater to the north.

Figure 31 shows DBCP contents in water from D24-3, which is located near California and Fowler Avenues, in one of the highest areas of DBCP content in the sub-area. This well is perforated from 160 to 260 feet in depth and has had some of the highest DBCP contents observed in the sub-area. DBCP contents in water from this well often exceeded 10 ppb, and sometimes exceeded 20 ppb, prior to 1983. However, since 1983, DBCP contents have usually been below 3.0 ppb. It was reported that when wells farther north (D24-1 and D24-2) were heavily pumped, the DBCP contents in water from D24-3 decreased. The substantial decreases in DBCP content may be due to downgradient movement of high-DBCP groundwater to the northwest. For example, some of the former FCWD No. 5 wells are downgradient of D24-3. A similar substantial decline in DBCP content in water from another well that formerly had DBCP contents in excess of 10 ppb has also been observed north of the study area, at Tarpey Village, in former FCWD No. 8.

Well D24-4 (also termed PS 244) is located near the Briggs Canal, north of Kings Canyon Road. This well was drilled to a depth of 255 feet, cased to 232 feet, and is an open-bottomed well. DBCP contents in water from this well have decreased since 1979, and have usually been less than 1.0 ppb since 1984 (Figure 32). By 1990-91, contents ranged from about 0.2 to 0.9 ppb, exceeding the MCL. This may be partly due to recharge from seepage from the nearby canal. In late Summer 1991, a DBCP treatment unit was placed on this well.

Figure 34 shows DBCP hydrographs for D29-1 and D29-2. Well D29-1 is located south of Kings Canyon Road and west of Fowler Avenue. Well D29-1 was drilled to a depth of 283 feet, cased to 152 feet, and is open-bottomed. DBCP contents in water from this well have remained relatively constant since 1979. By 1990-91, contents ranged from about 0.1 to 1.0 ppb, usually exceeding the MCL. D29-2 is located near Sunnyside Avenue and south of Kings Canyon Road. D29-2 was drilled to a depth of 206 feet, cased to 151 feet, and is open-bottomed. Prior to 1987, DBCP contents in water from this well remained less than 0.1 ppb except during 1985-86, when they exceeded 0.2 on several occasions. By 1990-91, contents were sometimes almost as high as 0.5 ppb, exceeding the MCL. These wells are located north of D5-1 and D5-2, and show a similar pattern of increasing DBCP contents.

Summary

DBCP contents in the sub-area have increased in some former FCWD wells and Bakman Water Company wells since 1979, primarily due to the downgradient movement of high DBCP groundwater from the southeast. This has occurred primarily in Sections 4 and 9 of T14S/R21E, between Tulare and California Avenues, east of Clovis Avenue. On the other hand, DBCP contents have either decreased or remained relatively constant in water from wells in the part of the sub-area where DBCP contents exceed 1.0 ppb. The decreases are probably due to recharge of low-DBCP water from canal seepage and deep percolation of irrigation return flow since DBCP was banned and degradation of DBCP. In downgradient areas where DBCP contents are detectable and less than about 0.1 ppb, slight increases in content have generally occurred, due to downgradient migration of contaminated groundwater.

Ethylene Dibromide

Figure 22 shows the distribution of ethylene dibromide (EDB) in groundwater in and near the urban area in 1990-91. The locations of public-supply wells for which analyses are available are shown, and for wells where EDB contents exceeded the MCL of 0.02 ppb, the range in EDB content is provided. EDB contents were determined in the water samples collected from 53 private wells sampled in this area in 1991, and no content exceeded the detection limit of 0.01 ppb.

The highest EDB contents known in groundwater in the urban area are present in the eastern part of the Sunnyside area. Water from four wells (D24-1, D24-2, D24-4, and D29-1) had EDB contents periodically exceeding the MCL. The highest contents, ranging from 0.1 to 1.1 ppb, were found in water from D29-1. The source of the EDB also appears to be pesticide applications to agricultural lands in close proximity to the sampled wells. This is also the part of the urban area where some of the highest DBCP contents are present in groundwater.

Apparently more localized zones of EDB contamination have been found at two other wells in the southern part of the urban area (C-3 and PS 82). EDB contents in water from PS 82, near the Internal Revenue Service Center, ranged from less than 0.02 to 0.04 ppb. An EDB content of 0.11 ppb was found in water from C-3 in Calwa.

Aquifer Tests

Aquifer tests were conducted on four wells in the sub-area in March-April 1987, in order to determine aquifer characteristics. Methodologies for the tests were provided by Kenneth D. Schmidt and Associates (1987b). These wells were intentionally selected to evaluate coarse-grained strata in the older alluvium above a depth of about 200 feet, where most of the horizontal migration of DBCP would be expected to occur. This expectation is based both on sub-surface geologic considerations and the results of depth sampling programs, which indicate that most of the DBCP is present above this depth.

Well D5-4 is located about one quarter mile west of Clovis Avenue and north of the Southern Pacific Railroad tracks. This well is an open-bottomed well, drilled to a depth of 192 feet and cased to a depth of 144 feet. Cross Section C-C' from Schmidt (1984, Plate 4) indicates that a coarse-grained unit (primarily sand) is present in the vicinity in the depth interval tapped by D5-4. The static water level prior to pumping was 53.7 feet and the average pumping rate was 995 gpm. The final pumping level was 74.3 feet, and the specific capacity was 48.3 gpm per foot. Corrected recovery measurements for this test indicated an aquifer transmissivity of 66,000 gpd per foot. Using an estimated thickness of permeable deposits tapped by the well of 40 feet, the average permeability was 1,700 gpd per square foot.

Well D24-1 is located north of Butler Avenue and east of Fowler Avenue. This well is also an open-bottomed well, drilled to a depth of 153 feet and cased to 142 feet. About 45 feet of coarse-grained deposits (primarily sand) are present in the vicinity in the depth interval tapped by D24-1. The static water level prior to pumping was 40.8 feet and the average pumping rate was 481 gpm. The final pumping level was 49.7 feet, and the specific capacity was 54 gpm per foot. Corrected recovery measurements for this test indicated a transmissivity of 109,000 gpd per foot. Using a thickness of permeable deposits tapped by the well of 45 feet, the average permeability was 2,400 gpd per square foot.

Well PS 63 is located near the intersection of McKinley and Chestnut Avenues. This well is perforated from 146 to 287 feet in depth. Only about 25 feet of permeable coarse-grained, deposits (primarily sand) were present in the perforated interval at the well, according to the drillers log, and about two-thirds of these were above a depth of 180 feet. The static level prior to pumping was 82.1 feet and the average pumping rate was 907 gpm. The pumping level at the end of pumping was 105.7 feet and the specific capacity was 38 gpm per foot. Corrected recovery measurements for

$Q = TIL,$
 where Q = groundwater underflow (gpd)
 T = transmissivity (gpd per foot)
 I = hydraulic gradient (feet per mile)
 L = width of flow (miles)

the amount of underflow was calculated. Using an average permeability of 2,100 gpd per foot for the coarse-grained deposits, and an estimated average thickness of 50 feet for the DBCP-contaminated groundwater, the average transmissivity is about 105,000 gpd per foot. The amount of underflow of high-DBCP groundwater past the line is about 12,000 acre-feet per year.

The Need for Recharge Downgradient of the DBCP Plume

Because of the high DBCP contents in groundwater in the Southeast Fresno Sub-Area, unmitigated flow of this water into the downgradient urbanized area will degrade the quality of public water supplies.

Presently, water-level elevations beneath the DBCP contaminated part of the sub-area range from about 220 to 280 feet, and exceed 250 feet beneath most of the contaminated area. This compares to less than 200 feet in downtown Fresno and less than 220 feet in most of the Northwest Fresno Sub-area. The most important reason for recharging good quality canal water in the Southeast Fresno Sub-Area is for enhancement of groundwater quality in downgradient areas. Recharge of good quality canal water, particularly in areas where the under-lying groundwater contains less than about 0.1 ppb of DBCP, would be highly beneficial, by flattening the water-level slope between this area and the upgradient more contaminated area. Also, this recharged water could be re-pumped later, probably without treatment.

The Case for Extraction of High-DBCP Groundwater

Potential impacts on downgradient public-supply wells in the future could be minimized by implementing an intentional extraction program for the high-DBCP water. Since the MCL was established several years ago, a number of wells formerly used for public supply have been shut down. This allows the DBCP-contaminated groundwater to continue to migrate downgradient. If groundwater pumped for agricultural purposes in the sub-area decreases in the future due to urbanization, then there will be less pumping of high-DBCP water from irrigation wells. The trend of decreasing pumping of this contaminated groundwater should be reversed in the future.

A project to intentionally extract about 15,000 acre-feet of high-DBCP groundwater should be implemented in the sub-area. This water would be pumped from either existing public-supply wells that have been shut down, existing irrigation wells, or newly installed wells. Water pumped from public-supply wells could be treated and

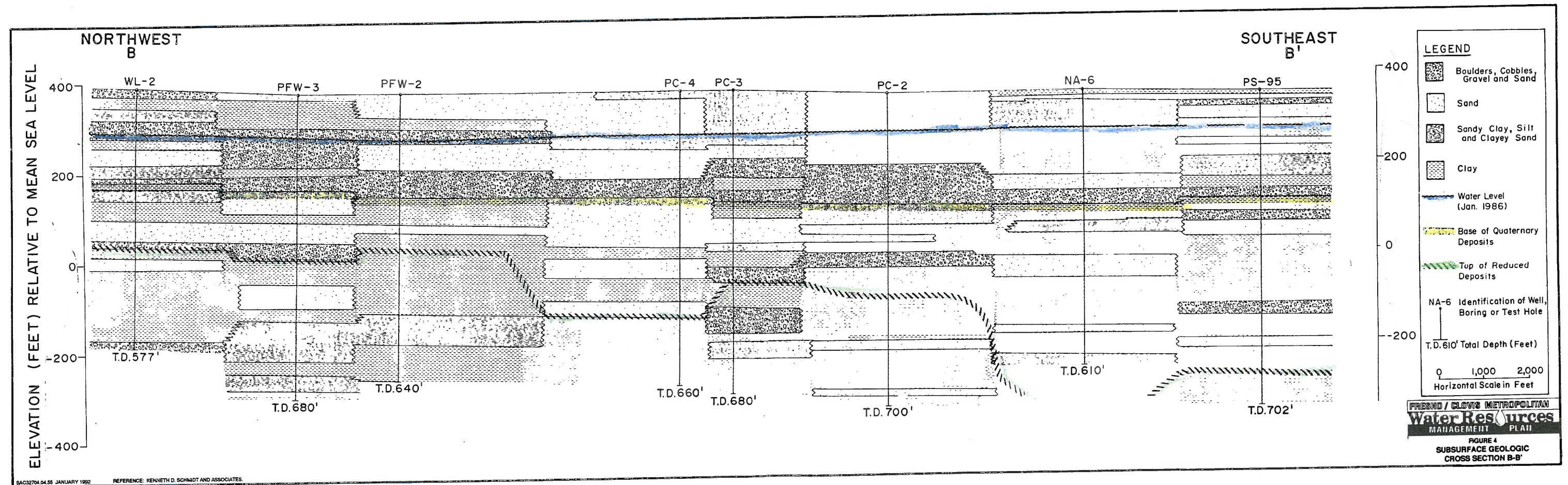
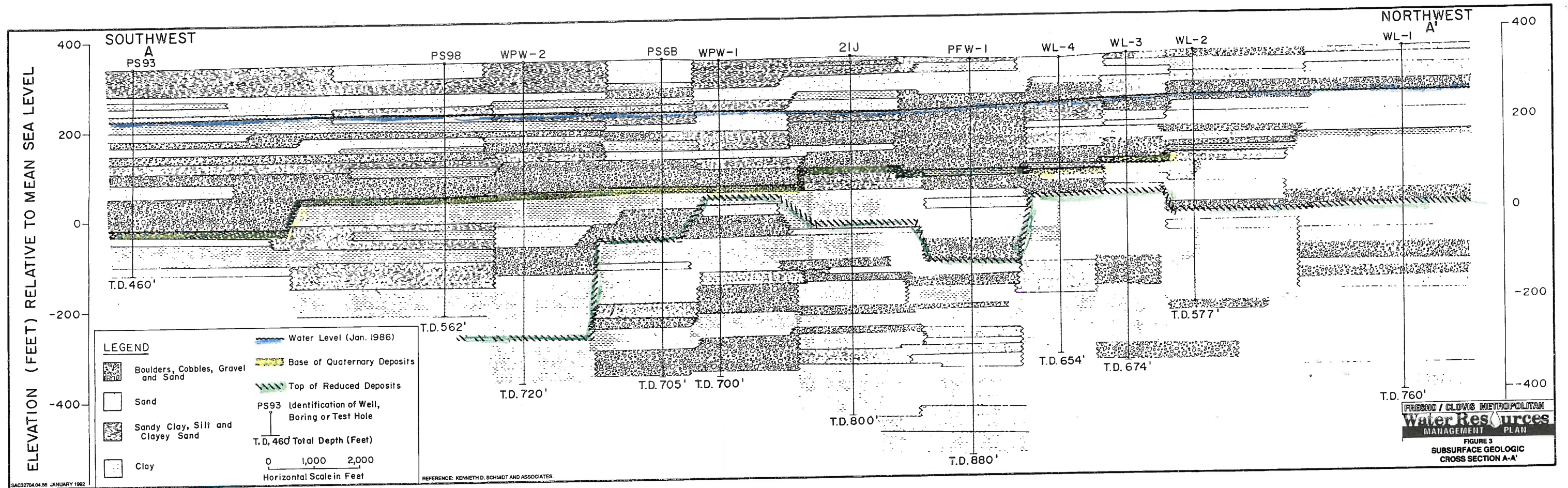
used directly. Subject to approval of the appropriate regulatory agency or agencies, water pumped from other wells could be piped to nearby canals, blended with canal water, and used for irrigation. However, one or more permits would need to be obtained, and concerns have been expressed about transporting DBCP from one area to another and about potential impacts on groundwater in other areas. Such pumping would help to flatten the water-level slope between the contaminated area and downgradient areas now threatened by this contamination. The combination of recharging good quality canal water in DBCP-free areas and extracting the high-DBCP groundwater in the Southeast Fresno Sub-Area would minimize the farther down-gradient migration of DBCP-contaminated groundwater into the urban area. It would also help protect the quality of groundwater in the prime Northwest Fresno Sub-area over the long-term.

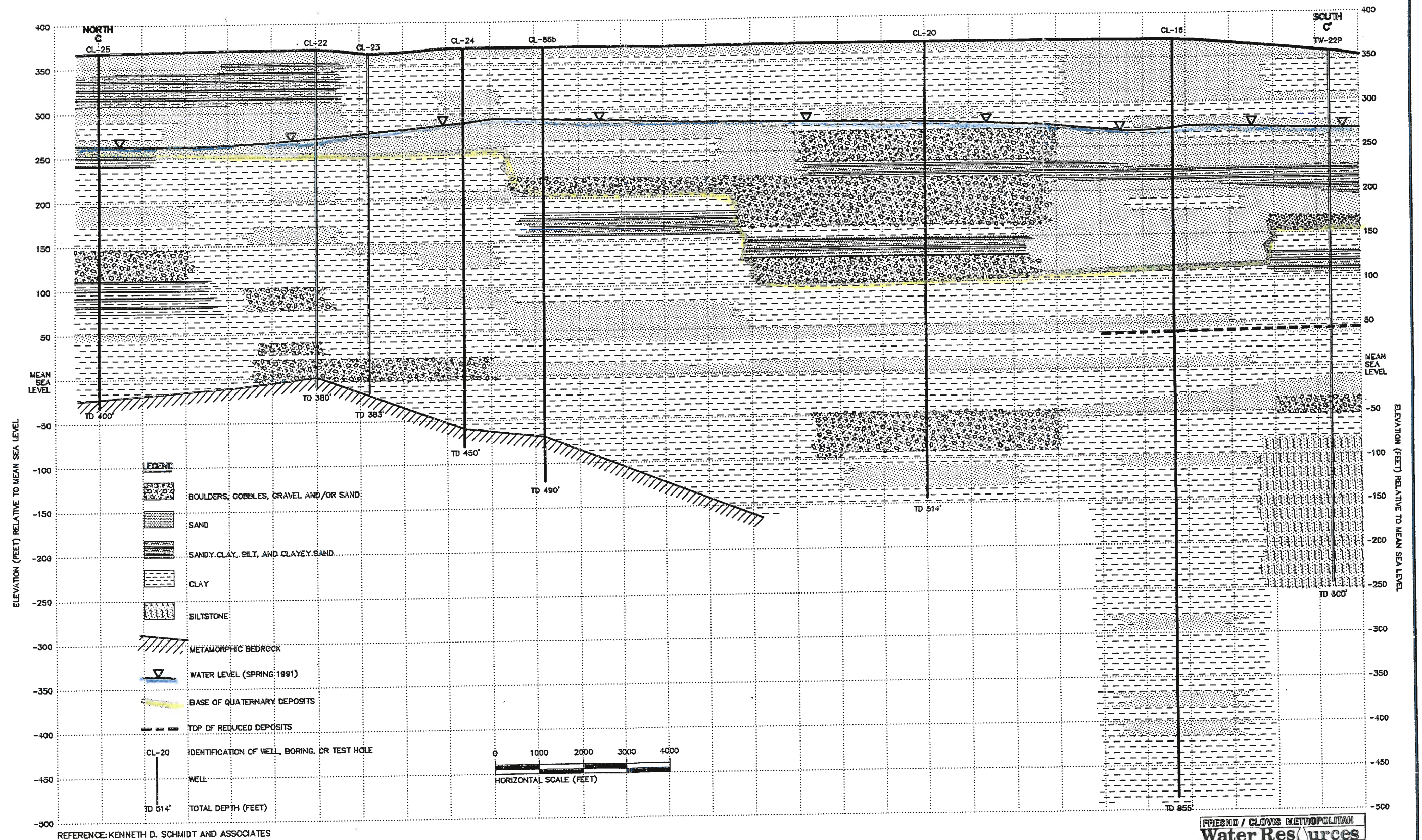
REFERENCES:

- Behnke, J.J., and E.E. Haskell, Jr., 1968, "Ground Water Nitrate Distributions Beneath Fresno, California", Journal AWWA, Vol 60, No. 4, pp 477-480.
- BSK & Associates, 1990, "Report on Supplemental Groundwater Contamination Assessment and Soil/Groundwater Remediation at Ace Trans-State Tires, Inc., Broadway and Ventura, Fresno, Fresno County".
- California Division of Water Resources, 1952, "Investigation of Cooling Water Return, City of Fresno", Report to Central Valley Regional Water Pollution Control Board, Project No. 52-5-10, 44 p.
- California Division of Water Resources, 1953, "Effect of Waste Discharges from the Pacific Fruit Express Ice Plant and the Southern Pacific Zeolite Water Softening Plant, Fresno County", Report to Central Valley Regional Water Pollution Control Board, Project No. 53-5-8, 35 p.
- California Department of Water Resources, 1957, "Fresno Metropolitan Area Investigation", Report to Central Valley Regional Water Pollution Control Board.
- California Department of Water Resources, 1965, "Fresno-Clovis Metropolitan Area Water Quality Investigation", Bulletin 143-3.
- California Air National Guard, 1991, "Fresno Air National Guard Base", Site Investigation Fact Sheet No. 2, 3 p.
- County of Fresno, 1976, "Northeast Fresno Ground Water Study", Public Works Department, Environmental Health System, and Planning Department, 73 p.
- County of Fresno, et al, 1979, "Interim Best Management Plan for Water Quality, Fresno-Clovis Urban and Northeast Fresno County", EPA 208 Water Quality Management Program.

- County of Fresno, et al, 1986, "Draft Water Resources Management Plan for Fresno-Clovis Urban & Northeast Fresno County", EPA 205J Water Quality Management Program.
- Day, B.A., Nightingale, H.I., Bianchi, W.C., and T.R. Cockrum, 1977, "Northeast Fresno Ground Water Study - A Data Inventory for Detailed Sampling in Areas of Suspected High Nitrates", Fresno Ground Water Recharge Field Station, Agriculture Research Service, 37 p.
- Engineering-Science, Inc., 1970, "Central Fresno County Water and Liquid Waste Program", with Grunwald, Crawford, & Associates, prepared for the County of Fresno Planning Department.
- EPA, 1989, "Purity Oil Sales Superfund Site", Fact Sheet, 7 p.
- EPA, 1990, "FMC-Fresno Superfund Site", Fact Sheet, 4 p.
- Geomatrix Consultants, 1991, "Interim Report, Municipal Pumping and Recharge Monitoring through December 1990", prepared for the Vendo Company, Fresno, California.
- John Carollo Engineers, 1969, "Report on Water Resources, City of Fresno", with a section on hydrogeology by Harshbarger & Associates, prepared for the City of Fresno Public Works Department.
- Kennedy/Jenks/Chilton, 1991, "Report on Phase II/III Groundwater Investigation, TH Agriculture and Nutrition Company, Inc., Eastern Fresno County, CA", prepared for TH Agriculture & Nutrition Company, Woodland Hills, CA, 12 p.
- Kenneth D. Schmidt and Associates, 1987a, "Groundwater Conditions in the Fresno North Growth Area", prepared for City of Fresno, 46 p.
- Kenneth D. Schmidt and Associates, 1987b, "Further Evaluation of the Distribution of DBCP in Groundwater in Southeast Fresno", prepared for City of Fresno, 26 p.
- Kenneth D. Schmidt and Associates, 1988, "Evaluation of Volatile Organic Chemical Contamination of Groundwater in North Fresno", Draft Report, prepared for City of Fresno, 14 p.
- Metcalf & Eddy, 1990, "Pinedale Groundwater Private Well Sampling", prepared for California Department of Health Services, Sacramento, California.
- Metcalf & Eddy, 1990, "Preliminary Groundwater Results-Pinedale Monitoring Wells", prepared for California Department of Health Services, Sacramento, California.
- Nightingale, H.I., 1970, "Statistical Evaluation of Salinity and Nitrate Content and Trends Beneath Urban and Agricultural Areas - Fresno, California", Ground Water, Vol 8, No 1, pp 22-28.

- Nightingale, H.I., 1972, "Nitrates in Soil and Ground Water Beneath Irrigated and Fertilized Crops", Soil Science, Vol 114, No 4, pp 300-311.
- Nightingale, H.I., 1974, "Soil and Ground-Water Salinization Beneath Diversified Irrigated Agriculture", Soil Science, Vol 118, No 6, pp 365-373.
- Nightingale, H.I., and W.C. Bianchi, 1974, "Ground-Water Quality Related to Irrigation with Imported Surface or Local Ground Water", Journal of Environmental Quality, Vol 3, No. 4, pp 356-361.
- Nightingale, H.I., and W.C. Bianchi, 1977, "Ground-Water Chemical Quality Management by Artificial Recharge", Ground Water, Vol 15, No 1, pp 15-21.
- Page, R.W., and R.A. LeBlanc, 1969, "Geology, Hydrology, and Water Quality in the Fresno Area, California", U.S. Geological Survey Open-File Report, Menlo Park, 70 p.
- Schmidt, K.D., 1971, "The Distribution of Nitrate in the Ground-water in the Fresno-Clovis Metropolitan Area, San Joaquin Valley, California", Unpublished Dissertation, Committee on Hydrology and Water Resources, The University of Arizona, 301 p.
- Schmidt, K.D., 1979, "Water Supply Evaluation for Tracts 2794 and 2795, Fresno County Water Works District 42", prepared for County of Fresno, Department of Public Works, 22 p.
- Schmidt, K.D., 1984, "The Distribution of DBCP in Groundwater in Southeast Fresno", prepared for City of Fresno, 19 p.
- Schmidt, K.D., Krancher, J.A., and G. Bisel, Jr., 1981, "Brine Pollution at Fresno - Twenty-six Years Later", Ground Water, Vol 19, No. 1.

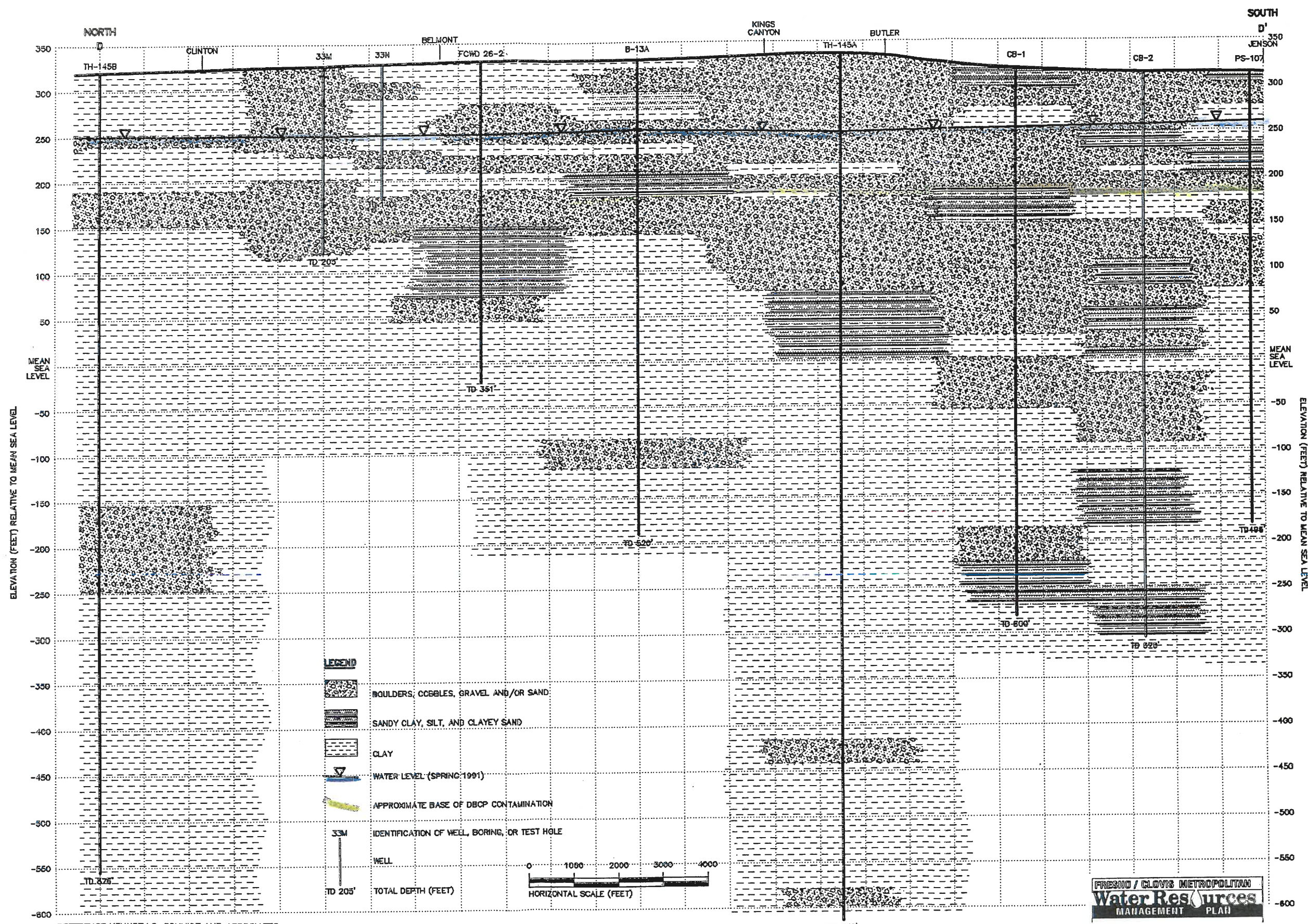




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Water Resources
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FIGURE 5
 SUBSURFACE GEOLOGIC
 CROSS SECTION C-C'

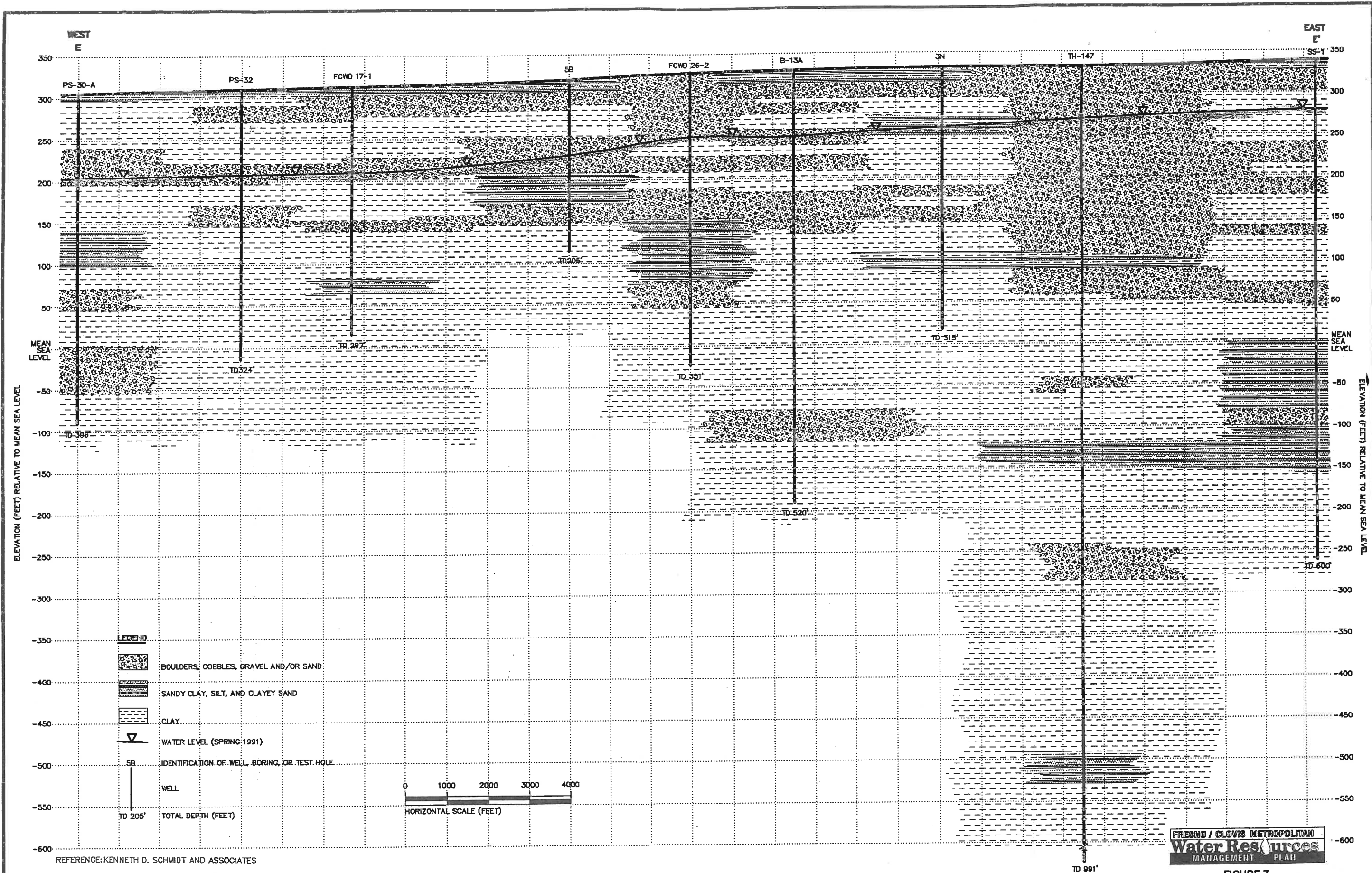
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FIGURE 6
 SUBSURFACE GEOLOGIC
 CROSS SECTION D-D'

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Water Resources
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FIGURE 7
SUBSURFACE GEOLOGIC
CROSS SECTION E-E'

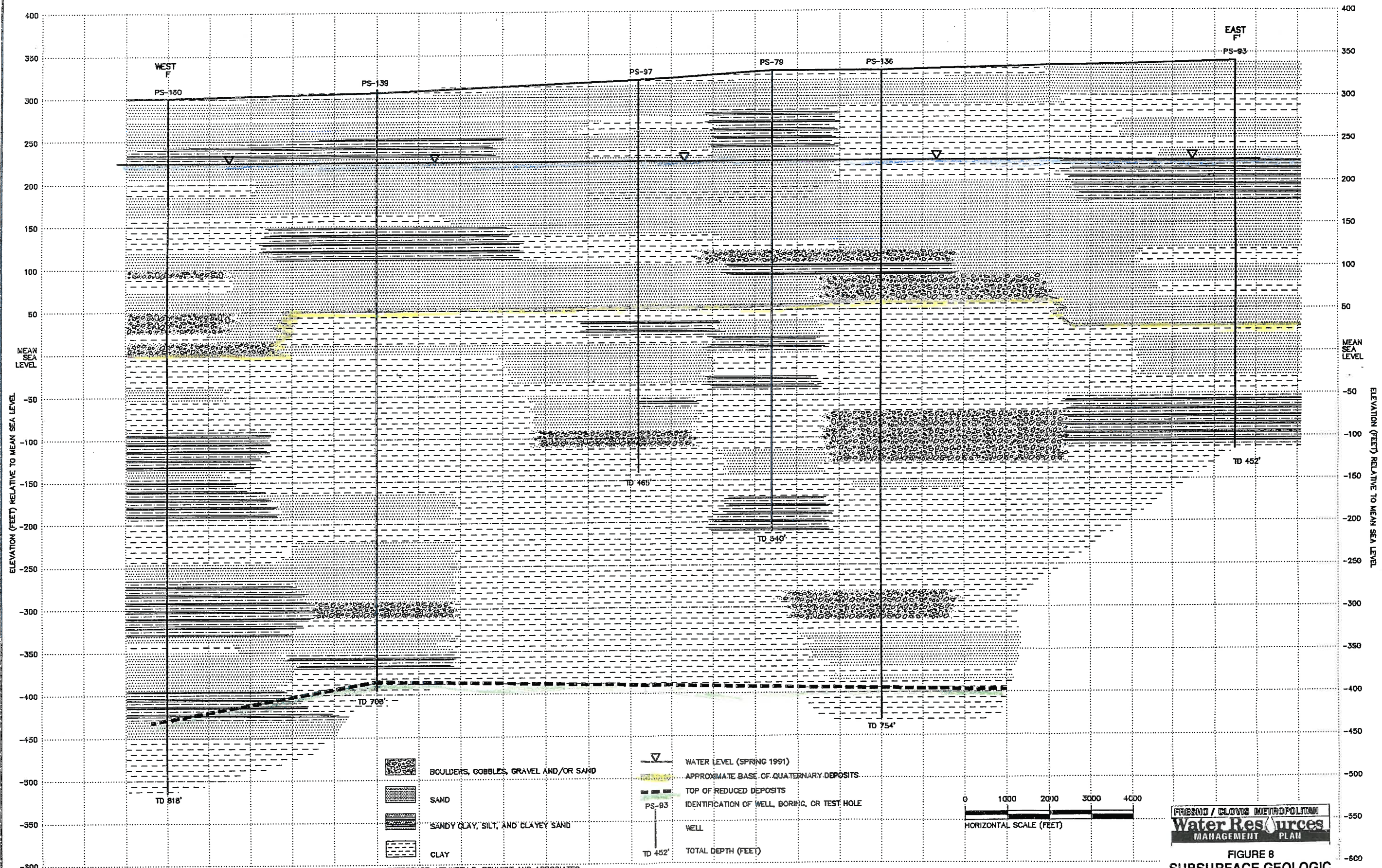
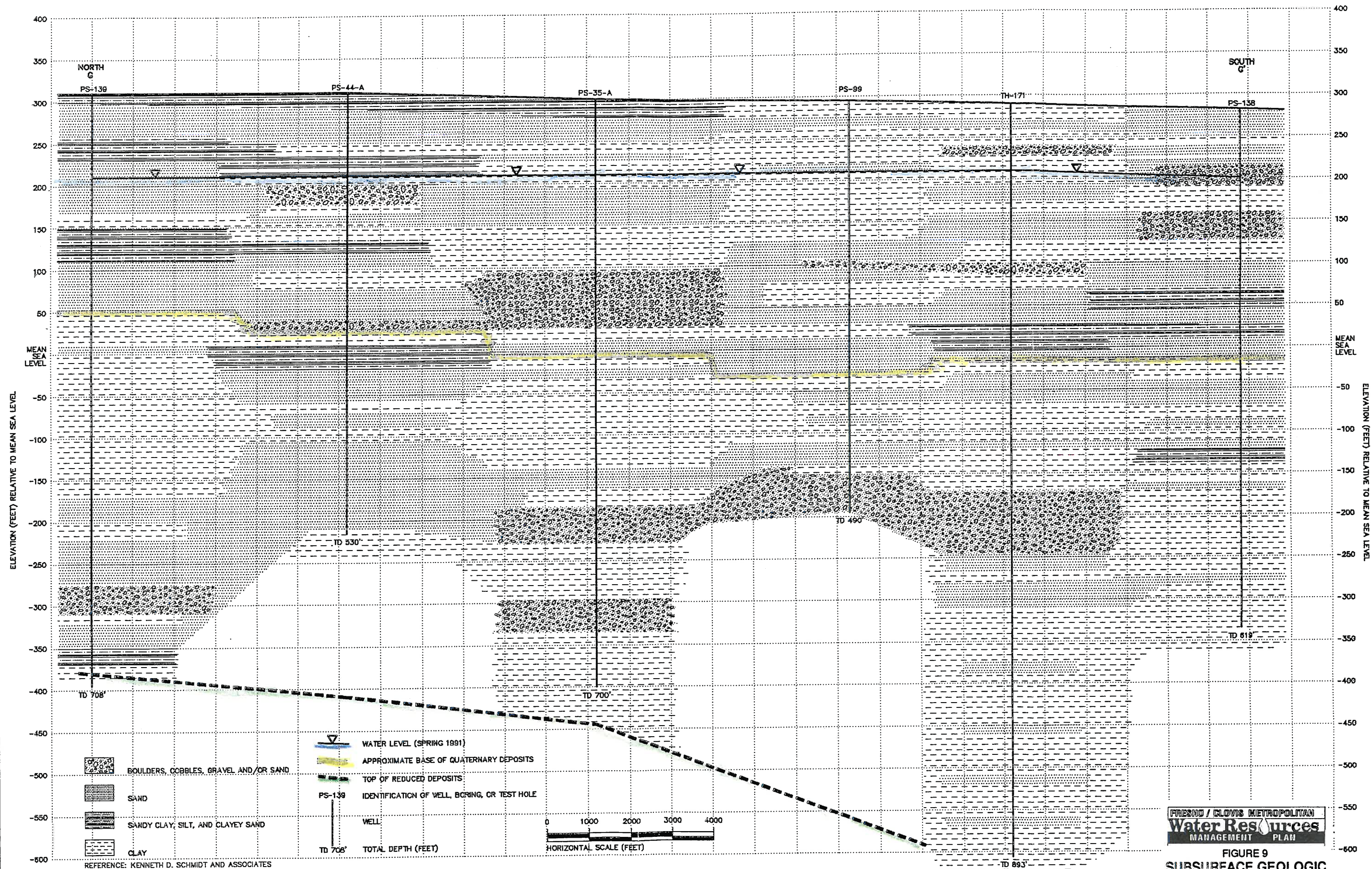


FIGURE 8
SUBSURFACE GEOLOGIC
CROSS SECTION F-F'

REFERENCE: KENNETH D. SCHMIDT AND ASSOCIATES

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FIGURE 9
SUBSURFACE GEOLOGIC
CROSS SECTION G-G'

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