WATER MANAGEMENT PLAN

TARRANT REGIONAL WATER DISTRICT

HDR Engineering, Inc.
Austin, Texas

in Association with

Alan Plummer Associates, Inc.

June 1999

TARRANT REGIONAL WATER DISTRICT
WATER MANAGEMENT PLAN

SIGNATURE PAGE

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Tarrant Regional Water District
Water Management Plan

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Executive Summary

ES-1 Introduction

The Tarrant Regional Water District (District) authorized HDR Engineering, Inc. in association with Alan Plummer Associates, Inc. to prepare a Water Management Plan for the District. The fundamental purpose of this effort is to provide planning to meet the projected 50-year needs of the District. This planning effort included:

- Projections of Population Growth and Water Demand
- Estimates of Water Supply from Existing Sources
- Options for Increased Water Supply from Existing Sources
- Options for New Water Supplies
- Integrated Water Supply Planning.

In addition to the water planning items listed above, the District authorized work on other important items, including:

- Water Conservation and Drought Contingency Plan (contained in a separate document)
- Water Quality and Treatment Considerations (Section 4, this document)
- Assessment of Reservoir Sedimentation Rates (Appendix A, this document)
- Recreation Analysis (Appendix C, this document)
- Risk and Reliability Assessment (Appendix D, this document)
- Survey of Customers Related to Water Quality and Treatment Issues (Appendix E, this document).

ES-2 Projected Population, Water Demand and Supply Comparison

Population and Water Demand Projections

Currently, about 1.5 million people are supplied water from District lakes and reservoirs. Population of the District's service area, including potential new customers, is projected to grow to 2.11 million in 2020 and to 2.66 million in 2050. Projected base case water demands to meet the needs of this growing population are estimated to be 381,078 acft/yr in 2000, 485,108 acft/yr in 2020, and 591,083 acft/yr in 2050. (Base case water demands are for dry-year conditions with water conservation savings resulting only from the low-flow plumbing fixture regulations.) By meeting the water conservation goals established by the major District customers (Fort Worth, Arlington, Mansfield, and Trinity River Authority), projected water demand in 2050 is reduced by 3.9 percent to 568,001 acft/yr.

Current Water Supply

As shown in Table ES-1, existing water supply is currently about 441,800 acft/yr and decreases to 383,000 acft/yr in 2050. This decrease in water supply over time is due to loss of storage capacity in the District's lakes and reservoirs as sedimentation occurs.

Water Demand and Supply Comparison

Figure ES-1 provides a graphical comparison of projected water demands and current supplies. Beginning about 2009, projected dry-year demands will exceed current District supplies. Projected water shortages for base case (i.e., plumbing fixture only conservation) are 67,051 acft/yr in 2020 and 208,083 acft/yr in 2050.

Table ES-1
Tarrant Regional Water District
Water Supply Summary

System Component	Water Supply (acft/yr)		
	1995	2015	2050
West Fork System[1]	**78,000**	**74,000**	**67,000**
Benbrook Reservoir[2]	**6,800**	**6,700**	**6,000**
Cedar Creek Reservoir Safe Yield[3]	**154,900**	**148,000**	**135,600**
Richland-Chambers Reservoir Safe Yield[3]	**202,100**	**195,200**	**174,400**
Total Existing System Supply	**441,800**	**423,900**	**383,000**

1 Includes Lake Bridgeport, Eagle Mountain Lake, and Lake Worth. TRWD has diversion rights on the West Fork in excess of the yield of the reservoirs. Such diversion authorizations allow the District to improve operational efficiency.

2 TRWD's portion of yield in Benbrook Reservoir that is generated by natural streamflows in the Benbrook watershed. Does not include pass-through flows from East Texas Reservoirs via the Benbrook connection. The District's Benbrook Reservoir water right also includes diversion authority in excess of reservoir yield.

3 Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoirs during the critical drought for the analysis reported here is 430,000 acft (197,000 acft at Richland-Chambers; 157,000 acft at Cedar Creek; and 76,000 acft in West Fork reservoirs. Safe yield operation provides a significant degree of protection in the event a future drought occurs which is worse than historic droughts.

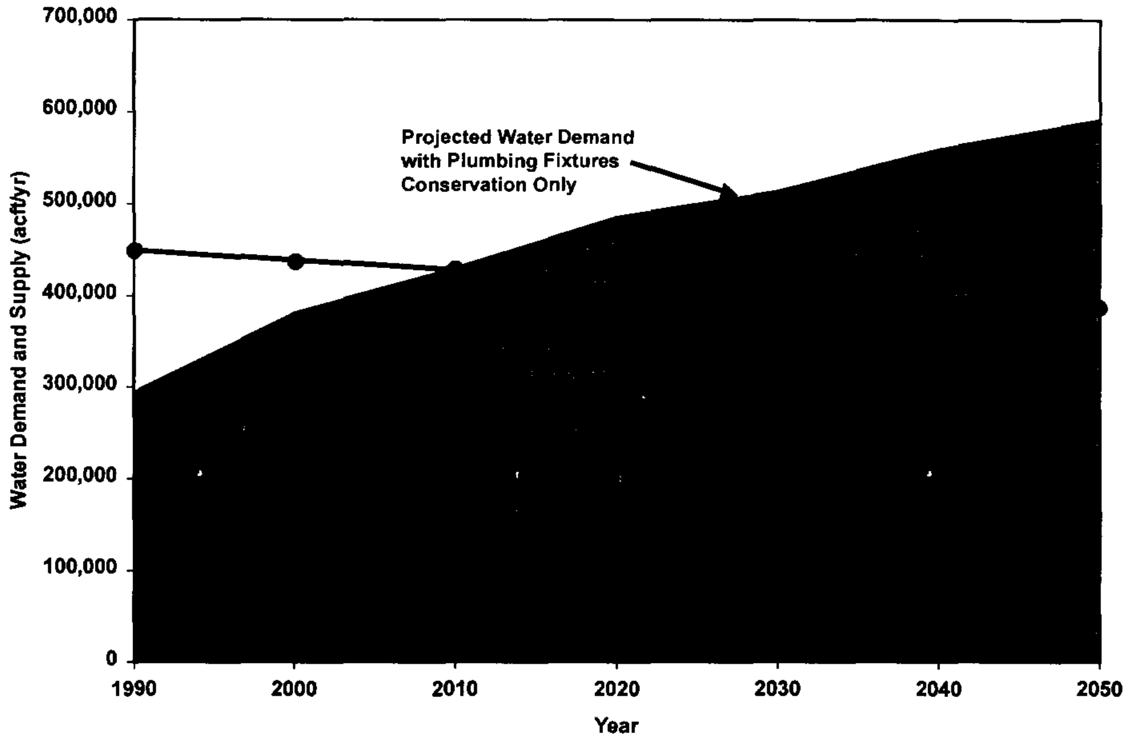


Figure ES-1. Water Demand and Supply

ES-3 Integrated Water Supply Plans to Meet Projected Demands

Integrated water supply planning includes the following elements:

- Customer involvement (i.e., review and input to the planning process);
- Water conservation and demand management;
- Maximization of supply from existing sources;
- Delivery system capabilities; and
- Supply side alternatives (i.e., new water supplies).

Two alternative integrated plans have been developed.[1] Plan 1 includes water conservation, the Trinity River reuse project, interim reservoir operation changes, Tehuacana Reservoir, and construction of associated delivery system facilities. Plan 2 includes water conservation, the Trinity River reuse project, and Marvin Nichols I Reservoir in the Sulphur River Basin. The components of each plan and water supply to be obtained from each component are listed in Table ES-2.

[1] The order presented for Plan 1 and Plan 2 is not indicative of a recommended alternative, as elements of each plan will require additional study before plan adoption by the District.

Table ES-2
Integrated Water Supply Plan Components

Plan 1		*Plan 2*	
Component	*2050 Yield (acft/yr)*	*Component*	*2050 Yield (acft/yr)*
Safe yield operation of existing system	**383,000**	**Safe yield operation of existing system**	**383,000**
Achieve water conservation goals	**23,082**	**Achieve water conservation goals**	**23,082**
Trinity River Project Reuse		**Trinity River Project Reuse**	
Richland-Chambers Reuse	**63,000**	**Richland-Chambers Reuse**	**63,000**
Cedar Creek Reuse	**52,500**	**Cedar Creek Reuse**	**52,500**
Tehuacana Reservoir	**65,547**	**Marvin Nichols I Reservoir****	**187,000**
Total 2050 Supply	**587,129**	**Total 2050 Supply**	**708,582**
Projected 2050 Demand	**591,083**	**Projected 2050 Demand**	**591,083**
Potential Shortage*	**(3,954)**	**Potential Shortage**	**0**
* Shortage can be supplied by temporarily reducing drought reserves or by implementing reuse at Tehuacana Reservoir.		** Full project yield is 560,151 acft/yr. TRWD has indicated an interest in contracting for up to 187,000 acft/yr from the project.	

Figure ES-2 is a plot of projected District water demand and existing system supply. Superimposed onto Figure ES-2 is a step-diagram of increased water supply available from each component of integrated supply Plan 1. As shown on Figure ES-2, achieving the adopted water conservation goals would be accomplished gradually throughout the 50-year planning period. The Richland-Chambers portion of the Trinity River reuse project would need to be completed[2] by the end of 2006, and the Cedar Creek portion would be needed by 2022. Supply from Tehuacana Reservoir would be needed by 2034.

Figure ES-3 also is a plot of projected District water demand and existing system supply. Superimposed onto Figure ES-2 is a step-diagram of increased water supply available from each component of integrated supply Plan 2. As shown on Figure ES-3, achieving the adopted water conservation goals would be accomplished gradually throughout the 50-year planning period. As with Plan 1, the Richland-Chambers portion of the Trinity River reuse project would need to be completed by the end of 2006, and the Cedar Creek portion would be needed by 2022. Supply from Marvin Nichols I Reservoir would be needed by 2034. Under both alternatives the reuse project is critical, as neither Tehuacana nor Marvin Nichols can realistically be online by 2006.

[2] Project implementation year is set 3 years earlier than date of projected shortage to allow for potential delays or needs greater than projected.

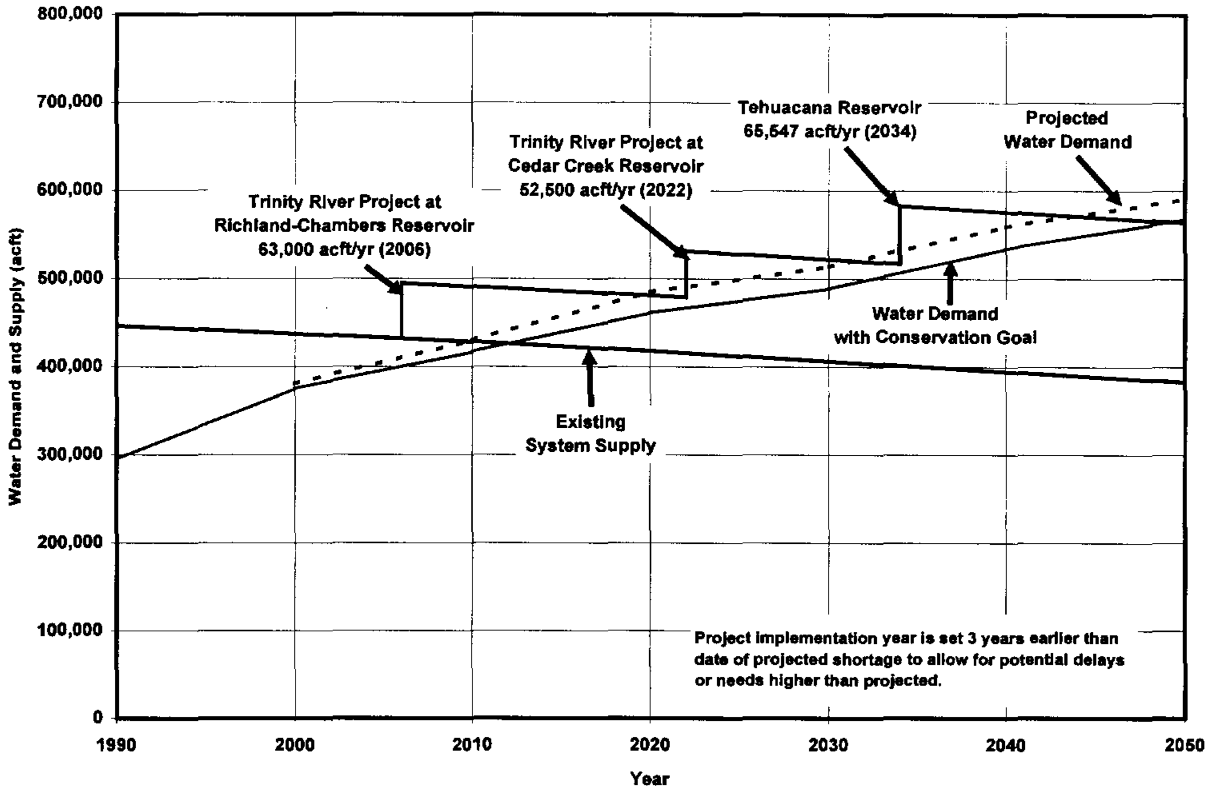


Figure ES-2. Water Demand and Supply with Integrated Water Supply Plan 1

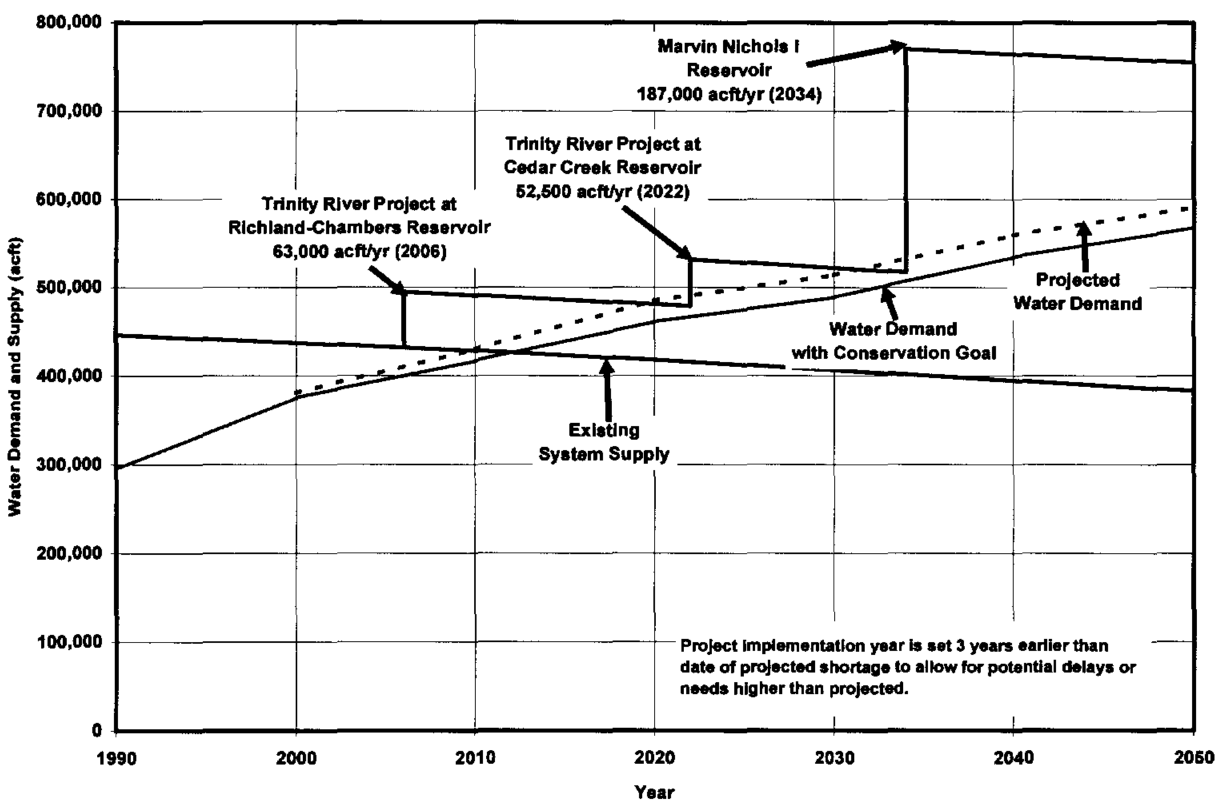


Figure ES-3. Water Demand and Supply with Integrated Water Supply Plan 2

Table ES-3 summarizes capital costs in 1998 dollars of each of the components of Plans 1 and 2 through 2034. The total capital cost of Plan 1 through 2034 is $490.1 million and the total capital cost of Plan 2 through 2034 is $431.1 million. Plan 1 costs an additional $59 million compared to Plan 2 because the delivery facilities from Richland/Chambers Reservoir to Kennedale have been upsized to accommodate the future supply potentially available from Tehuacana Reservoir. Marvin Nichols Reservoir, being a significantly larger project, offers the advantage of providing water supply to the District well beyond year 2050.

Recommendations

To continue to meet the water supply needs of the Tarrant Regional Water District service area for the 2000 to 2050 period, it is recommended the District pursue the following:

a) Continue to monitor amendments to the Safe Drinking Water Act, particularly the Source Water Protection Rules, for impacts to the District and treatment requirements that may be placed on it's customers. Current District programs for monitoring and modeling water quality of it's water supplies is thorough and reasonable.

b) Continue working closely with its customers to achieve the water conservation goals established under the Average Water Conservation demand projections.

c) Construct and operate a field-scale wetland to demonstrate the effectiveness of wetlands for improving water quality in conjunction with the Trinity River reuse project.

d) Obtain the necessary TNRCC permits and implement the Trinity River reuse project at Richland-Chambers and Cedar Creek Reservoirs. This would include construction of a full-scale wetland treatment system.

e) To assist customers in efficiently and cost-effectively treating raw water supplied by the District, the District should strive to effectively communicate water supply changes to treatment plant operators. Further, adding flexibility (i.e. storage and alternate supplies) to the raw water delivery system will reduce abrupt changes in raw water characteristics and aid effective water treatment.

f) Proceed with planning of delivery facilities for increased supplies at Richland-Chambers Reservoir.

g) Conduct studies of Marvin Nichols I Reservoir to compare permitting issues, construction costs, and delivery facility costs to Tehuacana Reservoir.

h) Proceed with engineering design studies for enhancement of water supply to the West Fork in order to provide water supply to the rapidly growing northwest Tarrant County area.

Table ES-3
Estimated Costs for Integrated Water Supply Plans 1 and 2

Component	Date Needed[(1)]	Plan 1 Estimated Cost		Plan 2 Estimated Cost	
		Delivery Capacity (MGD)	Estimated Cost (millions, 1998 dollars)	Delivery Capacity (MGD)	Estimated Cost (millions, 1998 dollars)
Richland-Chambers Pipeline High Capacity Operation	end of 2006	98	$16.4	98	$16.4
Trinity River Reuse Project – Richland-Chambers Portion	end of 2006	122	$24.1	122	$24.1
Richland-Chambers Pipeline No. 2, from lake to Ennis PS[(2)]	2014	172	$127.5	88	$83.5
Pipeline, Ennis PS to Kennedale [(2)]	2014	280	$217.4	196	$202.4
Kennedale Resv Expansion and Booster PS	2022	280	$16.4	280	$16.4
Trinity River Reuse Project – Cedar Creek Portion	2022	99	$28.6	99	$28.6
Cedar Creek Pipeline No. 2, from lake to Ennis PS	2022	108	$59.7	108	$59.7
Total Cost			$490.1		$431.1
New Reservoir	2034	84 (Tehuacana Resv.)	Note 3	240 (Marvin Nichols 1 Resv.)	Note 3

(1) Project implementation year is set 3 years prior to date of projected shortage to allow for potential delays or needs greater than projected.
(2) Cost for Plan 1 is higher due to upsized pipeline and pumping capacity to accommodate future supply from Tehuacana Reservoir.
(3) Cost for reservoirs and delivery facilities is dependent on terminus locations, potential phasing, and cost share arrangements with other entities. Further study is needed to quantify District costs.

i) Field surveys of the reservoir volume of Richland-Chambers and Cedar Creek Reservoirs should be performed approximately every five years to monitor the actual sedimentation rate occurring in the reservoirs.

j) Continue to update the Risk Index database to track the reliability of system components and to spot increasing risk trends in order to make timely maintenance decisions. This will become increasingly important as demands on the system increase and there is less unused system capacity.

k) Regarding Regional Water Supply Planning under SB 1 (75^{th} Texas Legislature), the District should coordinate with the Regional Water Planning Group to inform them of District water demand and supplies, and incorporate the result of this water management plan into the regional water plan.

Section 1

Introduction

Section 1
Introduction

The Tarrant Regional Water District (herein referred to as either TRWD or District) authorized HDR Engineering, Inc., in association with Alan Plummer Associates, Inc., to prepare a Water Management Plan for the District. The fundamental purpose of this effort was to provide planning to meet the projected 50-year needs of the District. Included in this work are a presentation of water demand projections (Section 2), a current depiction of the District's water supply (Section 3.1), a study of potential new water supplies (Section 3.2), information on issues affecting the District's customers (Section 4), and integrated water supply plans for long-range needs (Section 5).

The Scope of Work authorized by the District included the development of the following elements:

- Water Management Plan
  - Population and Water Demand Projections
  - Existing Water Supply
  - Maximizing Water Supply Resources
  - Water Quality and Treatment Considerations
  - Integrated Water Supply Planning
- Water Conservation and Drought Contingency Plan
- Assessment of Reservoir Sedimentation Rates
- Recreation Analysis
- Risk and Reliability Assessment
- Customers Survey Related to Water Quality and Treatment Issues

This document is the Water Management Plan, containing not only the items listed above, but also appendices for reservoir sedimentation rates, hydrologic analyses, survey questionnaires on water quality and treatment issues, and environmental water needs criteria and implementation methods. The Water Conservation and Drought Contingency Plan was published in 1997 as a separate document. The Recreation Analysis and the Risk and Reliability Assessment are standalone documents that are included as appendices in this document.

Funding and assistance for completion of this work was provided by the District and a grant from the Texas Water Development Board (TWDB).

1.1 Background

On April 12, 1922, Fort Worth, Texas suffered a severe flood in which property damage and the loss of life were catastrophic. As a result, on October 7, 1924, the Tarrant County Commissioners' Court created the Tarrant County Water Improvement District Number One, whose purpose was to provide flood protection within Tarrant County. In 1925, the Texas Legislature broadened the powers of water control and improvement districts to include water supply in their respective counties. On January 12, 1926, the District became the Tarrant County Water Control and Improvement District Number One. Over the past 70 years, the District has provided significant raw water supplies, flood protection, and assisted in the protection of water quality. On October 1, 1996, by action of the Texas Natural Resource Conservation Commission (TNRCC), the District's name was changed to "Tarrant Regional Water District: A Water Control and Improvement District." TRWD is a wholesaler of raw water to four major wholesale customers (City of Fort Worth, Trinity River Authority, City of Arlington, and City of Mansfield) and to individual water utilities throughout it's ten-county service area. The District's authority to operate is its enabling legislation, Tex. Civ. Stat. Ann. art. 8280-207 (Vernon, 1959), and Chapters 49 and 51 of the Water Code, which enumerates the powers and duties of water control and improvement districts.

The District is governed by a five-member board of directors who are elected by the voters of the District. Directors' terms of office are 4 years, with three directors elected and seated in January of an even numbered year and two directors elected and seated in January of the next consecutive even numbered year, such that there is an overlapping of terms of office for directors to provide continuity on the Board. The District has a staff of approximately 150. An Advisory Committee was established by the TRWD Amendatory Contract of 1980 with its Initial Contracting Parties (City of Fort Worth, Trinity River Authority, City of Arlington, and City of Mansfield). Annually, the governing body of each of the Initial Contracting Parties and the Board of Directors of the District appoints one of the members of its governing body or one of its officers as a voting member of the Advisory Committee, with the term of membership being for 12 months, beginning on March 1 of each year.

The Advisory Committee consults with and advises the District, through its General Manager, with regard to:

- The issuance of bonds;
- The operation and maintenance of the system;
- Additional customers and sales of water to entities that are not contracting parties, including prices, terms, and conditions of such sales, in order to assure consistency;
- The District's annual budget and review of the District's annual audit;
- Matters pertinent to the management of the system; and
- Improvements and extensions of the system, including provisions for any additional source of water supply.

1.2 Tarrant Regional Water District Water Supply System

The District's main water supply system facilities include Lake Bridgeport, Eagle Mountain Lake, Lake Worth, Lake Arlington, Cedar Creek Reservoir, Richland-Chambers Reservoir, Lake Benbrook, a 72-inch diameter 68-mile pipeline from Cedar Creek Reservoir to a balancing reservoir in south central Tarrant County, a 90-inch diameter 72-mile pipeline from Richland-Chambers Reservoir to the balancing reservoir in south central Tarrant County, and a 90-inch diameter 18-mile pipeline connecting Lake Benbrook to the system (Figure 1-1). Lake Bridgeport, Eagle Mountain Lake, Cedar Creek Reservoir and Richland-Chambers Reservoir are owned and operated by the District. Lake Worth is owned and operated by the City of Fort Worth, and Lake Arlington is owned and operated by the City of Arlington. Lake Benbrook is owned and operated by the U.S. Army Corps of Engineers.

Lake Bridgeport, Eagle Mountain Lake, and Lake Worth are located on the West Fork of the Trinity River and were completed in 1931, 1932, and 1914, respectively. Lake Bridgeport is located in Wise County, Eagle Mountain Lake is located downstream of Lake Bridgeport in northwest Tarrant County, and Lake Worth is located downstream of Eagle Mountain Lake in Tarrant County. The estimated safe yield of these West Fork reservoirs (Western Division) is 78,000 acre-feet per year (acft/yr), which is gravity-fed to water treatment plants in Fort Worth and neighboring cities and industries.

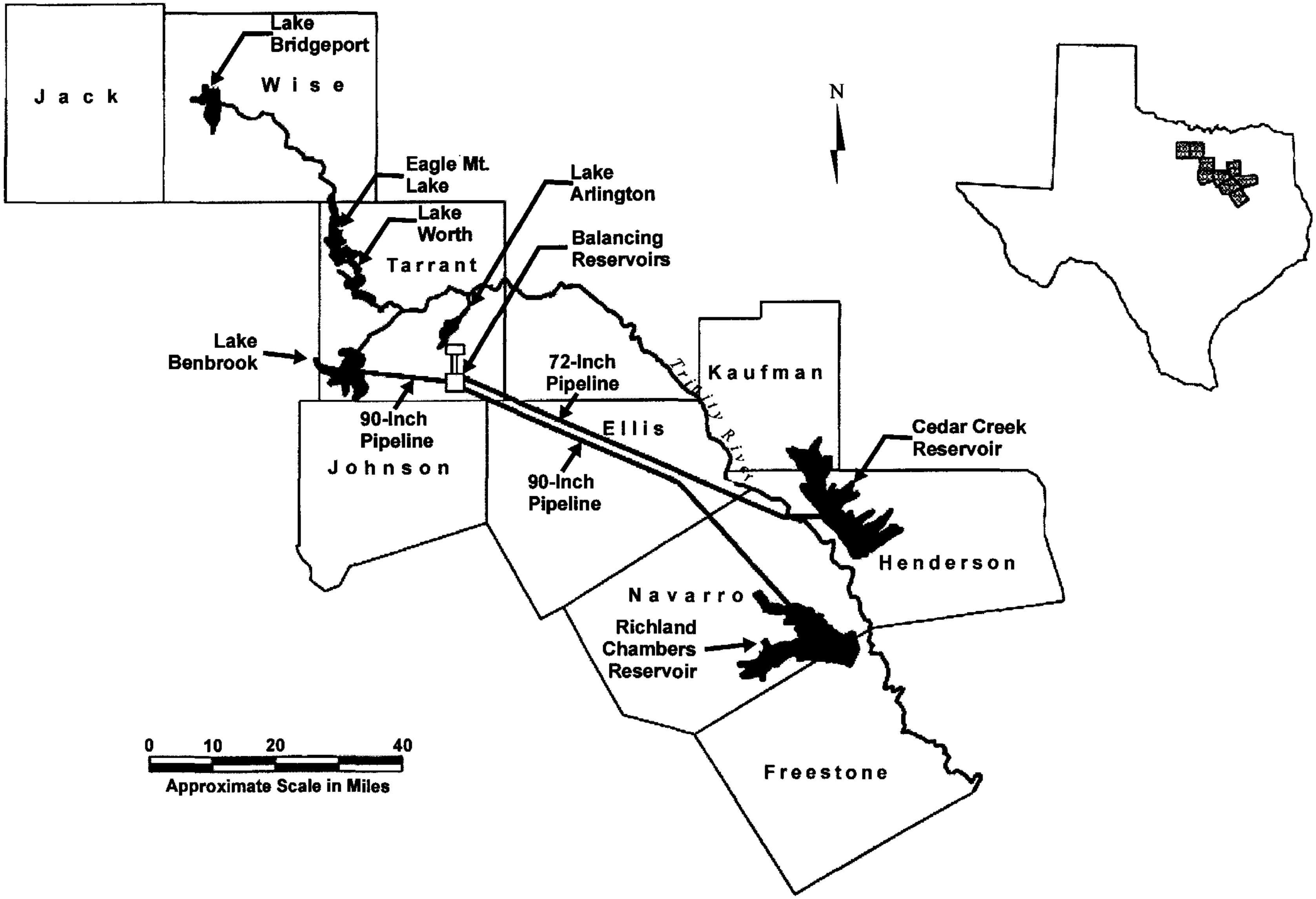


Figure 1-1. Tarrant Regional Water District Water Supply System

Lake Arlington, located on Village Creek in Tarrant County, was completed in 1957. Lake Arlington has a yield of approximately 7,050 acft/yr, and supplies water to the Trinity River Authority (TRA), City of Arlington, and TU Electric Company. However, Lake Arlington's yield is not adequate to meet the needs of these customers and is supplemented from TRWD's pipelines from its Eastern Division Reservoirs, as is explained below.

The District's Eastern Division reservoirs (Cedar Creek and Richland-Chambers) were completed in 1966 and 1987, respectively. Cedar Creek Reservoir, located in Henderson and Kaufman Counties, has a diversion water right of 175,000 acft/yr, and its water is pumped approximately 74 miles to Tarrant County via a 72-inch diameter pipeline that was completed in 1971.

The District's Richland-Chambers Reservoir, located in Navarro and Freestone Counties, has a permitted annual safe yield of 210,000 acft/yr. Richland-Chambers water is pumped approximately 78 miles to Tarrant County via a 90-inch diameter pipeline. The Richland-Chambers pipeline is interconnected with the Cedar Creek pipeline at the Ennis pump station and at other points closer to Tarrant County. The interconnections allow each pipeline to convey either Cedar Creek Reservoir water or Richland-Chambers Reservoir water and discharge to the balancing reservoirs at Kennedale. At the Kennedale balancing reservoirs, a 108-inch diameter pipeline delivers water to an outlet on Village Creek upstream of Lake Arlington, in order to maintain Lake Arlington water levels to meet the water supply needs of customers who obtain water from Lake Arlington, including the cooling needs of Texas Electric Service Company's electric power generation plant.

In addition to the reservoirs of the Western and Eastern Divisions mentioned above, in 1987 the District acquired a permit to use Benbrook Reservoir as a storage reservoir for water from the Eastern Division reservoirs in order to decrease pumping costs by storing water pumped during off-peak periods. Benbrook, completed in 1952, is a U.S. Army Corps of Engineers project located in southwest Tarrant County. A 90-inch diameter pipeline connects Fort Worth's Rolling Hills Water Treatment Plant to Lake Benbrook.

At the present time, the District supplies raw water to meet the needs of approximately 1.5 million people. Projected population of the District's service area is 1.9 million in 2020, and

2.4 million in 2050.[1] In order to meet the needs of its customers in future years, the District is developing a water management plan to increase efficiency of its present water resources through water conservation and reuse, systems operation of present supplies, system expansion, or some combination of available options. The water supply operations of each of the District's wholesale customers are described below.

1.3 City of Fort Worth Water System

The City of Fort Worth Water Department obtains raw water from four sources: (1) West Fork of Trinity River via Lake Worth, Eagle Mountain Lake, and Lake Bridgeport; (2) Clear Fork of Trinity River via Lake Benbrook; (3) Richland-Chambers Reservoir; and (4) Cedar Creek Reservoir. Fort Worth operates 4 water treatment plants, 15 pump stations, 19 treated water storage tanks, and a treated water distribution system. The distribution system supplies treated water retail to the citizens of Fort Worth, and wholesale water to 22 customers in Tarrant County, 3 customers in neighboring Denton County, 2 customers in neighboring Johnson County, plus DFW Airport and Haslet (which supplies Alliance Airport), and TRA, which supplies a part of Grand Prairie. Present treatment capacity of the system is 350 million gallons per day (MGD). Total population served by the system was approximately 700,000 in 1990, of which 448,000 were residents of Fort Worth and 252,000 were served by Fort Worth wholesale customers listed below.

Fort Worth Wholesale Water Customers

1. Bethesda Water Supply Corp.
2. Burleson
3. Crowley
4. Dalworthington Gardens
5. Edgecliff Village
6. Everman
7. Forest Hill
8. Haltom City
9. Hurst
10. Keller
11. Kennedale
12. Lake Worth
13. North Richland Hills
14. Richland Hills
15. Roanoke
16. Saginaw
17. Sansom Park Village
18. Southlake
19. Tarrant County MUD No. 1
20. Trophy Club MUD No. 1
21. Watagua
22. Westover Hills
23. Westworth Village
24. White Settlement
25. DFW Airport
26. Haslet (Alliance Airport)
27. Trinity River Authority
    a. Mosier Valley
    b. Grand Prairie
28. Benbrook
29. River Oaks

[1] Texas Water Development Board, 1996 Consensus Water Plan Projections, Austin, Texas, 1995.

1.4 Trinity River Authority Tarrant County Water System

Through a contract with TRWD, the TRA obtains raw water from Lake Arlington, which is supplied via the District's pipelines from Cedar Creek and Richland-Chambers Reservoirs. TRA treats the water in a 57 MGD capacity water treatment plant located in northeastern Tarrant County, and supplies treated water wholesale to five cities in northeast Tarrant County, who in turn retail the treated water to their respective customers.[2] The five TRA wholesale water customers are:

Trinity River Authority Wholesale Water Customers

1. Bedford
2. Euless
3. Colleyville
4. Grapevine
5. North Richland Hills

The total population served by this system was approximately 130,000 in 1990. In addition, TRA transfers treated water from Fort Worth to Grand Prairie to serve approximately 18,000 customers.

1.5 City of Arlington Water System

The City of Arlington operates two water treatment plants with a total treatment capacity of 93 MGD, nine elevated treated water storage tanks, three pump stations, and supplies treated water retail to the people, businesses, and industries located within the City. In 1990, the population served by the Arlington system was 261,721. Raw water to supply Arlington's Pierce-Burch Water Treatment Plant is obtained from Lake Arlington, which receives runoff from Village Creek and is partially supplied from the District's Cedar Creek Reservoir and Richland-Chambers Reservoir when needed.[3] In the case of Arlington's John F. Kubala Water Treatment Plant, raw water is supplied directly from the District's pipelines.

1.6 City of Mansfield Water System

The City of Mansfield operates one 10 MGD water treatment plant which is supplied directly from the District's Cedar Creek Reservoir and Richland-Chambers Reservoir pipelines.

[2] Lake Arlington is located on Village Creek in Tarrant County and has a drainage area of 143 square miles.
[3] Ibid.

The current service area is the corporate limits of the City, having a population of 15,607 in 1990, with the projected service area to include the City and its extra-territorial jurisdiction.

1.7 Individual Customers Water Systems

In addition to its four wholesale customers discussed in Section 1.3 through 1.6, TRWD has individual customers located in the Eastern and Western Divisions. The Eastern Division includes customers that are served from Cedar Creek Reservoir, Lake Benbrook, and Richland-Chambers Reservoir, and are as follows:

Cedar Creek Reservoir
Tecon Water Supply
East Cedar Creek FWSD
City of Kemp
City of Mabank
City of Star Harbor
City of Trinidad
West Cedar Creek MUD
Cedar Creek Country Club
City of Malakoff (pending)
Pinnacle Club
Long Cove Ranch Co.
Warren Petroleum, Eustace Plant
Bill Sisul

Lake Benbrook
Benbrook Water and Sewer Authority
City of Weatherford
Fort Worth Country Day School
Southwest Christian School
Meditrust Golf Group II (pending)
Mira Vista Country Club
Riglea Country Club

Richland-Chambers Reservoir
City of Corsicana
TRA (Freestone County)
Winkler Water Supply
Texas Parks and Wildlife Dept.

The Western Division includes customers that are served from Lake Bridgeport and Eagle Mountain Lake, and are as follows:

Lake Bridgeport
City of Bridgeport
City of Runaway Bay
Walnut Creek WSC
West Wise Rural WSC
Wise County WSD
Bay Golf Club
Gifford Hill
Pioneer Aggregates
Texas Industries (TxI)

Eagle Mountain Lake
Arc Park (Irrigation)
City of Azle
Community Water Supply
The Landing Home Owners Association (Irrigation)
City of River Oaks
City of Springtown
Shady Oaks County Club
Golf Driving Range (pending)

In addition to the Eastern and Western Division customers listed above, the District has significant future customers in Freestone and Ellis Counties. For example, TRA has entered into a contract with 13 entities in Ellis County for a supply of raw water purchased by TRA from TRWD, with the development of facilities to deliver raw or treated water to any of these parties being subject to further planning and negotiations between TRA and the wholesale customers of Ellis County. TRWD's Cedar Creek and Richland-Chambers Reservoir pipelines pass through Ellis County en route to Tarrant County.

Entities of Freestone County, which borders Richland-Chambers Reservoir to the south, are growing and in need of water to meet future needs. Through a TWDB-funded planning study completed in August of 1997, water supply alternatives to meet the needs of entities in Freestone County, including the supply of raw water from Richland-Chambers Reservoir, were evaluated.

In addition to the municipal water customers listed above, TRWD has nine industrial and golf course customers for industrial and irrigation water, respectively. Taken as a whole, TRWD's existing and future service area includes rapidly expanding population centers and an increasing demand for industrial and irrigation water supplies. It is widely believed that existing water need projections for this region will be exceeded. For these reasons, and others, it is critical that TRWD have adequate water conservation and system management plans in place.

Section 2

Population and Water Demand Projections

Section 2
Population and Water Demand Projections

2.1 Population Projections

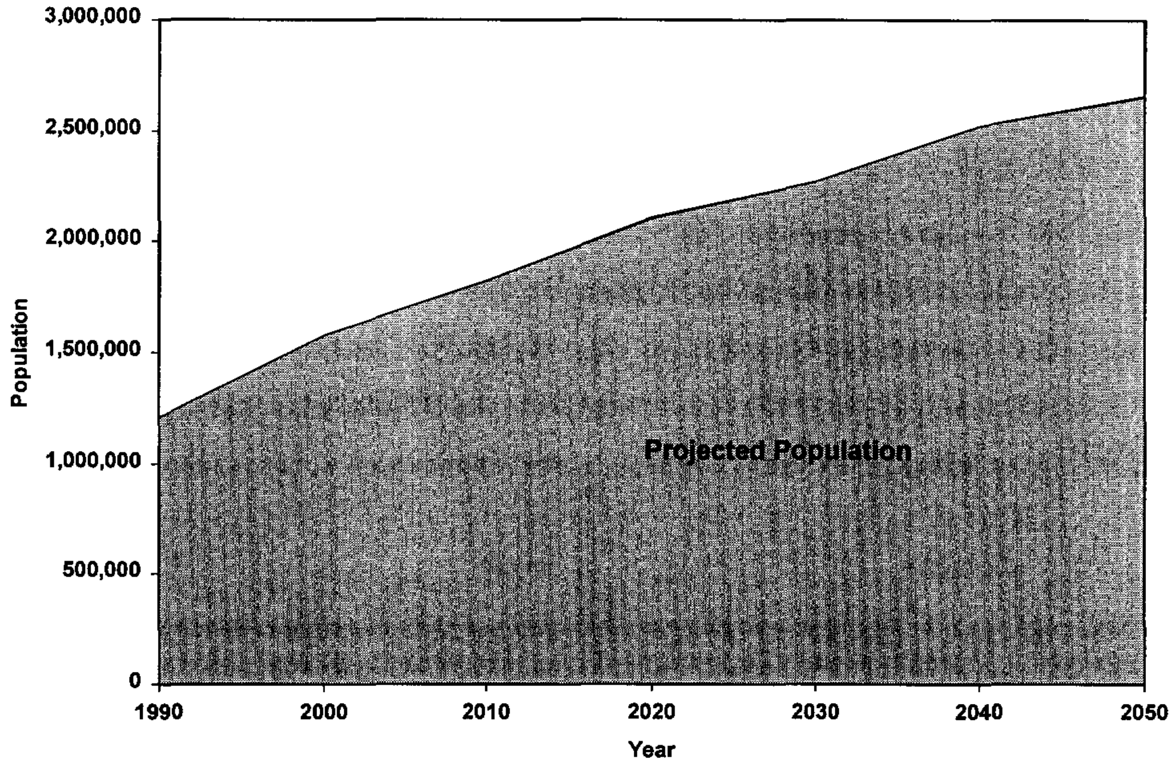
In 1990, approximately 1.2 million people were supplied water from District lakes and reservoirs. Population of the District's service area is projected to increase to 1.9 million in 2020,[1] and to 2.4 million in 2050, with population of the total areas supplied from TRWD, including potential new customers, being projected at 2.11 million in 2020 and 2.66 million in 2050 (Table 2-1). Figure 2-1 contains a graph of the projected total population of the District service area.

Table 2-1.
Tarrant Regional Water District
Wholesale and Individual Customers
Population Projections Summary

		Projections					
Customer	1990	2000	2010	2020	2030	2040	2050
Wholesale Customers							
Fort Worth	700,593	811,738	915,373	1,020,806	1,068,102	1,159,155	1,234,906
Trinity River Authority	129,366	178,010	203,672	222,738	229,227	231,277	231,277
Arlington	261,721	318,653	336,400	366,760	384,917	399,173	413,986
Mansfield	15,607	27,750	40,304	54,214	69,573	85,303	102,169
Subtotal	1,107,287	1,336,151	1,495,749	1,664,518	1,751,819	1,874,908	1,982,338
Individual Customers							
Eastern Division	60,022	91,735	111,654	134,520	154,889	171,470	188,608
Western Division	37,448	52,964	67,250	79,515	88,566	96,831	105,064
Ellis County	0	10,692	36,869	78,260	103,450	116,633	127,227
Subtotal	97,470	155,391	215,773	292,295	346,905	384,934	420,899
TRWD Subtotal	1,204,757	1,491,542	1,711,522	1,956,813	2,098,724	2,259,842	2,403,237
Potential New TRWD Customers		85,751	110,614	148,534	172,085	260,464	252,137
TRWD Total	1,204,757	1,577,293	1,822,136	2,105,347	2,270,809	2,520,306	2,655,374

Source: Texas Water Development Board; 1996 Consensus Water Planning Projections, most likely case, for individual cities, with local area study projections for individual customers located in the Eastern and Western Divisions

[1] Texas Water Development Board, 1996 Consensus Water Planning Projections.



Source: TWDB, 1996 Consensus Projections, most likely case, with amendments for individual customers located in the Eastern and Western Divisions.

Figure 2-1. Population Projections

2.2 Per Capita Water Use

Projected water demands for the District's customers are shown for two cases of water conservation as follows: (1) plumbing fixtures only water conservation; and (2) average water conservation. In the case of plumbing fixtures only water conservation, the expected reductions in per capita water use are estimated at approximately 17 gallons per person per day (gpcd) in Tarrant County as the low-flow fixtures are installed in new residential and commercial structures, and as older high flow fixtures are replaced. However, the projected effects of plumbing fixtures upon per capita water demands are based upon the degree of water conservation in effect for each city and water utility service area, and the rate of growth projected for each service area. For example, for lower growth areas, the overall effect of new construction with low-flow plumbing fixtures is projected to be at a slower pace than for high growth areas where new construction more quickly becomes a larger percentage of the total. Table 2-2 shows projected per capita water demand for the plumbing fixture only water conservation case for Fort Worth, Arlington, Mansfield, and the cities served by TRA (Hurst, Euless, and Bedford).

Table 2-2.
Per Capita Municipal Water Demand Projections
Plumbing Fixtures Only for Water Conservation

City	Use in 1990 (gpcd)	Projections					
		2000 (gpcd)	2010 (gpcd)	2020 (gpcd)	2030 (gpcd)	2040 (gpcd)	2050 (gpcd)
Arlington*	166	190	183	181	178	174	173
Bedford	159	191	179	176	172	170	169
Mansfield	118	174	170	166	161	158	157
Euless	152	192	186	181	177	174	173
Fort Worth	210	205	201	197	193	187	182
Hurst	160	163	158	154	150	147	146

Source: Texas Water Development Board; 1996 Consensus Water Planning Projections; most likely case, plumbing fixtures only for water conservation.
* Adjusted to be somewhat higher than Texas Water Development Board projections.

2.3 Water Conservation

In the case of per capita water demand projections for the average water conservation case, it is planned that in addition to the use of low-flow plumbing fixtures in new construction and in normal replacement of existing fixtures, organized water conservation programs will be used by TRWD's customer cities and water supply districts to encourage water conservation. Such programs could include incentives to replace existing plumbing fixtures with low-flow fixtures, the use of drought tolerant landscaping plants and shrubs to reduce lawn watering, leak detection and repair, and water conservation pricing. Projected per capita water demands for the average water conservation case for Fort Worth, Arlington, Mansfield, and the cities served by TRA (Hurst, Euless, and Bedford) are shown in Table 2-3. For Tarrant County, these per capita projections are approximately 6 percent lower than for the plumbing fixtures only case. For the individual customers of the Eastern and Western Divisions, the plumbing fixtures and average cases are expected to have the same per capita projections, since it is estimated that growth in these areas will include residences and commercial structures that have more water-using appliances and lawn irrigation than present users of these areas have.

Table 2-3.
Per Capita Municipal Water Demand Projections
Average Water Conservation

City	Use in 1990 (gpcd)	Projections					
		2000 (gpcd)	2010 (gpcd)	2020 (gpcd)	2030 (gpcd)	2040 (gpcd)	2050 (gpcd)
Arlington*	166	186	176	168	165	162	161
Bedford	159	184	173	165	161	159	158
Mansfield	118	171	163	155	151	148	147
Euless	152	189	178	169	166	163	162
Fort Worth	210	202	194	187	184	181	180
Hurst	160	159	150	142	138	135	134

Source: Texas Water Development Board; 1996 Consensus Water Planning Projections; most likely case, plumbing fixtures only for water conservation.
* Adjusted to be somewhat higher than Texas Water Development Board projections.

2.4 Water Demand Projections

Water use reported to the TWDB by the TRWD customers of Tarrant County in 1990 was 294,582 acft/yr (Table 2-4). Of this total, 232,671 acft/yr was surface and ground water used by retail customers of the District's four wholesale customers, 15,733 acft/yr was by individual customers for municipal purposes in the Eastern and Western Divisions near the District's lakes, and 46,178 acft/yr was for industrial, steam-electric power generation, and irrigation (Table 2-4).

Projected water demands for the plumbing fixtures water conservation case is 381,078 acft/yr in 2000, 485,108 acft/yr in 2020, and 591,083 acft/yr in 2050 (Table 2-4). For the average water conservation case, projected water demand for the TRWD system is 375,290 acft/yr in 2000, 461,009 acft/yr in 2020, and 568,001 acft/yr in 2050 (Table 2-4). The average water conservation case projected water demand is 5,788 acft/yr, or 1.5 percent less in year 2000 than the plumbing fixtures only water conservation case. In 2020, projected water

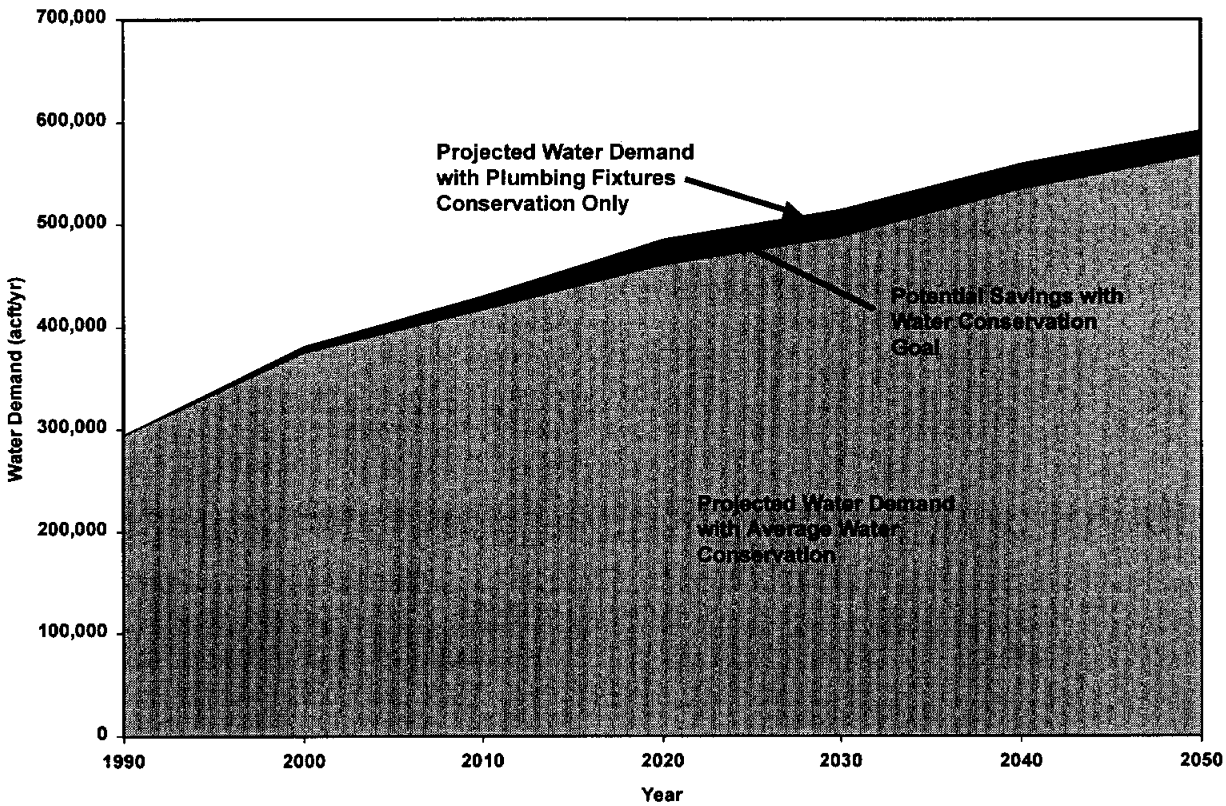
Table 2-4.
Tarrant Regional Water District
Wholesale and Individual Customers
Water Demand Projections Summary

Customer	Use in 1990 (acft)	Projections 2000 (acft)	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)
Plumbing Fixtures Water Conservation							
Wholesale Customers							
Fort Worth	157,929	190,269	215,108	238,009	248,169	268,409	286,499
Trinity River Authority	24,016	38,717	42,716	46,037	46,405	46,314	46,136
Arlington	48,664	67,818	68,957	74,359	76,747	77,801	80,224
Mansfield	2,063	5,409	7,675	10,081	12,547	15,097	17,968
Subtotal	232,671	302,212	334,456	368,486	383,868	407,621	430,827
Individual Customers							
Eastern Division	10,421	16,240	19,134	23,298	25,779	28,457	31,212
Western Division	5,312	6,928	8,042	9,008	9,733	10,338	11,002
Ellis County	0	1,940	6,417	13,191	17,104	18,988	20,588
Subtotal	15,733	25,108	33,593	45,497	52,616	57,783	62,802
Industrial Demand[1]	40,466	42,990	46,206	48,806	51,414	54,518	59,131
Steam-Electric Power	4,212	5,000	5,000	5,000	5,000	5,000	5,000
Irrigation	1,500	1,500	1,500	1,500	1,500	1,500	1,500
TRWD Subtotal	294,582	376,810	420,755	469,289	494,398	526,422	559,260
Potential New TRWD Customers		4,268	9,259	15,819	19,777	32,946	31,822
TRWD Total	294,582	381,078	430,014	485,108	514,175	559,368	591,083
Average Water Conservation							
Wholesale Customers							
Fort Worth	157,929	187,298	207,636	225,682	235,782	257,237	277,812
Trinity River Authority	24,016	37,822	41,024	43,078	43,475	43,319	43,060
Arlington	48,664	66,390	66,320	69,018	71,142	72,435	74,660
Mansfield	2,063	5,315	7,359	9,413	11,768	14,142	16,823
Subtotal	232,671	296,826	322,338	347,191	362,167	387,133	412,355
Individual Customers							
Eastern Division	10,421	16,240	19,134	23,298	25,779	28,457	31,212
Western Division	5,312	6,928	8,042	9,008	9,733	10,338	11,002
Ellis County	0	1,892	6,086	12,151	15,679	17,348	18,892
Subtotal	15,733	25,060	33,262	44,457	51,191	56,143	61,106
Industrial Demand[1]	40,466	42,990	46,206	48,806	51,414	54,518	59,131
Steam-Electric Power	4,212	5,000	5,000	5,000	5,000	5,000	5,000
Irrigation	1,500	1,500	1,500	1,500	1,500	1,500	1,500
TRWD Subtotal	294,582	371,376	408,306	446,954	471,272	504,294	539,092
Potential New TRWD Customers		3,914	8,349	14,055	17,701	30,024	28,908
TRWD Total	294,582	375,290	416,655	461,009	488,973	534,319	568,001

Source: Texas Water Development Board; 1996 Consensus Water Planning Projections, most likely case, for individual cities, with local area study projections for individual customers located in the Eastern and Water Divisions.

[1] That part of industrial water demand which is not included in wholesale customers totals above.

demand for average water conservation is 24,099 acft/yr, or 5.0 percent less than for plumbing fixtures only, and in 2050 is 23,082 acft/yr or 3.9 percent less than for water conservation using plumbing fixtures only. Figure 2-2 contains a graph of projected water demands for both the plumbing fixture only conservation set and the average water conservation set.



Source: TWDB, 1996 Consensus Projections, most likely case, with amendments for individual customers located in the Eastern and Western divisions.

Figure 2-2. Water Demand Projections

Section 3

Water Supply

Section 3
Water Supply

3.1 Existing Water Supply

The TRWD currently operates, or shares in the operation of, five water supply reservoirs, and the District's system supplies raw water to all or parts of ten counties in North Texas. The five reservoirs are Lake Bridgeport, Eagle Mountain Lake, Lake Benbrook, Richland-Chambers Reservoir, and Cedar Creek Reservoir, as previously shown in Figure 1-1. The District subdivides its system into two major, and until this year independent, reservoir sub-systems: the East Texas System and the West Fork System. The East Texas Reservoir System includes Cedar Creek Reservoir and Richland-Chambers Reservoir and their associated raw water delivery systems. The West Fork System includes Lake Bridgeport and Eagle Mountain Lake on the West Fork of the Trinity River, and Lake Benbrook on the Clear Fork of the Trinity River. Recently, a pipeline has been constructed that allows for East Texas water to be supplied to Lake Benbrook and to customers who were solely dependent on West Fork water.

3.1.1 East Texas Reservoir Supply

The East Texas Reservoir System is comprised of the District's two largest reservoirs, Cedar Creek Reservoir and Richland-Chambers Reservoir (Figure 1-1). The majority of the raw water from these two reservoirs is delivered to the District's balancing reservoirs in southern Tarrant County. Raw water is delivered to the balancing reservoirs from Cedar Creek Reservoir in a 72-inch diameter, 74-mile pipeline, and from Richland-Chambers Reservoir in a 90-inch diameter, 78-mile pipeline.

The combined safe yield from the East Texas System is 357,000 acft/yr, or 81 percent of the District's total supply. Therefore, the East Texas System is the major source of water for the future. As will be explained below, sediment accumulation in the East Texas Reservoirs is expected to decrease existing supplies to 310,000 acft/yr by the year 2050.

3.1.1.1 Reservoir Sedimentation Rate

A critical factor in estimating the yield of a particular reservoir is the storage volume in the reservoir pool. Over time, sediments suspended in the inflow to the reservoir settle out in the lake and decrease the volume available to store water. This in turn decreases the yield of the reservoir. In 1995, the TWDB performed bathymetric surveys on both the East Texas Reservoirs.[1,2] Volumetric surveys like these help in determining the rate at which sediment is being deposited into the reservoir, which in turn determines the rate at which the yield of the reservoir is depleted.

Analyses of these new bathymetric surveys, as compared to previous topography for the lakes, indicated that the accumulation of sediment in Cedar Creek Reservoir and Richland-Chambers Reservoir is 1,453 acft/yr and 4,976 acft/yr, respectively (Appendix A). The estimated sedimentation rate for Cedar Creek Reservoir was found to be reasonable and was used to determine the expected storage volume for analysis of reservoir yield in the years 2015 and 2050. The Richland-Chambers Reservoir computed sedimentation rate of 4,976 acft/yr was much higher than expected. It is hypothesized that the relatively short period between sediment surveys (1987 to 1994), in conjunction with questions regarding the accuracy of the original pre-construction volumetric survey, have combined to adversely inflate the apparent sedimentation rate.

During the 1987 to 1994 period, there were several high rainfall events resulting in high inflows to Richland-Chambers Reservoir. As shown in Appendix A, TRWD staff, in conjunction with the Natural Resources Conservation Service (formerly Soil Conservation Service), applied the Soil and Water Assessment Tool (SWAT Model). The SWAT Model is a continuous-time, basin-scale hydraulic model capable of long-term simulations including hydrology, pesticide and nutrient loading, erosion, and sediment transport. The SWAT Model was calibrated to the sediment loads estimated from the 1995 bathymetric survey. Had the reservoir been in place during the 1950 to 1995 period, the SWAT Model estimated the resulting long-term sedimentation rate would have been 2,918 acft/yr. Until enough time has passed to perform another volumetric survey on Richland-Chambers Reservoir to refine the observed sedimentation rate, a sediment accumulation rate of 3,867 acft/yr was used based on long-term

[1] Texas Water Development Board (TWDB), "Volumetric Survey of Cedar Creek Reservoir," Tarrant County Water Control and Improvement District Number One, July 31, 1995.

[2] TWDB, "Volumetric Survey of Richland-Chambers Reservoir," Tarrant County Water Control and Improvement District Number One, March 31, 1995.

observed rates in other North Texas reservoirs containing similar watershed soils, as discussed in Appendix A.

3.1.1.2 Richland-Chambers Reservoir

Richland-Chambers Reservoir is located in Navarro and Freestone Counties and impounds approximately 1,136,600 acft. Water rights permits for Richland-Chambers Reservoir provide for the diversion of up to 210,000 acft/yr from the lake, and the majority of the diversions are delivered to the District's balancing reservoirs via a 90-inch diameter, 78-mile pipeline. The accumulation of sediment in the reservoir pool and the District's operation policy for the reservoir (Section 3.2.5) have combined to reduce the existing yield of the lake to approximately 202,100 acft/yr (approximately 46 percent of the District's supply). A summary of the current and future yield estimates for Richland-Chambers Reservoir is presented in Table 3-1.

Table 3-1.
Richland-Chambers Reservoir
Safe Yield Summary

Sediment Accumulation Year	*Safe Yield[1] (acft/yr)*	*Difference from Permitted Withdrawal[2] (acft/yr)*
1995	202,100	7,900
2015	195,200	14,800
2050	174,400	35,600

1 Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoir during the critical drought for the analysis reported here is 197,000 acft.

2 The District has a permit to divert up to 210,000 acft/yr from Richland-Chambers Reservoir.

The District currently operates the reservoir under a safe yield operation that results in a drought reserve of 197,000 acft remaining in storage during the driest year of the drought of record. As shown in Table 3-1, the combination of sediment accumulation and reservoir operating policy effectively decrease the Richland-Chambers Reservoir supply by 35,600 acft/yr (17 percent) by the year 2050.

3.1.1.3 Cedar Creek Reservoir

Cedar Creek Reservoir, the second lake in the East Texas System, is located in Henderson and Kaufman Counties approximately 74 miles from the District's largest customers in Tarrant County. Cedar Creek Reservoir impounds approximately 637,180 acft from Cedar Creek and its tributaries, and has a permitted withdrawal amount of 175,000 acft/yr. Diversions from Cedar Creek Reservoir are delivered to the District's balancing reservoirs via a 72-inch diameter pipeline. Like its partner in the East Texas System, the accumulation of sediment in the Cedar Creek Reservoir reservoir pool and the current operation policy for the reservoir (Section 3.2.5) have combined to reduce the existing yield of the lake to approximately 154,900 acft/yr (approximately 35 percent of the District's supply). A summary of the current and future yield estimates for Cedar Creek Reservoir is presented in Table 3-2.

Table 3-2.
Cedar Creek Reservoir
Safe Yield Summary

Sediment Accumulation Year	*Safe Yield[1] (acft/yr)*	*Difference from Permitted Withdrawal[2] (acft/yr)*
1995	154,900	20,100
2015	148,000	27,000
2050	135,600	39,400

1 Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoir during the critical drought for the analysis reported here is 157,000 acft.

2 The District has a permit to divert up to 175,000 acft/yr from Cedar Creek Reservoir.

The District currently operates the reservoir under a safe yield operation that results in a drought reserve of 157,000 acft remaining in storage during the driest year of the drought of record. As shown in Table 3-2, the combination of sediment accumulation and reservoir operating policy effectively decrease the Cedar Creek Reservoir supply by 39,400 acft/yr (23 percent) by the year 2050.

3.1.2 West Fork System Supply

The West Fork System is comprised of Lake Bridgeport and Eagle Mountain Lake serving as the water supply sources, and Lake Worth, immediately downstream of Eagle Mountain Lake, as the delivery point for the City of Fort Worth (the primary customer for West Fork water). In contrast to the large pipeline and pump station infrastructure of the East Texas System, the West Fork System is a gravity system using the West Fork of the Trinity River to deliver water to its customers. The estimated current safe yield of the West Fork System is 78,000 acft/yr (approximately 18 percent of the District's current supply). A summary of the current and projected future safe yields of the West Fork System is provided in Table 3-3. As with the East Texas reservoirs, accumulation of sediment in Lake Bridgeport and Eagle Mountain Lake decreases the safe yield over time.

Table 3-3.
West Fork System[1]
Safe Yield Summary

Sediment Accumulation Year	Safe Yield[2] (acft/yr)
1995	78,000
2015	74,000
2050	67,000

1 West Fork System comprised of Lake Bridgeport, Eagle Mountain Lake, and Lake Worth.
2 Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoir system during the critical drought for the analysis reported here is 76,000 acft.

Due to the relatively low cost of delivery of water from the gravity-fed West Fork System, and the fact that the water rights permits for the reservoirs exceed the divertable supply, the West Fork System is overdrafted when system storage is above 250,000 acft (combined storage in Lake Bridgeport and Eagle Mountain Lake) and underdrafted when storage is below this trigger. Overdrafting means that more than the yield of the reservoir is diverted in wet and average years, and subsequently, operations during drought are such that diversions are less than the yield of the reservoir. In the case of the West Fork System, the District supplies the City of Fort Worth 100,000 acft/yr when storage in Lake Bridgeport and Eagle Mountain Lake is greater than 250,000 acft, and decreases supplies to 46,000 acft/yr when storage drops to below 250,000 acft. This operation policy decreases the volume of water that must be pumped from the East Texas System in most years, which in turn decreases power costs associated with delivering water from East Texas.

3.1.3 Total Water System Supply

In addition to the two major supply systems, the West Fork System and the East Texas System, the District also holds 6,800 acft of water rights (approximately 1 percent of the District's current water supply) in Lake Benbrook on the Clear Fork of the Trinity River. While the volume of supply from Lake Benbrook is minimal compared to the other components of the District's System, the lake will soon become a key component in the overall system. The Benbrook Connection, a pipeline connecting the balancing reservoirs and East Texas water to Lake Benbrook, has been constructed that allows the District to deliver water to customers that previously relied solely on the West Fork System for supply (namely the City of Fort Worth's Holly Water Treatment Plant). The 90-inch diameter pipeline, which should be completed this year, will greatly enhance the District's ability to provide water throughout their system. Lake Arlington is a major delivery point for raw water from the East Texas System, and also has a small yield from local runoff. Diversion rights for the small amount of local yield are held by the City of Arlington and TU Electric Company. The water available from these rights is not included in the District's safe yield summary.

At present, the District maintains a total existing supply of 441,800 acft/yr. As shown in Table 3-4, due to sediment accumulation alone, the total system supply diminishes approximately 15 percent to 383,000 acft/yr by the year 2050. A summary of the current and projected total system supplies is presented in Table 3-4.

3.1.4 Water Demand and Supply Comparison

A comparison of projected water demands and supplies is presented in Table 3-5 for the Plumbing Fixtures Only Conservation and the Average Water Conservation. For the Plumbing

Table 3-4.
Tarrant Regional Water District
Safe Yield Summary

System Component	Safe Yield[1] (acft/yr) 1995	2015	2050
West Fork System[2]	78,000	74,000	67,000
Benbrook Reservoir[3]	6,800	6,700	6,000
Cedar Creek Reservoir	154,900	148,000	135,600
Richland-Chambers Reservoir	202,100	195,200	174,400
Total Existing System Supply	441,800	423,900	383,000

1 Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoir during the critical drought for the analysis reported here is 430,000 acft.
2 Includes Lake Bridgeport, Eagle Mountain Lake, and Lake Worth. TRWD has diversion rights on the West Fork in excess of the yield of the reservoirs. Such diversion authorizations allow the District to improve operational efficiency.
3 TRWD's portion of yield in Benbrook Reservoir that is generated by natural streamflows in the Benbrook watershed. Does not include pass-through flows from East Texas Reservoirs via the Benbrook connection.

Table 3-5.
Tarrant Regional Water District
Water Demand and Supply Comparison

	Use in 1990 (acft)	Projections 2000 (acft)	2010 (acft)	2020 (acft)	2030 (acft)	2040 (acft)	2050 (acft)
Projected Demand with Plumbing Fixtures Only Conservation[1]	294,582	381,078	430,014	485,108	514,175	559,368	591,083
Total Existing System Supply[2]		437,325	428,375	418,057	406,371	394,686	383,000
Supply minus Demand		56,247	(1,639)	(67,051)	(107,804)	(164,682)	(208,083)
Projected Demand with Average Water Conservation[1]	294,582	375,290	416,655	461,009	488,973	534,319	568,001
Total Existing System Supply[2]		437,325	428,375	418,057	406,371	394,686	383,000
Supply minus Demand		62,035	11,720	(42,952)	(82,602)	(139,633)	(185,001)

1 From Table 2-4.
2 From Table 3-4.

Fixtures Only Conservation demand set, Table 3-5 shows that presently available supplies can meet projected demands through year 2009. By 2020, demands exceed supplies by 67,051 acft/yr, and in year 2050, demand would exceed supply by 208,083 acft/yr. Figure 3-1 presents a graphical comparison of demand and supply.

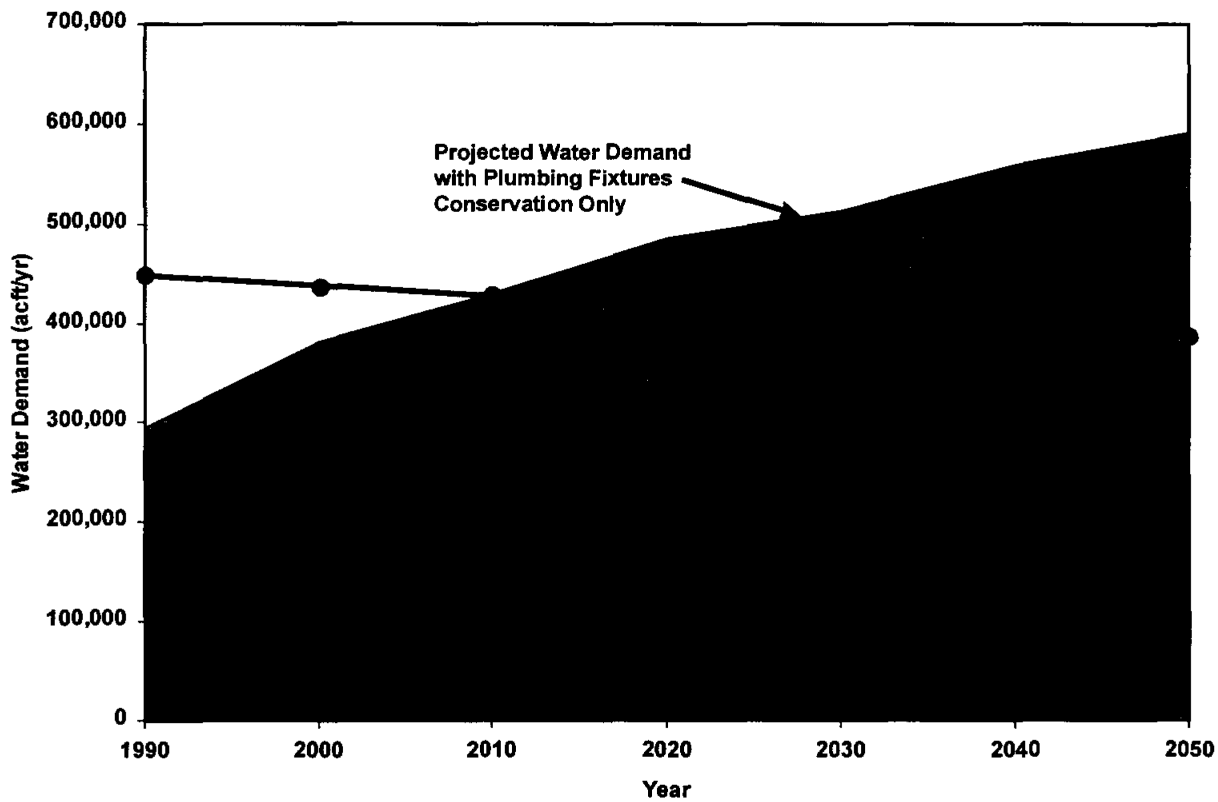


Figure 3-1. Water Demand and Supply

For the Average Water Conservation demand condition, Table 3-5 shows that presently available supplies can meet projected demands through year 2012. By 2020, demands exceed supplies by 42,952 acft/yr, which indicates a reduced shortage of 24,099 acft/yr compared to the Plumbing Fixtures Only Conservation demand set. In year 2050, demand would exceed supply by 185,001 acft/yr. A graphical comparison of the Average Water Conservation demands to supplies is also presented in Figure 3-1.

3.2 Maximizing Existing Water Supply Resources

As demands for the District's water continue to grow, maximizing the beneficial use of the District's current supplies and adding cost-effective new supplies using as much of the current infrastructure as possible will be critical. In order to delay, or at least minimize, the large capital costs associated with major new water supply projects, the current operations of the East Texas System as well as the West Fork System were reviewed to determine the potential benefits of changes in operating policies. In addition, with completion of the Benbrook Connection pipeline, interaction between the East Texas and West Fork Systems can now be used to potentially increase system-wide yield. The analyses reported in the following sections detail potential modifications to the District's operation policies and sources of potentially cost-effective new water supplies in order to maximize the District's supply. The sources investigated include:

- Water Reuse to Enhance East Texas Reservoir Yield;
- West Fork System Enhancement with East Texas Water;
- Potential Water Supplies from Other Sources;
- Systems Operation of the East Texas Reservoirs; and
- Changes in Reservoir Drought Supply Reserves in the East Texas Reservoirs.

The following sections describe in detail the analyses performed and the potential increases in yield to the District under each option alone. Section 5 contains potential integrated plans for long-range water supply planning.

3.2.1 Water Reuse to Enhance Reservoir Yield

The 1990 Regional Water Supply Plan[3] identified diversion of water from the Trinity River to the District's East Texas reservoirs as a key water supply alternative. The project involves capturing water returned to the Trinity River by District customers. Customer return flows are introduced into the Trinity River as treated effluent by the City of Fort Worth and TRA wastewater treatment plants. These return flows are conveyed by the Trinity River to locations near Cedar Creek and Richland-Chambers Reservoirs. The proposed project involves the

[3] Freese & Nichols, Inc. (F&N) and Alan Plummer and Associates, Inc. (APAI), "Regional Water Supply Plan," Tarrant County Water Control and Improvement District Number One, 1990.

diversion of a portion of these flows from the Trinity River into the reservoirs to augment natural inflows and increase existing reservoir yields.

Treatment of the diverted water is deemed necessary in order to maintain water quality in the reservoirs. One of several potential treatment schemes selected for this diversion involves construction of a "natural" system of sedimentation ponds and wetland areas. The District has tested a pilot-scale wetland system for 7 years, and continues testing on a larger scale to better assess operating parameters and management techniques. The preferred development plan for the Trinity River diversion recommended in the 1990 Regional Water Supply Plan consisted of four steps:

Step 1: *Construct facilities to divert supplemental water from the Trinity River into Richland-Chambers Reservoir for a potential gain in yield of 63,000 acft/yr.*

Step 2: *Construct facilities to divert supplemental water from the Trinity River to Cedar Creek Reservoir for a potential gain in yield of 52,500 acft/yr.*

Step 3: *Operate Richland-Chambers Reservoir and Cedar Creek Reservoir as a coordinated system,*[4] *for a potential gain in yield of 32,800 acft/yr.*

Step 4: *Construct Tehuacana Reservoir and connecting channel between Tehuacana and Richland-Chambers. Increase the diversion capacity from the Trinity River into Richland-Chambers in proportion to the added safe yield made available by Tehuacana Reservoir. The total gain in yield from Tehuacana and the additional Trinity diversion capacity will be 88,700 acft/yr.*

3.2.1.1 Constructed Wetlands

A key component of the reuse project involves treatment of diverted flows in constructed wetlands. Previous studies by the District showed that Trinity River flows to be diverted into Richland-Chambers or Cedar Creek Reservoirs should first be treated to remove nutrients and possibly other potential contaminants, toxicants, and/or pathogens. In 1992, a pilot-scale constructed wetlands research facility was constructed by District personnel. The major goal of this ongoing research is to determine the effectiveness of constructed wetlands in treating water diverted from the Trinity River to a degree of acceptable quality to introduce into the reservoirs for yield augmentation. It must be determined not only that this treatment goal is possible, but

[4] Due to water quality considerations, as discussed in Section 3.2.1.3, potential water supply increases from systems operations are not attainable with implementation of the reuse projects.

that it can be accomplished in a manner that is cost-effective in comparison to construction of other potential supply projects.

Data from the District's pilot-scale constructed wetlands demonstration project indicate that a wetlands treatment system consisting of a settling-pond/constructed wetland arrangement could provide treatment to effectively control toxicant, nutrient, and other contaminants, prior to being input to the reservoirs. There are a number of additional issues that require evaluations that are dependent upon long-term operations of larger scale wetland systems. These issues will be evaluated after the construction of a 241 acre field-scale wetlands demonstration project, the first phase of a 1,500 acre full-scale project for the Richland-Chambers site.

3.2.1.2 Water Rights and Regulatory Permits

The District's proposed reuse plan is a unique component in the development of new raw water sources for a regional water supply. Therefore, a number of water rights and regulatory issues must be resolved. The District is currently working with various state agencies to determine the appropriate approaches for implementation of this plan.

3.2.1.3 Analysis of Trinity River Diversions for East Texas Reservoir Yield Augmentation

Since the 1990 Regional Water Supply Plan[5] was developed, two additional projects have been completed involving analysis of diversion flows for yield augmentation. The first of these studies was conducted in 1991 and is documented in the report entitled "Water Quality Assessments and Recommended Pilot-Scale/Bench-Scale Studies Associated with Water Supply Diversion from the Trinity River."[6] The second study, conducted in 1997, is documented in the report entitled "Wetland Treatment System Conceptual Plan."[7] TRWD has since undertaken additional studies to define specific applications for the Cedar Creek and Richland-Chambers wetland treatment systems. These investigations resulted in sequential refinement of the diversion flow scenarios that were originally conceptualized in the 1990 Plan. The chief refinement in the flow analysis came about in the 1997 study and involved consideration of flow

[5] F&N and APAI, Op. Cit., 1990.

[6] APAI, "Water Quality Assessments and Recommended Pilot-Scale/Bench-Scale Studies Associated with Water Supply Diversion from the Trinity River," prepared for Tarrant County WCID No. 1, 1991.

[7] APAI, "Wetland Treatment System Conceptual Plan," Prepared for the Tarrant Regional Water District, January 1997.

losses through constructed wetlands. The pumping rates from the river to the reservoirs presented in the 1990 and 1991 reports include no assumptions for losses through the wetlands facilities prior to the introduction of these diversions flows into the reservoirs. Values published in these reports have since been referred to as the "treated" diversion flow rates (i.e., the rates of flow leaving the wetlands and entering the reservoirs). The analysis performed for the 1997 report include estimates for evapotranspiration, seepage, and other losses through the proposed wetlands facilities to determine the magnitude of "raw" flow diversions from the river required to produce the desired "treated" flows into the reservoirs. The following paragraphs briefly describe the diversion flow analysis methodology which has been utilized in the previous studies.

In the 1991 study, hydrology for the period from 1941 through 1986 was employed to simulate system operations and evaluate diversion scenarios. This period contains the record drought of the mid-1950s. A computer model was utilized to simulate monthly reservoir operations for Cedar Creek and Richland-Chambers Reservoirs. The computer model included a "trigger" condition for the addition of makeup flow from Trinity River diversion. The "trigger" condition occurs when the water surface level in the reservoir drops to 5 feet below the top of the conservation pool. Monthly diversion rates for treated water into the reservoirs were set at 5,360 acft/mo for Cedar Creek Reservoir and 6,050 acft/mo for Richland-Chambers Reservoir. In the 1990 report, an allowance for 20 percent average downtime was used to calculate the pumping rate; however, consultation with District personnel indicated that the District's diligent preventive maintenance program significantly reduces downtime. Therefore, a 5 percent downtime allowance was used in the 1997 study to determine the required pumping rates for both the raw and the treated water pump stations. The maximum pumping rates associated with the monthly diversion volumes presented above are shown in Table 3-6 for both "raw" and "treated" diversion flows.

The demand condition in the reservoir operation models was set to achieve a 30 percent increase in the safe yield of each reservoir. Reservoir yields from the previous studies are also summarized in Table 3-6. The "treated diversions" represents the actual flow to be added to the reservoirs to supplement yield for the first two steps of the proposed water supply plan. The "raw diversions" were developed based on assumptions for flow losses of the diversion water during treatment through a constructed wetland system. The following is an excerpt from

Table 3-6.
Reservoir Operation Summary with Trinity River Diversion Project

Diversion Parameters	Units	Raw Diversions (Pumpage from River to Constructed Wetlands): Richland-Chambers Reservoir (Step 1)	Raw Diversions (Pumpage from River to Constructed Wetlands): Cedar Creek Reservoir (Step 2)	Treated Diversions (Pumpage into Reservoir): Richland-Chambers Reservoir (Step 1)	Treated Diversions (Pumpage into Reservoir): Cedar Creek Reservoir (Step 2)
Maximum Diversion Pumping Rate @ 20% Downtime[1]	cfs MGD	167 107.9	148 95.9	125 81.0	111 71.8
Maximum Diversion Pumping Rate @ 5 percent Downtime[2]	cfs MGD	140.7 90.9	125.0 80.8	105.6 68.2	93.5 60.4
Maximum Monthly Diversion	acft/mo	8,062	7,164	6,050	5,360
Maximum Yearly Diversion	acft/yr MGD	96,741 86.4	85,965 76.7	72,600 64.8	64,320 57.4
Diversion Trigger[3]	ft.	5	5	5	5

Yield Parameters	Units	Richland-Chambers Reservoir (Step 1)	Cedar Creek Reservoir (Step 2)
2050 Yield, No River Diversion	acft/yr	205,824[4]	175,000[5]
2050 Yield with River Diversion[6]	acft/yr	273,000	227,500
Increase in Yield	acft/yr MGD	67,176 60.0	52,500 46.9
Percent Increase in Yield		33%	30%

Notes:

1 20 percent downtime was the original assumption employed in the 1990 Regional Water Supply Plan. This was superseded by the 1997 Conceptual Plan with 5 percent. Tabulated values included only for reference back to the original study.

2 Source: Alan Plummer Associates, Inc., "Wetland Treatment System Conceptual Plan," prepared for Tarrant Regional Water District, January 1997.

3 Reservoir drawdown below conservation pool elevation (as proposed in original conceptual plan).

4 Drought supply reserves are reduced as needed to maximize annual firm yield.

5 Current permitted annual diversion.

6 Source: Freese and Nichols, Inc., Alan Plummer Associates, Inc., "Regional Water Supply Plan," prepared for Tarrant County WCID No. 1, 1990.

the1997 Wetland Treatment System Conceptual Plan Report[8] that further describes the basis for estimating these losses.

> Potential losses from a constructed wetlands treatment system primarily include evapotranspiration and seepage. In order to deliver the projected yields to the reservoirs, compensation for the losses sustained during treatment must be included in the amount of diverted water from the Trinity River. Evapotranspiration is primarily a function of local weather conditions and wetland operating procedures. The amount of water loss through seepage is dependent on site-specific soil conditions. Evaluation of seepage at the pilot-scale wetland system indicated that seepage losses were negligible. Soil conditions should be investigated at any site selected to evaluate potential seepage losses. Other potential water losses from the constructed wetlands can be associated with operating procedures to control vegetation types, sediment buildup, damage to berms, and wetland manipulations to meet public usage needs and/or wildlife management needs (if these do not conflict with water supply operations).
>
> Gross evaporation data for Richland-Chambers and Cedar Creek Reservoirs are more or less similar during drought conditions and indicate an annual loss of approximately 7.25 feet. Details of the wetlands operations and wetland area required will continue to be refined from operations and analysis of data from the pilot-scale wetland facility and the proposed field-scale wetlands. The current estimate is that approximately 2,000 total acres at Richland-Chambers and 1,800 total acres at Cedar Creek could be required. If it is assumed that twice the gross evaporation rate will be adequate to satisfy all potential water losses at the wetlands, then the total maximum water loss at both wetlands could reach 55,100 acft/yr. Therefore, the quantities of water that must be pumped from the Trinity River are 105,019 and 90,799 acft/yr for Richland-Chambers and Cedar Creek, respectively. Comparisons to the historical evaporative losses calculated for Cedar Creek and Richland-Chambers Reservoirs in the 1991 report (Water Quality Assessments and Recommended Pilot-Scale/Bench-Scale Studies Associated with Water Supply Diversion from the Trinity River) indicate that the projected evaporative losses for the constructed wetlands will be conservative for both Richland-Chambers and Cedar Creek treatment wetlands even for record drought years.

Summarized in Table 3-7 are the yield and diversion values associated with all four steps of the District's proposed water supply plan (Table 3-6 referenced only Steps 1 and 2). With consideration for flow losses through the constructed wetlands, the proposed reuse project

[8] APAI, Op. Cit., January 1997.

requires a maximum annual diversion of approximately 195,805 acft/yr of Trinity River flow during the critical drought year. Lesser diversions are required under other hydrologic conditions. As previously mentioned, the District's proposed reuse plan limits all annual diversions to 70 percent of the magnitude of return flows from water originally supplied by the District and subsequently discharged by the District's customer wastewater treatment plants.

Table 3-7.
Pumping Rates and Annual Diversions for Trinity River Diversion Project

		Raw Diversion Rates (Pumpage from River to Constructed Wetlands)		*Treated Diversion Rates (Pumpage into Reservoirs)*		*Reservoir Yield*	
Project Step	*Description*	*Pumping Rate[1] (MGD)*	*Annual Diversion (acft/yr)*	*Pumping Rate[1] (MGD)*	*Annual Diversion (acft/yr)*	*Yield Increase (acft/yr)*	*New Yield (acft/yr)*
Step 1	River Diversion to Richland-Chambers Reservoir	90.9	96,741	68.2	72,600	67,176	273,000
Step 2	River Diversion to Cedar Creek Reservoir	80.8	85,965	60.4	64,320	52,500	227,500
Step 3	Operate Reservoirs as System[2] Step 1+2+3 ➧	183.2	194,995	137	146,100	32,800	533,300
Step 4	Construct Tehuacana Reservoir and River Diversion to Tehuacana Step 1+2+3+4 ➧	206.6	219,860	155	164,760	88,700	622,000

[1] Pumping rates based on 5 percent annual outage.
[2] For water quality considerations, a dilution rate of reservoir capacity to Trinity River annual diversion of 30 percent will be used (i.e., about 3:1). However, systems operation involves overdrafting Cedar Creek Reservoir to reduce loss due to spills and underdrafting Richland-Chambers Reservoir until needed. Analyses performed for this study have shown that systems operation will drawdown Cedar Creek Reservoir to a low volume and preclude adhering to the maximum concentration of 30 percent Trinity River water in Cedar Creek Reservoir. Therefore, the potential water supply increase from Step 3, systems operation, is probably not attainable.

Regarding reservoir water quality, some additional examination has been made, as a part of this study, of the relative volumes of reservoir storage derived from diversion waters versus natural inflows. A dilution rate of reservoir capacity to Trinity River annual diversion of 30 percent has been suggested in the past as a desirable mix. However, systems operation activities proposed in Step 3 of the water supply plan involve overdrafting Cedar Creek Reservoir to reduce loss due to spills and underdrafting Richland-Chambers Reservoir until its supply is needed. Analyses performed for this study have shown that systems operation will draw down Cedar Creek Reservoir to a low volume and preclude adhering to the 30 percent dilution criteria in that facility. These analyses indicate that the potential water supply increase from systems operation may not be attainable.

3.2.2 Enhancement of Water Supply in West Fork Area

The District is considering methods to increase raw water availability in the West Fork of the Trinity River. Together, Eagle Mountain Lake and Lake Bridgeport constitute the West Fork lakes that are owned by the District. There are three other lakes in the West Fork segments that are owned by others. These are Lake Arlington (owned by Arlington and TU Electric), Lake Worth (owned by Forth Worth), and Lake Benbrook (owned by the U.S. Army Corps of Engineers). Additional water supplies would result in significant benefits to the District and its customers through operational flexibility, system reliability, treatability (raw water blending), recreation, and meeting the needs of a high-growth area. One potential method to increase raw water availability in the District's West Fork resources would be to construct facilities to deliver water from the East Texas reservoirs (through the Benbrook connection and Lake Benbrook) to Eagle Mountain Lake. This would also increase the flexibility of all of the District's supply resources by providing a means of transferring water from the West Fork resources to Lake Benbrook and thereby supplementing the East Texas supply. Additionally, using Eagle Mountain Lake as terminal storage would make it possible to operate the District's existing and future East Texas pipelines at a more uniform pumping rate year-round.

Growth in north and northwest Tarrant County (led by the Intel microprocessor plant, Alliance Airport, and associated municipal and commercial development) is causing increased demand for water. The Eagle Mountain Water Treatment Plant (WTP), located in northwest Fort Worth, serves a portion of the area with treated water. The combined treatment capacity of the Eagle Mountain WTP and the Holly WTP will exceed the safe yield of the West Fork by 2030, assuming current City of Fort Worth WTP expansion plans are implemented. The District provides raw water to the Eagle Mountain WTP from its West Fork reservoirs. Although the sum of the diversion permits for the West Fork totals 159,600 acft/yr,[9] the current safe yield of the West Fork reservoirs is approximately 77,400 acft/yr. In addition to supplying raw water to the Eagle Mountain WTP, the West Fork also supplies water to meet a portion of the needs at the

[9] Eagle Mountain Lake diversion permit (includes contribution from Lake Bridgeport).

Holly WTP, local needs at Lake Bridgeport and Eagle Mountain, and for maintenance of water level at Lake Worth, and recreation interests. Currently, the demands on the West Fork total about 100,000 acft/yr. Subject to availability of raw water, the City of Fort Worth plans to expand Eagle Mountain WTP from 30 MGD to 190 MGD. This major expansion would significantly exceed the yield of the West Fork, and augmentation of Eagle Mountain Lake would be needed in dry years to firm up supplies. Additionally, the availability of West Fork water to the Holly WTP would be reduced and the shortfall would need to be made up from deliveries of East Texas reservoir water through Lake Benbrook.

Growth in northeast Tarrant County (Hurst, Euless, Bedford, and the Southern part of Grapevine) has also created a much larger dependence on Lake Arlington as a critical water supply source for the District's system-wide customers. In addition, in eastern Tarrant County, the continued rapid growth of Arlington is placing greater stress on Lake Arlington, particularly during the peak production months.

Potential benefits resulting from delivery of East Texas water to the West Fork lakes (Bridgeport and Eagle Mountain) include not only the additional water supply sources in the West Fork, but potentially include avoided demand charges in the East Texas pump stations by pumping more uniformly through the year, and maintaining lake levels at Lake Bridgeport and Eagle Mountain Lake to increase recreation benefits by maintaining the lakes at a more consistent water level. It would also provide a looped supply system that will enhance the District's ability to better maintain consistent levels in Lake Benbrook, Lake Arlington, and Lake Worth for drinking water supply and recreational purposes.

In order to decrease the volume of water that must be pumped from the District's East Texas reservoirs and to take advantage of the District's water rights permits on the West Fork, the West Fork facilities are operated in an overdrafting/underdrafting mode. When the combined storage in Lake Bridgeport and Eagle Mountain Lake is greater than 250,000 acft, the District overdrafts the West Fork and provides the City of Fort Worth with 100,000 acft/yr (more than the safe yield of the West Fork). When combined storage drops below 250,000 acft, diversions from the West Fork System are reduced (less than the safe yield is diverted) and the District supplies the City with 46,000 acft. Considering that 2050 demands are 112,500 acft/yr (directly diverted from Lake Bridgeport and Eagle Mountain Lake) this creates a shortfall in supply from the West Fork of approximately 66,500 acft/yr (neglecting any demand for West Fork water at Holly WTP). This shortfall must be delivered from East Texas supplies.

Until recently, decreased supply from the West Fork during dry periods necessitated an increase in the volume of raw water treated and distributed from the City of Fort Worth's Rolling Hills WTP in southeast Fort Worth. This was necessary because Rolling Hills WTP was the only facility operated by the City with the ability to receive East Texas water. However, now that the pipeline connecting the East Texas reservoirs to Lake Benbrook (via Rolling Hills WTP) is complete, East Texas water can be delivered to the City of Fort Worth's Holly WTP by pumping it into Lake Benbrook and releasing it down the Clear Fork of the Trinity River for diversion to Holly WTP through the Clear Fork Intake and Pump Station. While this pipeline and associated storage in Lake Benbrook greatly enhances the flexibility of the District's System, continued growth in north and northwest Tarrant County will increase demands for City of Fort Worth water in the region. Therefore, facilities that augment the raw water supply from the West Fork reservoirs will greatly enhance the District's ability to supply water and meet projected needs at the Eagle Mountain WTP.

Another concept which could provide additional water supply to Lake Benbrook, and indirectly to Lake Arlington, includes potential diversion of flows in the West Fork of the Trinity River to Lake Benbrook. Water potentially available includes spills from Eagle Mountain Reservoir (i.e., high flows occurring in wet weather) with diversions being made from Eagle Mountain Lake as authorized under existing permits. However, to utilize wet weather flows in the West Fork, an intake structure, pump station, and water transmission pipeline would be needed to convey water from some point on the West Fork to Lake Benbrook.

3.2.2.1 Delivery Options to Eagle Mountain Reservoir

3.2.2.1.1 Option 1

Two options were evaluated for the delivery of additional water to Eagle Mountain Reservoir. Option 1 incorporates, to the extent possible, the use of existing facilities to pump water from the East Texas reservoirs to the West Fork. This option offers the possibility of gravity flow from Lake Benbrook (normal wsel 673') to Lake Worth (normal wsel 594'). This could be accomplished by constructing a pipeline from Lake Benbrook to the existing pipelines that supply raw water from Lake Worth to Holly WTP. Once connected with a pipeline from Lake Benbrook, the existing pipelines would have a higher head than current service, and flow would be reversed for discharge into Lake Worth. The existing 60-inch pipeline (constructed 1928) and the 72-inch pipeline (constructed 1952) would probably require rehabilitation. Replacement of the 60-inch pipeline is also an option. This option is shown in schematic form in Figure 3-2 and would require the following facilities:

- New pipeline from Lake Benbrook to Holly WTP and connection to the existing 60-inch and 72-inch dia. pipelines from the Lake Worth intake to the Holly WTP;
- Rehabilitation of the 60-inch dia. pipeline from Lake Worth to Holly WTP;
- Modifications to the Eagle Mountain Pump Station to allow pumpage from Lake Worth into Eagle Mountain Lake; and
- New pump station and pipeline at Holly WTP to convey West Fork water to Lake Benbrook to allow use of West Fork spills.

An alternative to the pipeline from Lake Benbrook to Holly WTP would be to continue making releases from Lake Benbrook to the Clear Fork for pumping at the Clear Fork pump station. The Clear Fork pump station would be expanded and a short pipeline built to connect to the existing 60-inch and 72-inch Lake Worth pipelines. However, as Fort Worth begins to use more East Texas water at the Holly WTP, the new gravity pipeline from Lake Benbrook to the treatment plant offers the advantage of reduced contamination of Benbrook releases from urban runoff in the Clear Fork.

3.2.2.1.2 Option 2

Option 2 involves the construction of a new pipeline between Lake Benbrook and Eagle Mountain Lake capable of conveying water to Eagle Mountain Lake for West Fork supply enhancement and reversing the direction to deliver West Fork water to Lake Benbrook during West Fork spills. This option, which is shown in Figure 3-3, would require:

- New pipeline between Lake Benbrook and Eagle Mountain Lake;
- New pump station at Lake Benbrook to pump water to Eagle Mountain Lake; and
- New pump station (or modifications to existing pump station) to pump water in the new pipeline from Eagle Mountain Lake to Lake Benbrook.

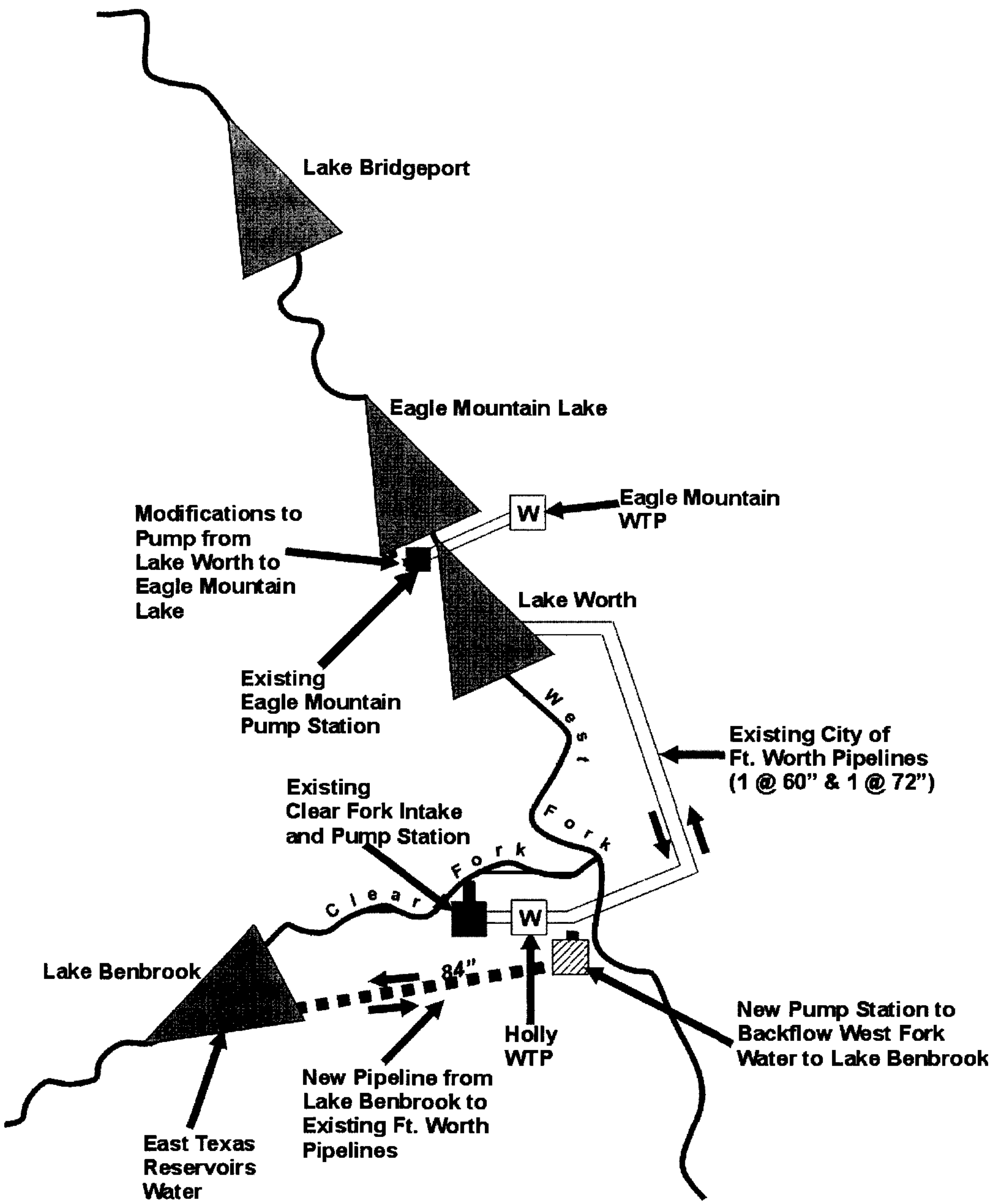


Figure 3-2. Enhancement of West Fork Water Supply (Option 1)

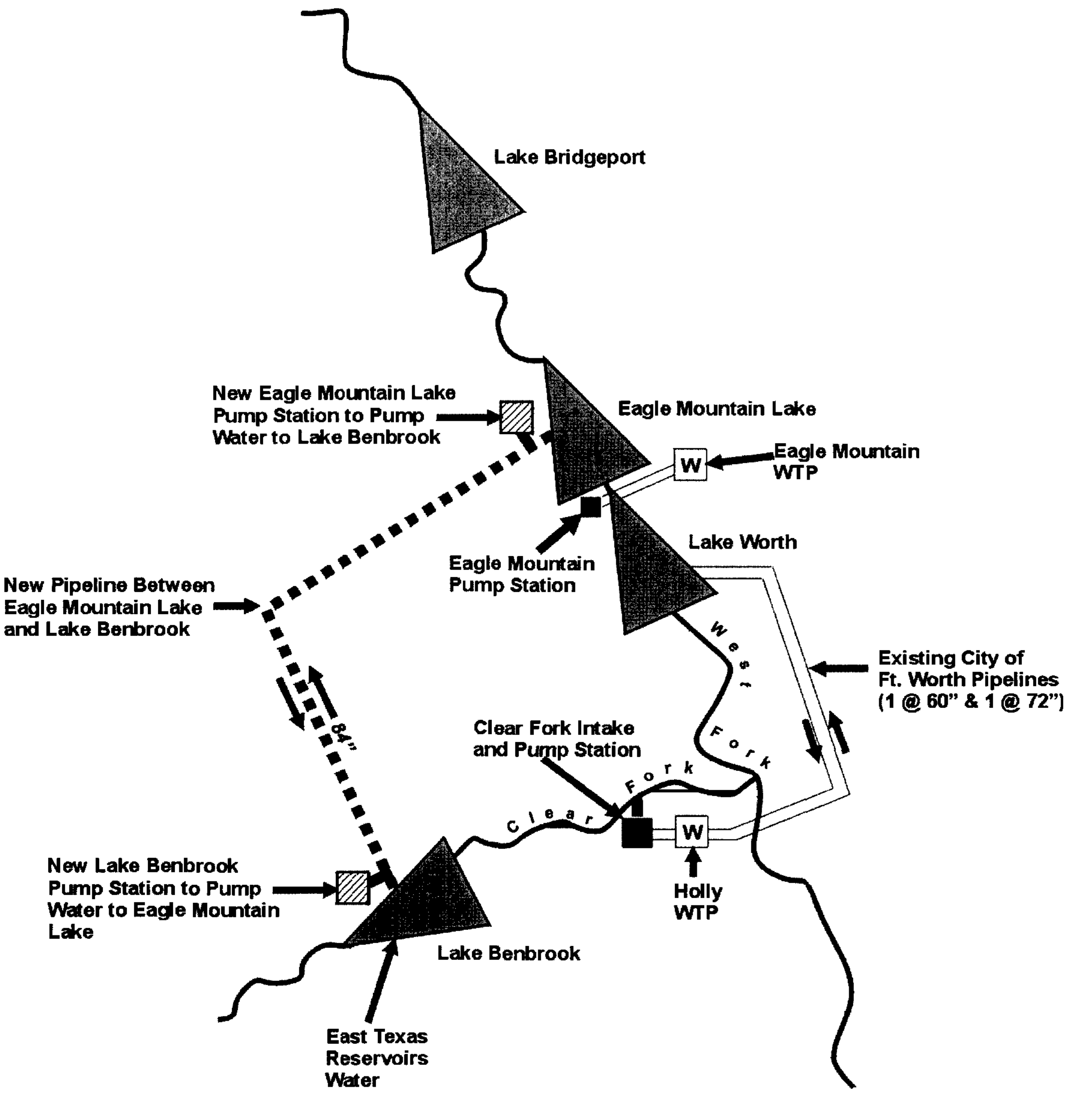


Figure 3-3. Enhancement of West Fork Water Supply (Option 2)

The primary difference in the two options is that one maximizes the use of existing facilities (Option 1) and the other requires new facilities to convey water between Lake Benbrook and Eagle Mountain Lake (Option 2). Option 2 would strengthen the District's overall system capability and does not rely on existing City of Fort Worth facilities.

3.2.2.2 Projected West Fork Shortages

Table 3-8 summarizes the safe yield available from the West Fork, projected demands on the West Fork, and the resulting potential shortages for the 2000 to 2050 period. The demand for West Fork water shown in Table 3-8 neglects any supply to the Holly WTP since it can now be supplied with East Texas water via the Benbrook connection. Therefore, the apparent surplus water shown in 2000, 2010, and 2030 will in actual practice be supplied to Holly WTP. However, if the Eagle Mountain WTP continues to expand as planned, by about 2022 demands for West Fork water will exceed the safe yield supply.

Table 3-8.
West Fork Supply and Projected Demands

	Annual Demand (acft/yr)					
Demand Projection Year	**2000**	**2010**	**2020**	**2030**	**2040**	**2050**
Eagle Mountain WTP Demand	18,500	34,100	58,200	86,000	93,800	101,500
Lake Bridgeport Local Demand	3,300	4,000	4,600	5,200	5,700	6,100
Eagle Mt. Lake Local Demand	3,600	4,000	4,400	4,500	4,700	4,900
Projected Total Demand [1]	25,400	42,100	67,200	95,700	104,200	112,500
West Fork Safe Yield	77,000	75,000	73,000	71,000	69,000	67,000
Projected Shortage	--- [2]	--- [2]	--- [2]	24,700	35,200	45,500

1 Projected demand for West Fork water based on annual Fort Worth demand projections prorated to Eagle Mountain WTP based on projected water treatment plant sizes at Holly, Rolling Hills, and Eagle Mountain WTPs.
2 Apparent surplus West Fork water will in actual practice be supplied to Holly WTP as available to decrease Holly's demand for East Texas water.

3.2.2.3 Modeling Tools Developed

In order to evaluate the benefits of new transfer facilities between Lake Benbrook and Eagle Mountain, a tool was needed to simulate possible future operation scenarios for the District's system. A monthly simulation model was developed using the TWDB's river basin simulation model SIMYLD-II[10] (SIMYLD). The simulation period for the model developed is 1941 to 1976 and includes the drought of record in the 1950s. SIMYLD input data includes reservoir area-capacity tables, monthly inflows, monthly net evaporation rates, annual diversions with associated seasonal patterns, and maximum pipeline capacities. SIMYLD uses a prioritization hierarchy to establish which water supply sources will be used first, depending on the hydrologic condition of the system. For the model developed here, the West Fork reservoirs (Lake Bridgeport and Eagle Mountain Lake) were chosen to define the hydrologic condition in the model. When the combined storage in these two reservoirs was greater than 250,000 acft, the priorities were set such that the maximum supply available was supplied from the West Fork reservoirs. Conversely, when the storage in these reservoirs was less than 250,000 acft, priorities for supply from East Texas sources were increased. Input data were developed for sediment conditions in the lakes and system demands equal to 2050 projected conditions. The model also simulates the District's proposed water reuse project to augment reservoir yields at Richland-Chambers Reservoir and Cedar Creek Reservoir, two East Texas reservoirs, as per the analyses performed as part of the District's permitting process for this project.[11]

3.2.2.4 Yield Analyses

Numerous model runs were performed to evaluate the effectiveness of potential connections between the East Texas and West Fork facilities via the utilization of connections between Lake Benbrook and Eagle Mountain Lake. Analyses were performed under 2050 sediment conditions and projected District demands, and the results are discussed below.

In order to simulate the District's complex system with SIMYLD, several assumptions were made regarding operations and facilities. The following is a list of the key modeling assumptions.

1. Fort Worth's 2050 demands were prorated to each of the City's three water treatment plants based on the ratio of a particular water treatment plant's maximum capacity divided by the sum of the maximum capacity at all three plants. The City's WTPs and 2050 capacities include Eagle Mountain WTP (190 MGD), Holly WTP (160 MGD), and Rolling Hills WTP (250 MGD).

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[10] TWDB, "Economic Optimization & Simulation Techniques for Management of Regional Water Resource Systems, River Basin Simulation Model, SIMYLD-II Program Description," July 1972.

[11] R. J. Brandes Company, "Yield Analysis of Trinity River Project," Tarrant Regional Water District, June 1998.

2. The District's proposed reuse project near the East Texas reservoirs was assumed to be in operation and able to provide water to meet all demands on the wetlands assuming maximum diversion rates from the wetlands to the reservoirs of 10,000 acft/month into Richland-Chambers Reservoir and 9,000 acft/month Cedar Creek Reservoir. This is consistent with recent analysis of the District's reuse project.[11]
3. Pipeline capacities from the East Texas reservoirs to demand centers in the West were assumed to be equal to the District's current ultimate facilities plans. A maximum month capacity of 22,770 acft/month (244 MGD) was assumed for Richland-Chambers Reservoir and a maximum month capacity of 18,950 acft/month (203 MGD) was assumed for Cedar Creek Reservoir.
4. Operation of the pipeline connecting Lake Benbrook to the East Texas reservoirs was modeled using a maximum monthly rate of 26,130 acft/month (280 MGD) from East Texas into Benbrook and a rate of 18,660 acft/month (200 MGD) from Lake Benbrook to Rolling Hills WTP.
5. The City of Fort Worth's raw water pipeline from Lake Worth to Holly WTP has a maximum monthly capacity of 14,930 acft/month (160 MGD).
6. The capacity of the Lake Worth to Holly WTP pipeline when pressurized and flowing from Holly to Lake Worth is 11,200 acft/month (120 MGD).

Figure 3-4 shows a schematic of the existing District System as included in the SIMYLD model.

3.2.2.5 Facility Sizes and Capacities – Option 1: Use of Existing City of Ft. Worth Facilities

Option 1 would potentially use the existing 60-inch and 72-inch diameter City of Fort Worth pipelines from Lake Worth to Holly WTP. To supply East Texas water to the West Fork, a new pipeline would be constructed from Lake Benbrook and connected to the existing Fort Worth pipelines. It was determined that an 84-inch diameter pipeline would have approximately the same capacity as the two existing parallel pipelines, or about 190 cfs (123 MGD). Water would flow by gravity from Lake Benbrook (normal wsel 673-ft) to Lake Worth (normal wsel 594-ft).

The Eagle Mountain pump station at the upper end of Lake Worth would need to be modified to pump Lake Worth water to Eagle Mountain Lake at an equivalent rate to the maximum monthly inflow of East Texas water, or about 190 cfs (123 MGD). The static lift would be 55-ft (from elev. 594-ft at Lake Worth to elev. 649-ft at Eagle Mountain).

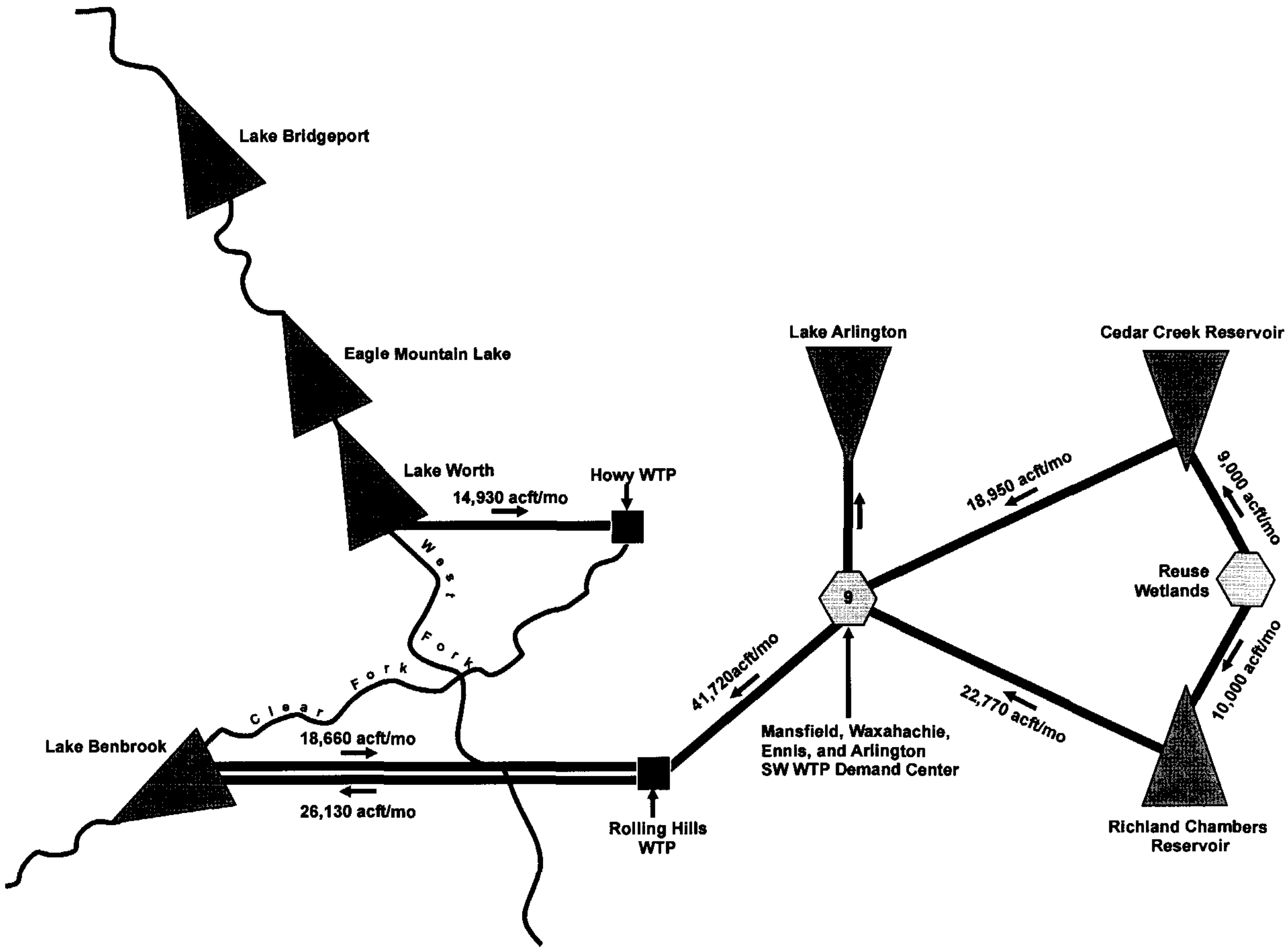

Figure 3-4. Schematic of SIMYLD Model of Tarrant Region Water District System

For use of West Fork excess flows (i.e. spills from Eagle Mountain Lake), a new pump station would be constructed on the West Fork to divert excess flows from the West Fork and pump into the new 84-inch diameter pipeline from Lake Benbrook to Holly WTP. The parallel City of Fort Worth pipelines have an estimated delivery capacity of 245 cfs (160 MGD). Subtracting the lowest monthly demand of the Holly WTP, or about 64 MGD (or 98 cfs), leaves a net availability of approximately 8,950 acft per month (147 cfs, 95 MGD) for pumping to Lake Benbrook. The static lift would be 80-ft (from elev. 594-ft at Lake Worth to elev. 673-ft at Lake Benbrook).

3.2.2.6 Facility Sizes and Pumping Capacities – Option 2: New Pipeline to Eagle Mountain Lake

Option 2 would construct new facilities to enhance the water supply in the West Fork with East Texas water. An intake, pump station, and pipeline would be constructed from Lake Benbrook to Eagle Mountain Lake. Although Eagle Mountain Lake is at a lower elevation than Lake Benbrook, the pipeline route would traverse high ground at about 850 elevation, thereby requiring pumping with a static lift of about 200-ft. The pumping capacity and pipeline would be sized the same as Option 1 facilities (i.e., 84-inch diameter with 190 cfs (123 MGD) capacity).

For use of West Fork excess flows (i.e., spills from Eagle Mountain Lake), a pump station would be constructed at Eagle Mountain Lake to divert excess flows from the West Fork and pump into the new 84-inch diameter pipeline. The static lift would be about 200-ft (from elev. 649-ft at Eagle Mountain Lake to elev. 850-ft at the ridge between the West Fork and the Clear Fork).

3.2.2.7 Summary of System Operation

The annual average volumes pumped under Options 1 and 2 are presented in Tables 3-9 and 3-10, respectively. The drought annual average period, 1948 through 1957, corresponds to the drought of record for Richland-Chambers Reservoir. Richland-Chambers Reservoir has the longest record drought sequence of all the District's reservoirs. As shown in Tables 3-9 and 3-10, the average pumpage from East Texas under either option is approximately equal in both the long-term annual average and during the drought (approximately 0.5 percent difference or less). Likewise, under both options, 2050 demands are met. Under Option 2, the long-term

Table 3-9.
Summary of System Operation[1] Utilizing Existing Connections between Lake Benbrook and Eagle Mountain Lake (Option 1)
2050 Sediment Conditions

	Long-Term Period (1941 to 1976)	Drought Period (1948 to 1957)
Average Annual Pumpage from East Texas System[2]	346,024 acft/yr	392,434 acft/yr
Average Annual East Texas Water Pumped to West Fork System[3]	34,704 acft/yr	52,916 acft/yr
Maximum Monthly Pumpage from Lake Benbrook to West Fork System	-------	11,200 acft
Maximum Monthly Pumpage from West Fork System to Lake Benbrook[4]	-------	8,949 acft

1 Target elevations at Eagle Mountain Lake and Lake Worth set at 0-ft drawdown (i.e., reservoir full target).
2 Based on 2050 projected demands and current East Texas System pipeline expansions to 203 MGD from Cedar Creek Reservoir (147 MGD existing pipeline at high capacity and 56 MGD expansion for reuse) and 244 MGD from Richland-Chambers Reservoir (existing pipeline at high capacity including reuse).
3 Pumpage between Lake Benbrook and the West Fork System via the City of Fort Worth's existing pipelines between Lake Worth and Holly WTP.
4 Pumpage from Holly WTP to Lake Benbrook via proposed new 72-inch pipeline.

Table 3-10.
Summary of System Operation[1] Utilizing a New Pipeline between Lake Benbrook and Eagle Mountain Lake (Option 2)
2050 Sediment Conditions

	Long-Term Period (1941-76)	Drought Period (1948-57)
Average Annual Pumpage from East Texas System[2]	343,912 acft/yr	393,234 acft/yr
Average Annual East Texas Water Pumped to West Fork System[3]	38,164 acft/yr	56,227 acft/yr
Maximum Monthly Pumpage from Lake Benbrook to West Fork System[4]	-------	11,600 acft
Maximum Monthly Pumpage from West Fork System to Lake Benbrook[4]	-------	11,600 acft

1 Target elevations at Eagle Mountain Lake and Lake Worth set at 0-ft drawdown (i.e., reservoir full target).
2 Based on 2050 projected demands and current East Texas System pipeline expansions to 203 MGD from Cedar Creek Reservoir (147 MGD existing pipeline at high capacity and 56 MGD expansion for reuse) and 244 MGD from Richland-Chambers Reservoir (existing pipeline at high capacity including reuse).
3 Pumpage between Lake Benbrook and Eagle Mountain Lake via proposed 108-inch pipeline between the reservoirs.
4 Maximum pipeline capacity based on a 84-inch diameter pipe flowing at 5 feet per second.

annual and drought annual average pumpage of East Texas water into the West Fork System is approximately 10 percent higher than under Option 1, which uses existing facilities. Lake levels in Eagle Mountain Lake were about the same under either option.

In the initial system model, the target water surface elevations in the District's West Fork reservoirs were all set at maximum capacity. In other words, for each month of operation, the SIMYLD computer model attempted to maintain full reservoirs in the West Fork, subject to the physical constraints of the system (e.g., pipeline capacities, hydrology, demands, etc.). A second set of model runs were computed assuming Lake Worth and Eagle Mountain Lake were allowed to draw down a small amount during normal operations. In the model runs described below, Eagle Mountain Lake was allowed to draw down to a target elevation 3 feet below conservation storage. In addition, Lake Worth was drawn down to an operating target elevation 1 foot below conservation storage. These operation practices follow the reservoir operating policies of the District and maintain higher water surface elevations in Lake Bridgeport during normal and wet years. In addition to lowering the target storages in Lake Worth and Eagle Mountain Lake, the water supply priorities in the SIMYLD model were also changed in the modeling runs discussed below to make Eagle Mountain Lake and Lake Worth more dependent on East Texas Water and less dependent on Lake Bridgeport.

In addition to lowering the storage targets at Eagle Mountain Lake and Lake Worth and adjusting the water supply priorities in the West Fork, the alternative set of runs (referred to as the alternative operations analysis) included higher reservoir level targets in Lake Benbrook. In these runs, Lake Benbrook's operating storage range was changed to conservation storage down to 5 feet of drawdown. Previous model runs included drawdowns to 10 feet below conservation storage.

All other modeling assumptions regarding pipelines and alternative connections between Lake Benbrook and the West Fork remained the same. The results of the alternative operations analysis are presented in Tables 3-11 and 3-12 for West Fork Options 1 and 2, respectively. The results under 2050 sediment conditions and demands and alternative operations shown in Tables 3-11 and 3-12 differ significantly from their counterparts in Tables 3-9 and 3-10. During long-term average periods, the East Texas pipelines pump approximately 10,000 acft/yr less under the alternative operations. However, during the drought, under original operations or alternative operations, the pumpage from East Texas is about the same. The long-term smaller volume pumped under alternative operations is believed to be a result of less volume needed to keep the reservoirs (Lake Worth and Eagle Mountain Lake) full and less need to overcome evaporation. Since the lakes are being maintained at a lower elevation and thus a smaller surface area, losses to evaporation are not as high. During the drought, however, the differences between pumpages are smaller because reservoir operations are essentially the same during drought (i.e., few storage targets are met).

Average annual pumpages to the West Fork from Lake Benbrook under alternative operations, however, are about 7,000 acft/yr higher than under original operations. This is due in part to two factors. First, the operation range over which Lake Benbrook is operated in the alternative operations analysis is significantly smaller than in the original analysis. Thus, there is less terminal storage in Lake Benbrook, meaning water pumped into Lake Benbrook from East Texas, must be pumped on through to the West Fork. In addition, the lowering of targets in Lake Worth and Eagle Mountain Lake, and the change in water supply source priorities (i.e., making East Texas Water pumped to Eagle Mountain Lake is preferable to drawing from Lake Bridgeport) causes the simulation model to leave more water in Bridgeport and thus pump more from Lake Benbrook to Eagle Mountain Lake (Option 2) or Lake Worth (Option 1).

3.2.2.8 Effect on Lake Levels

The following section compares and contrasts end-of-month storages in Lake Benbrook, Lake Bridgeport, Eagle Mountain Lake, Lake Worth, and Lake Arlington, with and without the pipeline connections between Lake Benbrook and the West Fork System and under original and alternative operations (as detailed in the previous section).

Figures 3-5 through 3-9 show end-of-month storages for original operations (i.e., storage targets in Lake Worth and Eagle Mountain Lake equal to full conservation storage). As shown in Figure 3-5, Lake Benbrook storage shows wide seasonal variations due to pumping into and out of the reservoir, and with the pipeline connection to the West Fork System, storage is heavily depleted during the 1948-57 drought period. Similarly, on Eagle Mountain Lake the storage during the drought is depleted almost as much as without the pipeline (Figure 3-7, however, in the simulation without the pipeline, there are a series of months during the drought when the

Table 3-11.
Alternative Operations Analysis[1]
Summary of System Operation Utilizing Existing Connections between Lake Benbrook and Eagle Mountain Lake (Option 1)
2050 Sediment Conditions

	Long-Term Period (1941 to 1976)	Drought Period (1948 to 1957)
Average Annual Pumpage from East Texas System[2]	337,831 acft/yr	391,927 acft/yr
Average Annual East Texas Water Pumped to West Fork System[3]	40,914 acft/yr	57,791 acft/yr
Maximum Monthly Pumpage from Lake Benbrook to West Fork System	-------	11,200 acft
Maximum Monthly Pumpage from West Fork System to Lake Benbrook[4]	------	8,949 acft

1 Target elevations at Eagle Mountain Lake and Lake Worth set 3 ft and 1 ft below conservation storage, respectively.
2 Based on 2050 projected demands and current East Texas System pipeline expansions to 203 MGD from Cedar Creek Reservoir (147 MGD existing pipeline at high capacity and 56 MGD expansion for reuse) and 244 MGD from Richland-Chambers Reservoir (existing pipeline at high capacity including reuse).
3 Pumpage between Lake Benbrook and the West Fork System via the City of Fort Worth's existing pipelines between Lake Worth and Holly WTP.
4 Pumpage from Holly WTP to Lake Benbrook via proposed new 72-inch pipeline.

Table 3-12.
Alternative Operations Analysis[1]
Summary of System Operation Utilizing a New Pipeline between Lake Benbrook and Eagle Mountain Lake (Option 2)
2050 Sediment Conditions

	Long-Term Period (1941-76)	Drought Period (1948-57)
Average Annual Pumpage from East Texas System[2]	332,839 acft/yr	388,980 acft/yr
Average Annual East Texas Water Pumped to West Fork System[3]	45,859 acft/yr	60,918 acft/yr
Maximum Monthly Pumpage from Lake Benbrook to West Fork System[4]	-------	11,600 acft
Maximum Monthly Pumpage from West Fork System to Lake Benbrook[4]	-------	11,600 acft

1 Target elevations at Eagle Mountain Lake and Lake Worth set 3 ft and 1 ft below conservation storage, respectively.
2 Based on 2050 projected demands and current East Texas System pipeline expansions to 203 MGD from Cedar Creek Reservoir (147 MGD existing pipeline at high capacity and 56 MGD expansion for reuse) and 244 MGD from Richland-Chambers Reservoir (existing pipeline at high capacity including reuse).
3 Pumpage between Lake Benbrook and Eagle Mountain Lake via proposed 84-inch pipeline between the reservoirs.
4 Maximum pipeline capacity based on a 84-inch diameter pipe flowing at 5 feet per second.

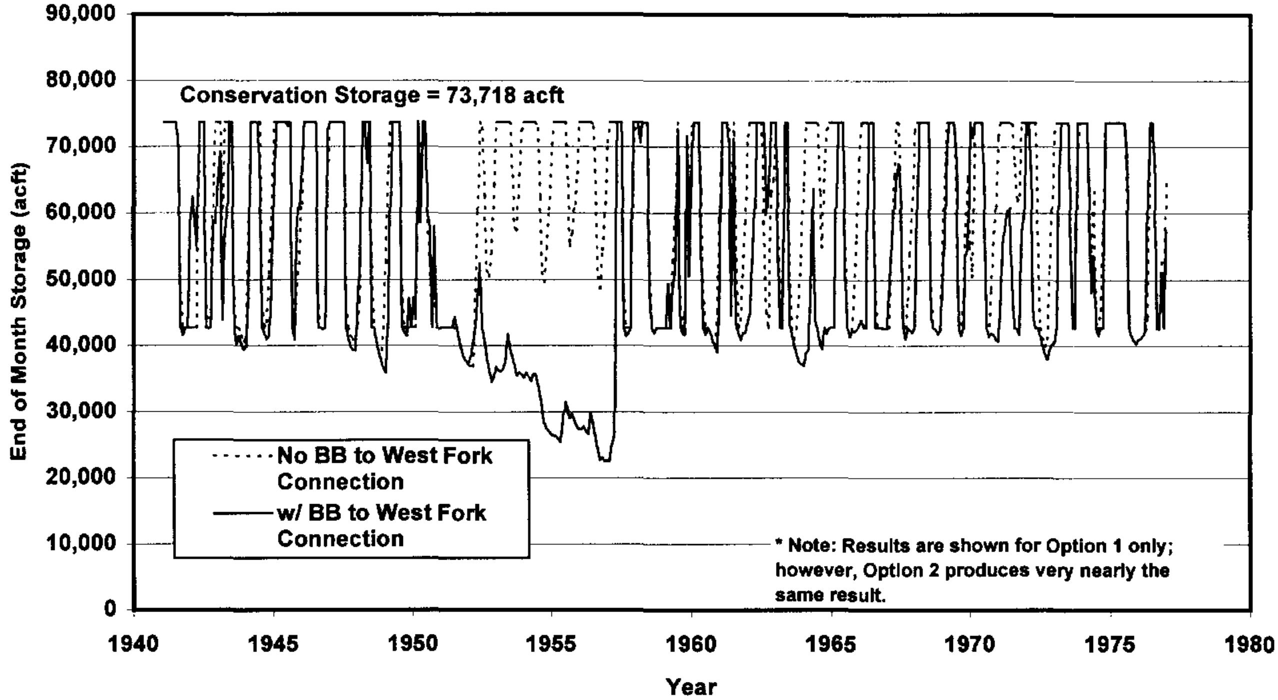

Figure 3-5. Comparison of Simulated Storage in Lake Benbrook with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Original Operations

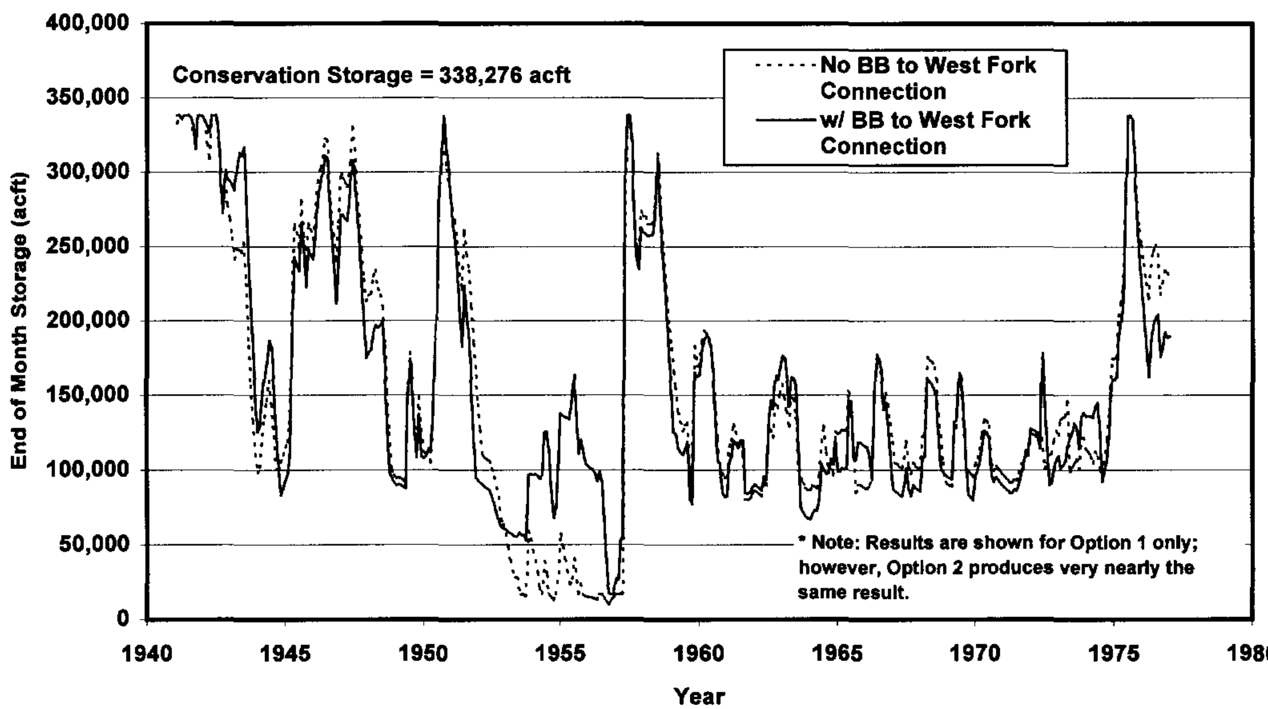

Figure 3-6. Comparison of Simulated Storage in Lake Bridgeport with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Original Operations

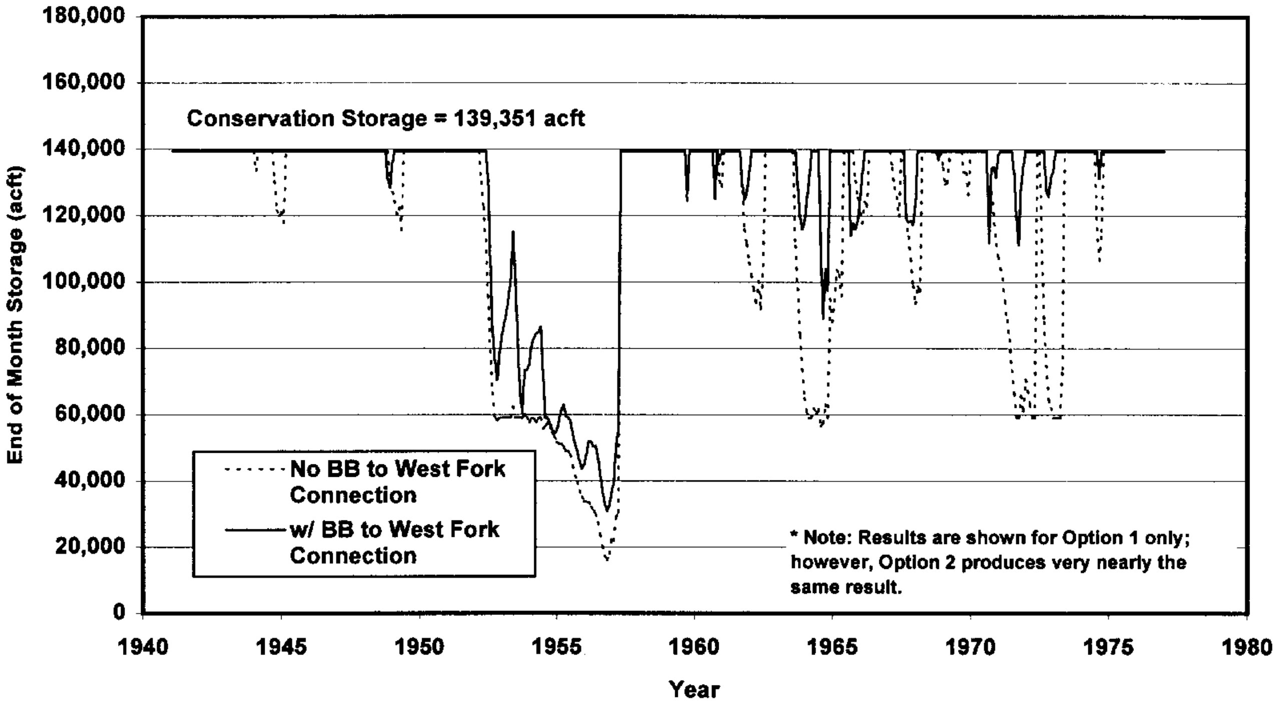

Figure 3-7. Comparison of Simulated Storage in Eagle Mountain Lake with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Original Operations

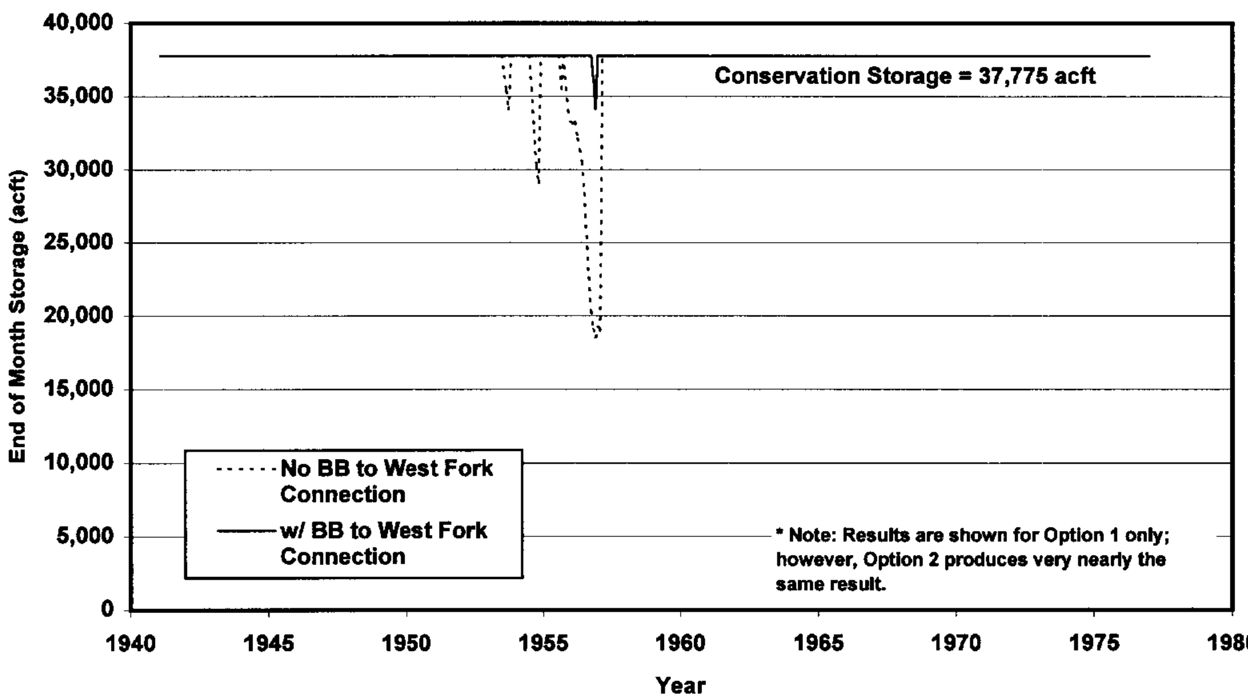

Figure 3-8. Comparison of Simulated Storage in Lake Worth with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Original Operations

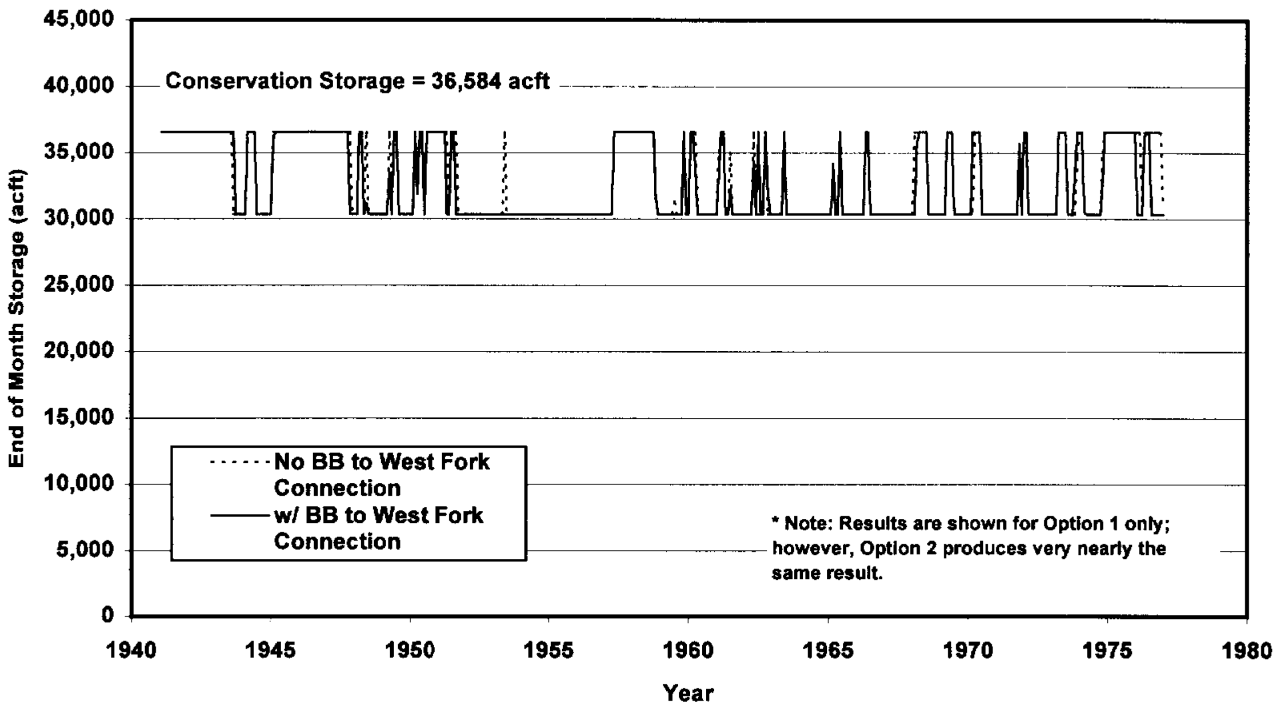

Figure 3-9. Comparison of Simulated Storage in Lake Arlington with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Original Operations

demands from Eagle Mountain Lake are not met and severe shortages are encountered. On Lake Bridgeport, the severity of the drought in the worst year (1956) is not diminished significantly (Figure 3-6). However, in the years leading up to the driest year (1953-55) Lake Bridgeport storage is significantly higher and shortages that occur in the run with no connection between Lake Benbrook and the West Fork are completely mitigated. Demand conditions are the same for the two reservoir end-of-month storage traces in Figures 3-6 and 3-7. However, for the no pipeline condition, a total of 173,631 acft of shortages occur in 1953, 1954, 1955, 1956, and 1957 at Lake Bridgeport and Eagle Mountain Lake. In contrast under either Option 1 or 2, all demands throughout the District's system are met under either option. In addition, during the mid-1960s and early 1970s, the impact of short drought periods are less severe as evidenced in the higher end-of-month storage volumes with the pipeline connection between Lake Benbrook and the West Fork. Figures 3-8 and 3-9 show similar end-of-month storage traces for Lake Worth and Lake Arlington. Table 3-13 shows a summary of median lake levels, with and without the pipelines connecting Lake Benbrook to the West Fork Reservoirs.

Table 3-13.
Effect of West Fork Supply Enhancement on Lake Levels[1]

	Median Lake Level	
	without Project (ft-msl)	with Project[2] (ft-msl)
Lake Benbrook	691.0	684.0
Lake Bridgeport	813.6	813.8
Eagle Mountain Lake	649.0	649.0
Lake Worth	594.2	594.2
Lake Arlington	546.9	546.9

1 Based on simulations assuming 2050 sediment conditions, 2050 demands, and original operations.
2 Median Levels presented are for Option 1 and are similar to Option 2 results.

Figures 3-10 through 3-14 show end-of-month storages for alternative operations analysis (i.e., lowered storage targets and adjustments to priorities in Lake Worth and Eagle Mountain Lake). As discussed with the previous graphs, Lake Benbrook is highly variable with the season, although the range of storage over which Lake Benbrook oscillates is narrower under alternative operations. As before, in the no project run, there are large shortages throughout the West Fork system in 1953, 1954, 1955, 1956, and 1957. Lake Arlington is essentially the same as with the original operation runs and Lake Work is primarily the same with the obvious difference being the storage target 1 foot below conservation storage.

The two major differences between the original operation runs and the alternative operations runs are at Eagle Mountain Lake and Lake Bridgeport. Because of the lower storage target at Eagle Mountain Lake and change in priority for supply from East Texas instead of Lake Bridgeport, Lake Bridgeport contains considerably more water in 1952-1955 than under original operations. Likewise, Eagle Mountain Lake reacts more like it does without the pipelines between Lake Benbrook and the West Fork and is highly variable over the simulation period. Table 3-14 shows a summary of median lake levels, with and without pipelines between Lake Benbrook and the West Fork for the alternative operations.

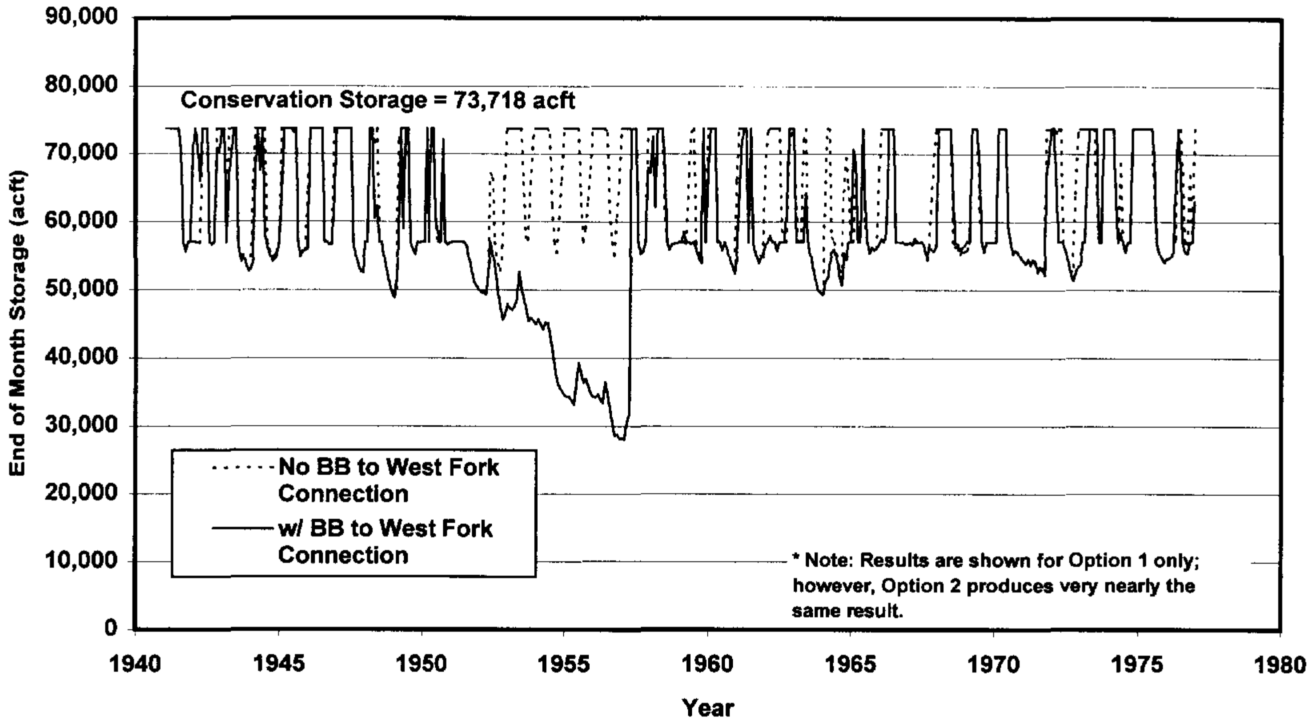

Figure 3-10. Comparison of Simulated Storage in Lake Benbrook with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Alternative Operations

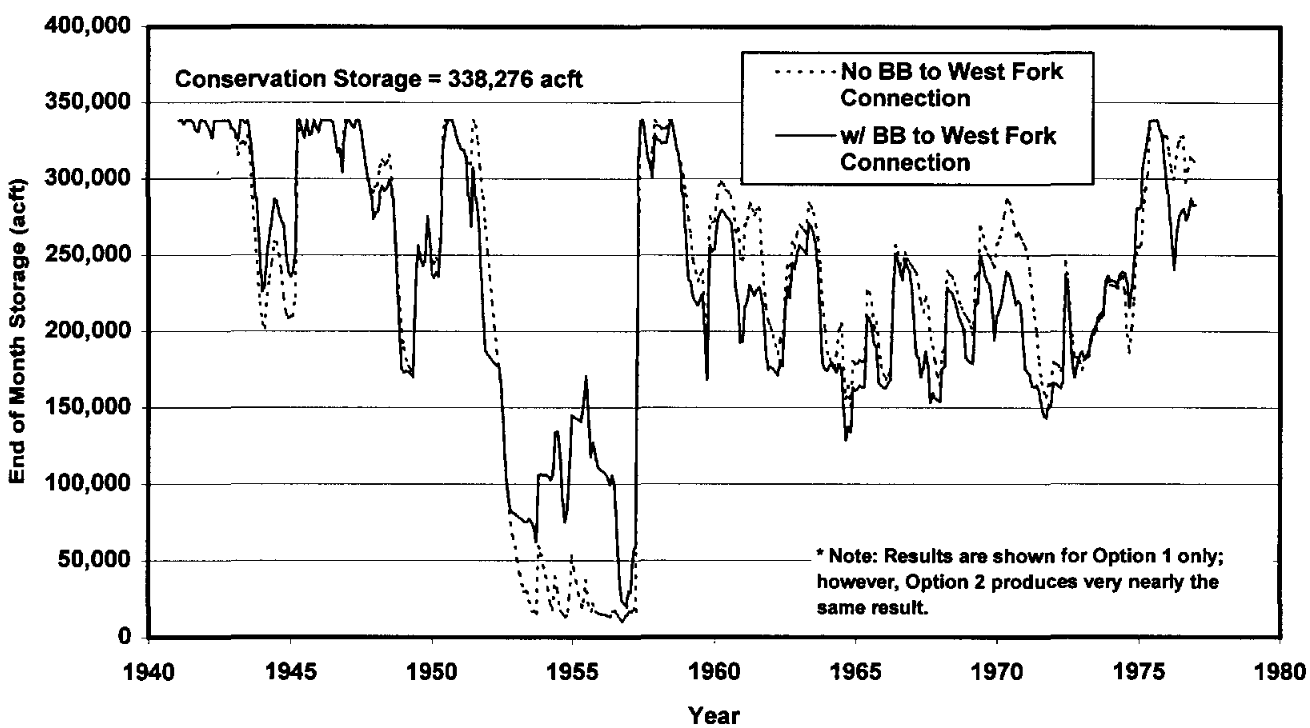

Figure 3-11. Comparison of Simulated Storage in Lake Bridgeport with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Alternative Operations

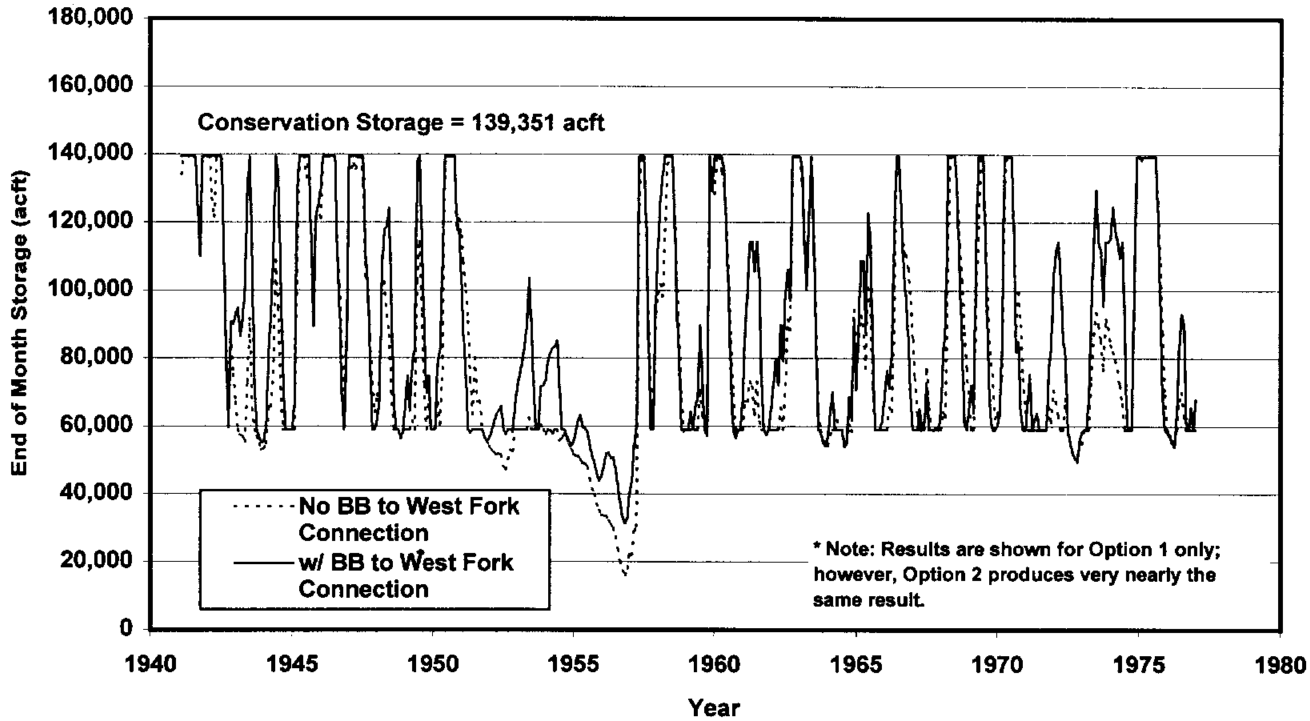

Figure 3-12. Comparison of Simulated Storage in Eagle Mountain Lake with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Alternative Operations

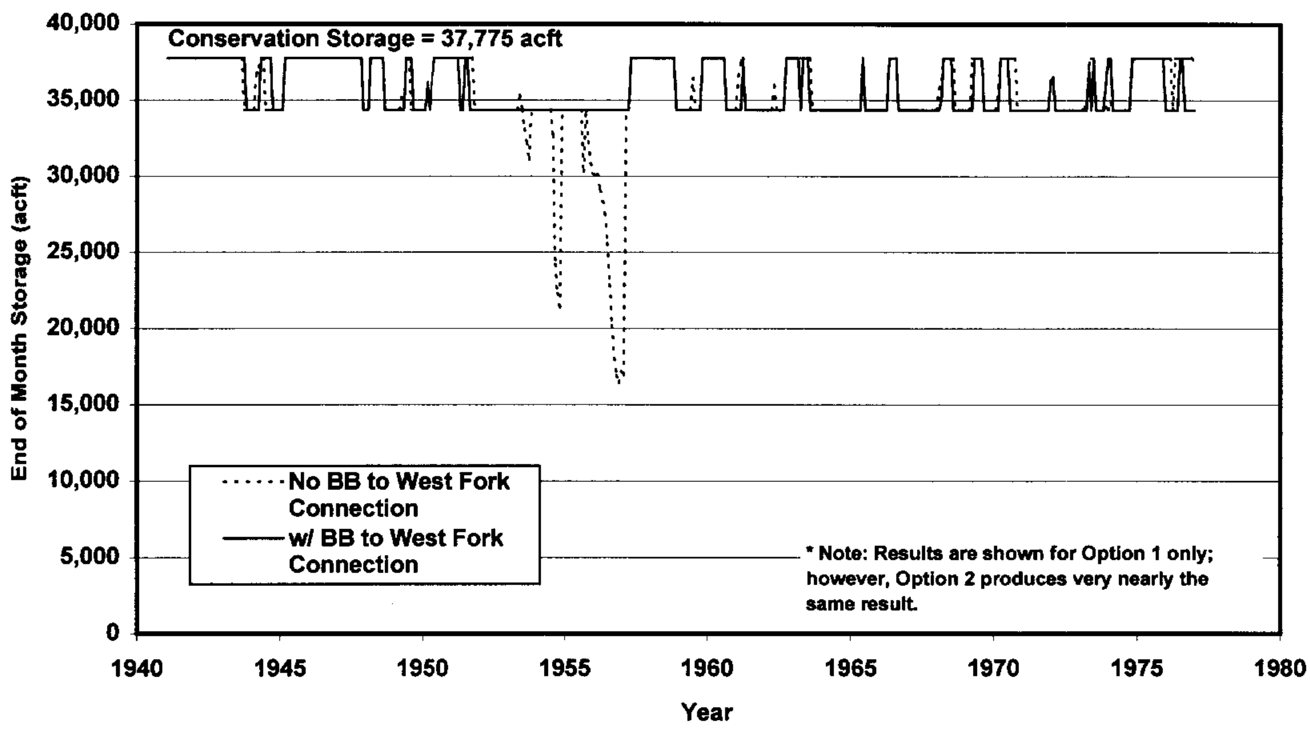

Figure 3-13. Comparison of Simulated Storage in Lake Worth with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Alternative Operations

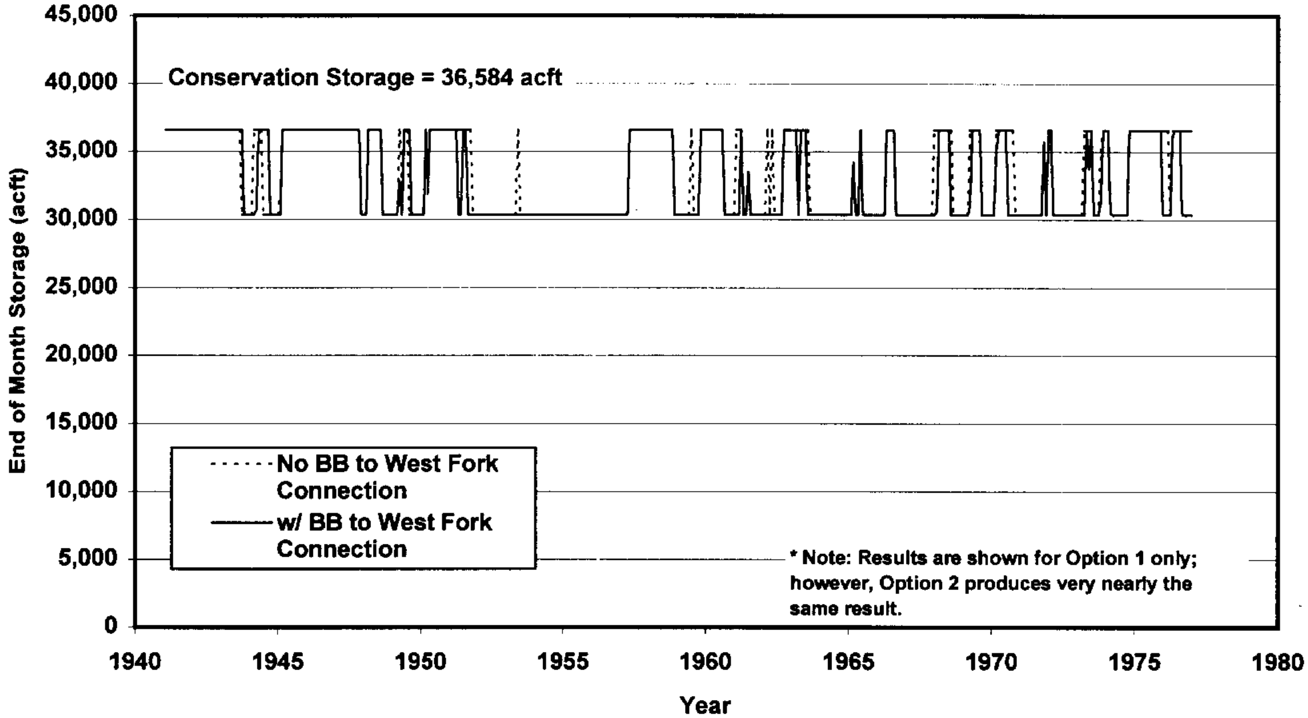

Figure 3-14. Comparison of Simulated Storage in Lake Arlington with and without a Pipeline Connection between Lake Benbrook and the West Fork under 2050 Demands, 2050 Sediment Conditions, and Alternative Operations

Table 3-14. Effect of West Fork Supply Enhancement on Lake Levels[1]

	Median Lake Level	
	without Project (ft-msl)	*with Project[2] (ft-msl)*
Lake Benbrook	688.6	687.7
Lake Bridgeport	827.8	826.4[3]
Eagle Mountain Lake	639.2	641.3
Lake Worth	593.2	593.2
Lake Arlington	546.9	546.9

1 Based on simulations assuming 2050 sediment conditions, 2050 demands, and original operations.
2 Median Levels presented are for Option 1 and are similar to Option 2 results (±0.5 ft).
3 Option 2 median lake storage at Lake Bridgeport is 825.0 ft-msl.

3.2.2.9 Estimated Costs

The estimated costs of the facilities needed to enhance the water supply of the West Fork are listed in Table 3-15.

Table 3-15.
Estimated Costs of West Fork Supply Enhancements

Component	Capacity and Size	Estimated Cost[1]
Option 1 – Use of Existing Facilities		
Pipeline from Lake Benbrook to existing Ft. Worth pipelines, including intake, pipeline, and connection to existing pipelines(1)	84-in dia. 190 cfs 62,300 ft	$38,690,000
Rehabilitate existing 60-inch and 72-inch Ft. Worth pipelines	60-in dia. 72-in dia. 27,000 ft	3,460,000
Pump station expansion at Eagle Mountain Lake, including discharge pipeline	190 cfs 1500 ft 3100 hp	5,390,000
Pump station at Holly WTP to Lake Benbrook to pump excess West Fork flows to Lake Benbrook	147 cfs 3600 hp	5,800,000
Total		$53,340,000
Option 2 – New Pipeline to Eagle Mountain Lake		
Intake and pump station at Lake Benbrook and pipeline to Eagle Mountain Lake	84-in dia. 190 cfs 115,500 ft 7400 hp	$69,840,000
Pump station at Eagle Mountain Lake to pump excess West Fork flows to Lake Benbrook	84-in dia. 147 cfs	6,380,000
Total		$76,220,000

1 Pump station on Clear Fork could be substituted for 84-in gravity line. Pump station cost estimated to be $7,400,000, resulting in cost savings of $37,090,000. Total cost for Option 1 would be $16,250,000 if 84-in gravity pipeline is not built.

3.2.2.10 Implementation Issues

Implementation pros and cons associated with each alternative are enumerated below.

Option 1 **Use of primarily existing facilities**	
Pros	***Cons***
• Uses existing facilities to minimize new construction. • Less long-term annual and drought annual average pumpage to West Fork System (potentially lower pumping costs). • Allows better utilization of District's East Texas pipelines and reduce power costs.	• District is dependent on old facilities (completed as early as 1928) it does not own (i.e. pipeline from Holly WTP to Lake Worth).

Option 2 **Use of primarily new facilities**	
Pros	***Cons***
• District owns and operates its own facilities minimizing coordination with the City of Fort Worth. • Allows better utilization of District's East Texas pipelines and reduce power costs. • Less long-term annual and drought annual average pumpage to West Fork System (potentially lower pumping costs).	• Potential new pipeline routes include some developed areas. • New facilities potentially more expensive than under Option 1. • Requires additional pumping costs to lift water over ridge between reservoirs.

3.2.3 Potential Water Supplies from Other Sources

Water supply options for the District exist from sources both in the Trinity River Basin and outside of the basin. Implementation of options outside the Trinity River Basin would require an interbasin transfer. There are currently more than 80 interbasin transfers in place in Texas that supply water for municipal and industrial use. Cities where interbasin transfers occur include Amarillo, Lubbock, Dallas, Houston, Galveston, Corpus Christi, Beaumont, Texarkana, Tyler, much of the Lower Rio Grande Valley, and other smaller communities. Abilene, Longview, Irving, and Victoria, among others, have approved interbasin transfer permits.

Potential water supply sources for the District from other sources include:

- Lake Texoma (Red River Basin);
- Lake Granbury (Brazos River Basin);
- Lake Palestine (Neches River Basin);
- Marvin Nichols Reservoir - Phase I (Sulphur River Basin);
- George Parkhouse Reservoir - Phase I (Sulphur River Basin); and
- Tehuacana Reservoir (Trinity River Basin).

3.2.3.1 Lake Texoma (Red River Basin)

Lake Texoma is located on the Red River in Grayson County, about 90 miles north of Fort Worth (Figure 3-15). Lake Texoma is owned and operated by the U.S. Army Corps of Engineers. The project was completed in 1944 and its permitted purposes include water supply, flood control, hydropower, recreation, and navigation. The top of the conservation pool is elevation 617-ft. Under the terms of the Red River Compact, yield of the lake is to be split equally between Oklahoma and Texas. Permitted annual diversion for municipal and industrial use in Texas is 147,500 acft. The Corps has water sale contracts in place[12] with TU Electric, Red River Authority, and North Texas Municipal Water District for about 115,000 acft/yr. A portion of the storage pool in Lake Texoma is dedicated to hydropower generation and the possibility exists to reallocate this storage to municipal water supply. The 1997 State Water Plan contains a recommended project to reallocate some of the storage in Lake Texoma from hydropower to municipal use. The reallocation project as recommended would increase the supply available for municipal use by 72,500 acft/yr, for a total supply of 220,000 acft/yr. Of this amount, up to 105,000 acft/yr is potentially available for acquisition.

Facilities needed to utilize water from Lake Texoma would include:

- Raw water intake and pump station at Lake Texoma;
- Raw water transmission pipeline to Tarrant County (probable discharge would be into Eagle Mountain Lake);
- Booster pump station(s);
- Discharge outfall; and
- Water treatment plant capacity expansion

Cost estimates for implementation of this supply source have not been performed.

[12] U.S. Army Corps of Engineers, "Water Resources Development in Texas," 1991.

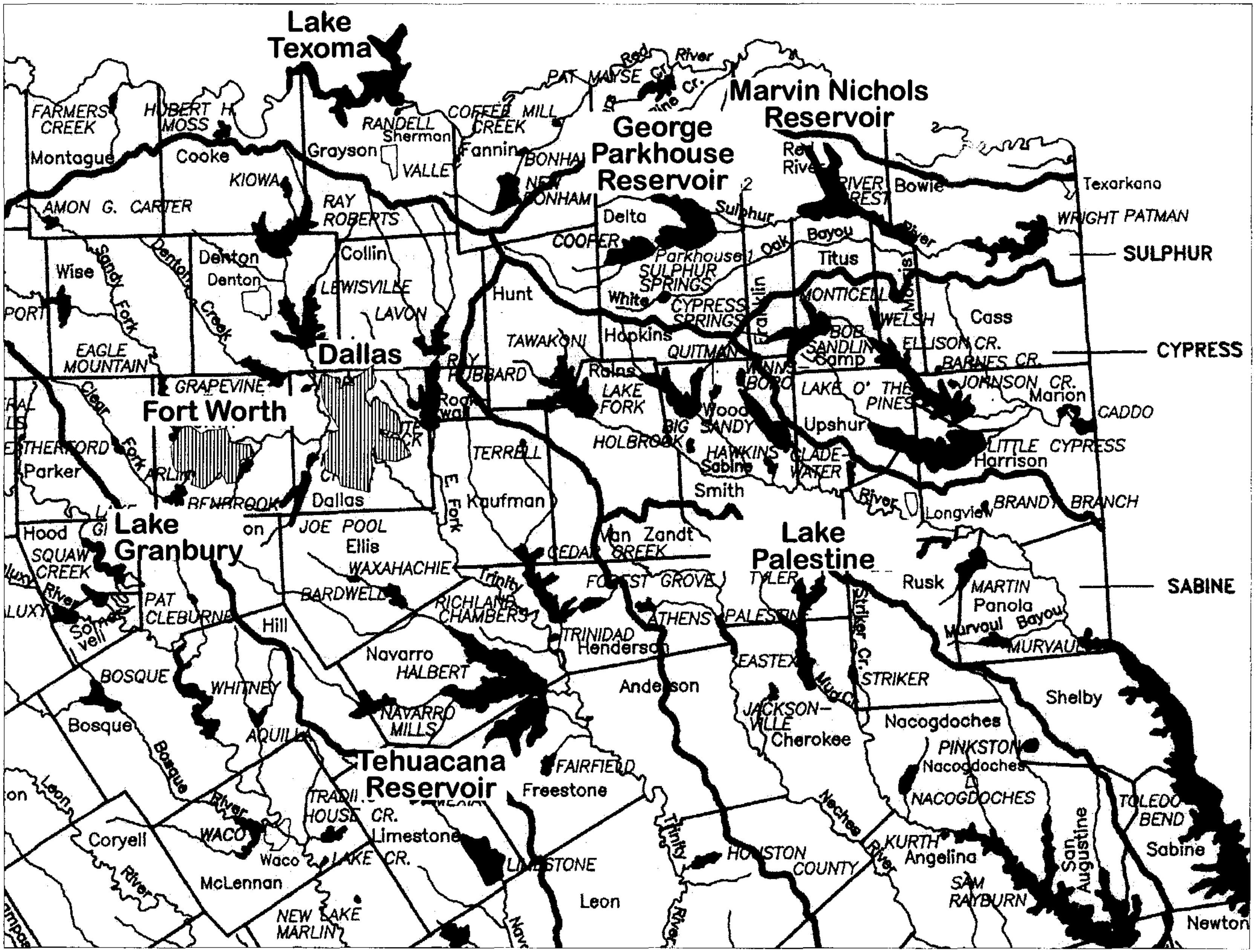

Figure 3-15. Potential Sources for Interbasin Supply

Implementation issues associated with this supply source include:

- Reallocation of storage from hydropower use to municipal use as well as additional diversions would require approval by the Corps of Engineers and TNRCC;
- Interbasin transfer permit from TNRCC would be needed;
- Water sale contract from Corps of Engineers would need to be negotiated; and
- Water quality of Lake Texoma is poor for municipal use, due to high dissolved mineral content; blending with higher quality water would be needed, or expensive treatment plants (e.g., reverse osmosis) needed to be constructed.

3.2.3.2 Lake Granbury (Brazos River Basin)

Lake Granbury is owned and operated by the Brazos River Authority (BRA) and is located on the Brazos River in Hood County (Figure 3-15). Lake Granbury is operated as part of the BRA system and currently there is 21,028 acft/yr available for purchase from BRA for delivery at Lake Granbury. However, BRA has requests from municipalities to purchase more than 36,000 acft/yr. Approval of the water purchase requests is contingent on meeting the terms of the BRA water sale criteria and Board of Directors action. It is likely that all remaining water in this part of the BRA system will be committed in the near future and no further consideration is warranted of Lake Granbury as a supply source for the District.

3.2.3.3 Lake Palestine (Neches River Basin)

Lake Palestine is owned and operated by the Upper Neches River Municipal Water Authority and is located on the Neches River between Smith and Henderson counties (Figure 3-15). The reservoir is about 40 miles southeast of Cedar Creek Reservoir. The top of the conservation pool is elevation 345-ft. The cities of Dallas, Tyler, and Palestine have contracted for the entire permitted yield of the project, which is 238,110 acft/yr.

The potential exists for Dallas Water Utilities (DWU) to cooperate with the District in development of a project to bring water from Lake Palestine to the Dallas/Fort Worth metroplex. The District could make surplus water available to DWU on an interim basis from Cedar Creek Reservoir, delivered through the existing District pipeline, to help meet a portion of DWU's water needs in southwest Dallas County. In the long term, this water will be needed by the District's customers and could be replaced with water obtained from Lake Palestine delivered to Cedar Creek Reservoir via a future 35-mile pipeline. At that point in time, the District may choose to meet its needs by purchasing a portion of the Lake Palestine water. The 35-mile pipeline from Lake Palestine to Cedar Creek Reservoir could potentially eliminate and/or significantly delay construction of an 80-mile pipeline which would be needed by DWU to deliver water from Lake Palestine to Dallas for DWU use only. DWU has purchased[13] 114,337 acft of the yield of Lake Palestine, and some or all of this water could be available for use by the District on an interim or permanent basis. With cooperative effort, a joint use pipeline could ultimately be built to deliver Lake Palestine water to Lake Joe Pool for DWU use and to Fort Worth for District use.

Facilities needed for TRWD to utilize water from Lake Palestine would include:

- Raw water intake and pump station at Lake Palestine;
- Raw water transmission pipeline to Cedar Creek Reservoir;
- Discharge outfall;
- Expansion of the Cedar Creek raw water intake and pump station; and
- A second Cedar Creek pipeline and associated booster pump stations.

Cost estimates for implementation of this supply source for TRWD have not been performed. However, cost estimates have been performed by others[14] for the proposed pipeline from Lake Palestine to Dallas. In 1998 dollars, the estimated cost of the conveyance facilities for DWU alone is $211,450,000.

Implementation issues associated with this supply source include:

- Interbasin transfer permit from TNRCC would be needed;
- Negotiation of water sale on interim or permanent basis with DWU would be needed; and
- Approval of the Upper Neches River Municipal Water Authority would be required.

3.2.3.4 Marvin Nichols I Reservoir (Sulphur River Basin)

The 1997 Texas Water Plan[15] recommends two new water supply projects be built in the Sulphur River Basin, Marvin Nichols I Reservoir, and George Parkhouse II Reservoir. These

[13] F&N and APAI, Op. Cit., 1990.
[14] Turner Collie & Braden, 1989.
[15] TWDB, "Water for Texas," August 1997.

projects could be used to meet local needs as well as the needs of the Fort Worth area and perhaps the Dallas area as well.

The Marvin Nichols I project would be located on the Sulphur River in Red River, Morris, and Titus counties and is about 160 miles northeast of Tarrant County (Figure 3-15). (Note: Marvin Nichols II reservoir would be a project adjacent to Nichols I, but on White Oak Creek.) The Nichols I project is downstream of the Parkhouse II site and the yield of the Nichols I project would be lower if built after Parkhouse II. The Nichols I project yield, without Parkhouse II being constructed would have a yield[16] of 560,151 acft/yr. If Parkhouse II is constructed first, then Nichols I would have a yield of 470,413 acft/yr.

Facilities needed for TRWD to utilize water from Marvin Nichols I reservoir would include:

- Dam and reservoir;
- Raw water intake and pump station;
- Raw water transmission pipeline and booster pump stations; and
- Discharge outfall (probably at Eagle Mountain Lake or Lake Worth).

The estimated cost[17] of Marvin Nichols I Reservoir is $344,150,000 in 1998 dollars. Cost estimates for the conveyance facilities to deliver raw water to the District have not been performed.

Implementation issues associated with this supply source include:

- Permit acquisition for this major new reservoir will require addressing several significant environmental issues, these issues include instream flows and inundation of bottomland hardwoods and associated habitat;
- Interbasin transfer permit from TNRCC would be needed; and
- A project of this magnitude would require a joint effort of several water supply entities to acquire permits and funding.

3.2.3.5 George Parkhouse Reservoir II (Sulphur River Basin)

The George Parkhouse II reservoir project is the other of the two water supply projects in the Sulphur River Basin recommended in the 1997 State Water Plan.[18] The Parkhouse II project

[16] Ibid.
[17] F&N and APAI, Op. Cit., 1990.
[18] TWDB, Op. Cit., August 1997.

would be located on the North Fork of the Sulphur River in Lamar and Delta counties and is about 115 miles northeast of Tarrant County (Figure 3-15). (Note: the George Parkhouse I reservoir project would be on the South Fork of the Sulphur River.) The yield of the Parkhouse II project would be 134,232 acft/yr.[19]

Facilities needed for TRWD to utilize water from George Parkhouse II reservoir would include:

- Dam and reservoir;
- Raw water intake and pump station;
- Raw water transmission pipeline and booster pump stations; and
- Discharge outfall (probably at Eagle Mountain Lake or Lake Worth).

The estimated cost[20] of George Parkhouse II Reservoir is $130,440,000 in 1998 dollars. Cost estimates for conveyance facilities to deliver raw water to the District have not been performed, however, previous studies[21] have estimated the cost of conveyance facilities to Dallas of about $209,000,000.

Implementation issues associated with this supply source include:

- Permit acquisition for this major new reservoir will require addressing several significant environmental issues, these issues include instream flows and inundation of bottomland hardwoods and associated habitat; and
- Interbasin transfer permit from TNRCC would be needed.

3.2.3.6 Tehuacana Reservoir (Trinity River Basin)

The 1997 Texas Water Plan[22] recommends that Tehuacana Reservoir be constructed and this project is the only recommended water supply reservoir in the upper Trinity River Basin. Tehuacana Reservoir would be located on Tehuacana Creek in Freestone County and is immediately south of Richland-Chambers Reservoir (Figure 3-15). The reservoir is planned to be interconnected with Richland-Chambers Reservoir by an open channel to allow water from Tehuacana to flow into Richland-Chambers. This project has been a part of the District's water

[19] Ibid.
[20] F&N and APAI, Op. Cit., 1990.
[21] Turner Collie & Braden, Inc., 1989.
[22] TWDB, Op. Cit., August 1997.

supply planning since it was first proposed[23] in the 1950's. Yield available from the project would be 65,547 acft/yr[24]. This project could also be developed in conjunction with the Trinity River Reuse project (see Section 3.2.1) which would increase the yield available from the reservoir.

Facilities needed for TRWD to utilize water from Tehuacana Reservoir would include:

- Dam and reservoir;
- Open channel to connect Tehuacana to Richland-Chambers Reservoir;
- Expansion of the raw water pump station at Richland-Chambers Reservoir; and
- Construction of a second raw water transmission pipeline from Richland-Chambers Reservoir to Tarrant County and associated booster pump stations.

The estimated cost[25] of Tehuacana Reservoir is $161,217,000 in 1998 dollars and the cost estimates for the conveyance facilities to deliver raw water to the District is $196,000,000, also in 1998 dollars.

Implementation issues associated with this supply source include:

- Permit acquisition for this new reservoir would require addressing several significant environmental issues, these issues include instream flows and inundation of bottomland hardwoods and associated habitat.

3.2.3.7 Summary Table

Table 3-16 summarizes information for potential water supplies from other sources.

3.2.4 Systems Operation of East Texas Reservoirs

As demands for the District's water continue to grow, the demand for East Texas water will likely continue to grow as well and operations which maximize the water supply potential of the two-reservoir, East Texas Reservoir System must be investigated. Previous studies have shown that a potential increase in system yield is available if the East Texas Reservoirs are overdrafted and underdrafted with respect to one another.[26] Overdrafting means that more than the yield of the reservoir is diverted in wet and average years, and subsequently, operations during drought are such that diversions are less than the yield of the reservoir. Of the two

[23] F&N and APAI, Op. Cit., 1990.
[24] TWDB, Op. Cit., August 1997.
[25] F&N and APAI, Op. Cit., 1990.
[26] Ibid.

Table 3-16.
Potential Water Supplies from Other Sources

Water Source and River Basin	Project Status	Project Yield (acft/yr)	Water Potentially Available (acft/yr)	Distance from Tarrant County
Lake Texoma Storage Reallocation (Red River Basin, Grayson County)	Reallocation not yet approved but recommended in '97 Water Plan	220,000	105,000	90 mi.
Lake Granbury (Brazos River Basin)	Existing reservoir, probably fully committed.	64,712	Arrangements needed with current contract holders to acquire supply.	20 mi.
Lake Palestine (Neches River Basin)	Existing reservoir, fully committed but not currently used.	238,110	Arrangements needed with current contract holders to acquire supply.	35 mi. pipeline to Cedar Creek, future 90 mi. pipeline needed to Tarrant Co.
Marvin Nichols I Reservoir (Sulphur River Basin)	Project not yet approved but recommended in '97 Water Plan	470,413 to 560,151	up to 560,151	160 mi.
George Parkhouse II Reservoir (Sulphur River Basin)	Project not yet approved but recommended in '97 Water Plan	134,232	up to 134,232	115 mi.
Tehuacana Reservoir (Trinity River Basin, Freestone County)	Project not yet approved but recommended in '97 Water Plan	65,547 (higher w/ reuse project)	up to 65,547	90 mi.

reservoirs in the East Texas Reservoir System, Cedar Creek Reservoir has a shorter critical drought period. This means that during the critical drought for Richland-Chambers Reservoir, Cedar Creek Reservoir is unable to store all inflows and spills. Therefore, if the reservoirs are operated as a system in which Cedar Creek Reservoir is overdrafted such that it does not spill during the longer Richland-Chambers Reservoir drought period, the yield of the East Texas System will be more than the simple addition of the stand alone yield of each reservoir.

3.2.4.1 Yield Analyses

In order to isolate the East Texas Reservoir System and analyze the potential benefits of operating its two reservoirs as a system, a monthly reservoir contents simulation model was developed for the East Texas Reservoir System. The system was modeled using the TWDB's river basin simulation model SIMYLD-II (SIMYLD). SIMYLD-input data includes area-capacity tables, monthly inflows, monthly net evaporation rates, and annual diversions with associated seasonal diversion patterns. SIMYLD uses a prioritization hierarchy to establish which water supply sources will be used first, depending upon the hydrologic condition of the system. In the analyses reported here, the operations rules were established so that Cedar Creek Reservoir was overdrafted and Richland-Chambers Reservoir underdrafted in wet and average conditions. In contrast, when depleted system storage indicated dry conditions, Cedar Creek Reservoir was underdrafted and Richland-Chambers Reservoir overdrafted.

A series of model runs were performed varying the overdraft/underdraft trigger in order to assess potential effects on the yield of the system. The trigger used was based on percentage of total storage capacity in the East Texas Reservoir System. When total storage was above the trigger, Cedar Creek Reservoir was overdrafted; likewise, when the total storage fell below the trigger, overdrafting was switched to Richland-Chambers Reservoir. Minimum annual diversions were generally included at each reservoir in order to maximize the yield of the system and maintain operable facilities at both reservoirs.

The potential system yield gains were bounded by the yield gains computed using current safe yield operations (i.e., maintaining current drought reserve volumes of 157,000 acft and 197,000 acft in Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, during the critical drought)[27] and firm yield operations (i.e., maintaining no drought reserve during the critical drought). Tables 3-17 and 3-18 and Figures 3-16 and 3-17 summarize the estimated yield gains of the East Texas Reservoir System under safe yield and firm yield operations, respectively. Simulations summarized in these tables were performed assuming 2015 sediment accumulation conditions. Current conditions (i.e., 1995 sediment accumulation) were not simulated because considerable increases in East Texas delivery capacity would be necessary to realize the full yield gain potential under system operation. Tables 3-19 and 3-20 and Figures 3-18 and 3-19 summarize the estimated yield gains of the East Texas Reservoir System, assuming 2050 sediment accumulation conditions, under safe yield and firm yield operations, respectively.

[27] F&N and APAI, Op. Cit., 1990.

Table 3-17.
System Safe Yield at Various Overdraft/Underdraft Trigger Levels[1]
2015 Sediment Accumulation

Overdraft/ Underdraft Trigger[2] (% of system capacity)	System Yield (acft/yr)	Potential Increase in System Diversion Beyond Safe Yield[3] (acft/yr)	Potential Increase in System Diversion Beyond Permits[4] (acft/yr)	Maximum Monthly Diversion at Cedar Creek Reservoir (acft/mo)	Maximum Monthly Diversion at Richland-Chambers Reservoir (acft/mo)
90%	349,200	6,000 (2%)	0	20,047	22,209
80%	350,800	7,600 (2%)	0	20,233	23,191
70%	354,700	11,500 (3%)	0	20,660	24,640
60%	362,200	19,000 (6%)	0	21,166	27,757
50%	362,600	19,400 (6%)	0	20,926	30,074
40%	358,000	14,800 (4%)	0	19,441	33,538
30%	351,400	8,200 (2%)	0	18,098	34,058
20%	347,100	3,900 (1%)	0	17,194	34,036

1 Based on drought reserves of 157,000 acft and 197,000 acft in Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.
2 Percent of system storage above which Cedar Creek Reservoir is overdrafted and below which Richland-Chambers Reservoir is overdrafted.
3 Yield increase based on projected safe yield of 148,000 acft/yr and 195,200 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, under 2015 sediment conditions (see Section 3.2.2, Changes in Reservoir Drought Supply Reserves).
4 Yield increase based on permitted diversion of 175,000 acft/yr and 210,000 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.

Review of Figure 3-2 indicates that a system operation with an overdraft/underdraft trigger of 50 to 60 percent of system capacity provides the largest increase in yield, an increase of approximately 19,000 acft/yr over the projected safe yield of the two reservoirs in 2015. This observation is based strictly on hydrologic considerations and does not include associated costs of the delivery facilities needed to obtain this yield increase. While the associated firm yield operations curve for 2015 (Figure 3-3) does not have the same apparent optimum, operating at the 50 percent trigger (the hydrologic optimum under safe yield operations) provides approximately 90 percent of the maximum potential yield increase. Therefore, a system overdraft/underdraft trigger of 50 percent in 2015 is approximately hydrologically optimal under either safe or firm operations.

Table 3-18.
System Firm Yield at Various Overdraft/Underdraft Trigger Levels[1]
2015 Sediment Accumulation

Overdraft/ Underdraft Trigger[2] (% of system capacity)	System Yield (acft/yr)	Potential Increase in System Diversion Beyond Firm Yield[3] (acft/yr)	Potential Increase in System Diversion Beyond Permits[4] (acft/yr)	Maximum Monthly Diversion at Cedar Creek Reservoir (acft/mo)	Maximum Monthly Diversion at Richland-Chambers Reservoir (acft/mo)
90%	439,900	6,400 (1%)	54,900 (14%)	28,577	25,753
80%	445,100	11,600 (3%)	60,100 (16%)	29,155	26,784
70%	448,500	15,000 (3%)	63,500 (16%)	29,536	28,633
60%	449,500	16,000 (4%)	64,500 (17%)	29,652	30,668
50%	452,000	18,500 (4%)	67,000 (17%)	29,919	34,321
40%	452,400	18,900 (4%)	67,400 (18%)	29,966	41,140
30%	453,700	20,200 (5%)	68,700 (18%)	29,435	44,107
20%	454,500	21,000 (5%)	69,500 (18%)	31,215	50,400

1 Based on drought reserves of 0 acft in both Cedar Creek Reservoir and Richland-Chambers Reservoir.
2 Percent of system storage above which Cedar Creek Reservoir is overdrafted and below which Richland-Chambers Reservoir is overdrafted.
3 Yield increase based on projected firm yield of 205,200 acft/yr and 228,300 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, under 2015 sediment conditions (see Section 3.2.2, Changes in Reservoir Drought Supply Reserves).
4 Yield increase based on permitted diversion of 175,000 acft/yr and 210,000 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.

Similarly, the results under 2050 sediment conditions (Figure 3-4) indicate the optimum safe yield increase is about 3,000 acft/yr (based solely on hydrologic considerations) at a system trigger of 50 percent. A 50 percent trigger on the 2050 firm yield curve (Figure 3-5) increases the system yield by 17,900 acft/yr (approximately 85 percent of the 2050 maximum potential yield increase). It should be noted that under 2050 sediment conditions, the combined reservoir storage has decreased to the point where there is little to be gained under a systems operation and safe yield assumptions (including drought reserves). However, if the District switches to a firm yield operation and a systems reservoir drafting approach, the system can still produce yields in 2050 that are in excess of the sum of the presently permitted diversions at each reservoir.

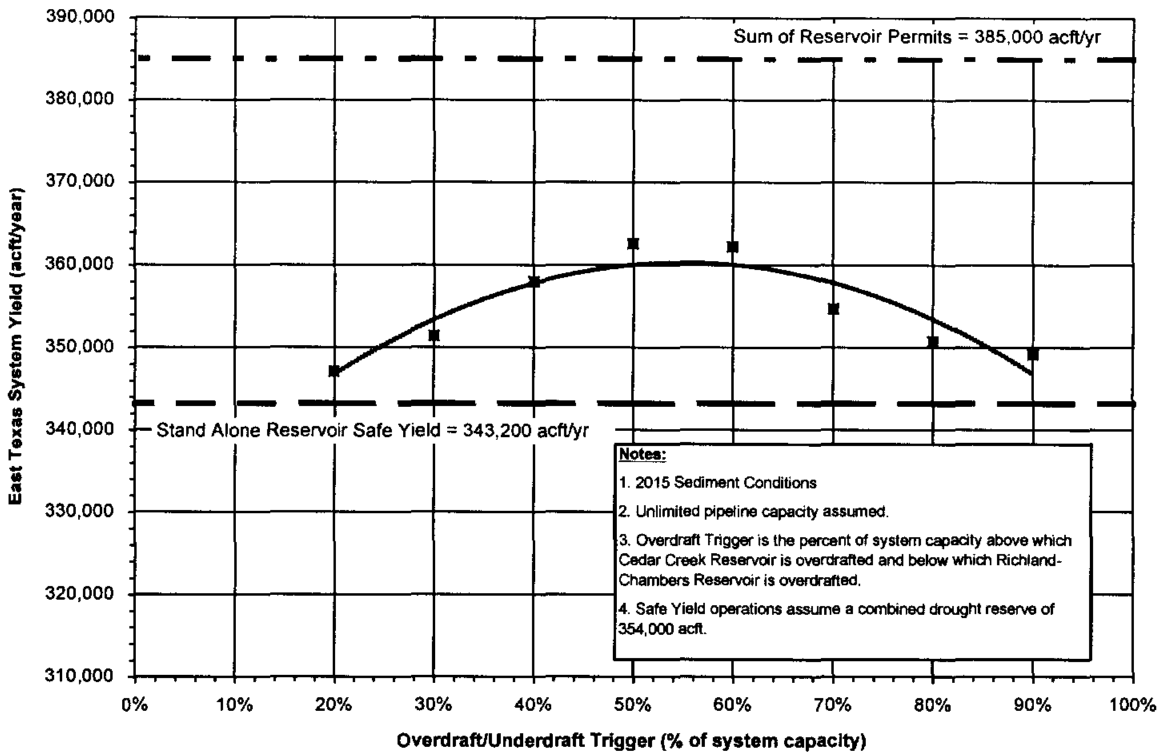

Figure 3-16. East Texas Reservoir System
System Safe Yield vs. Overdraft/Underdraft Trigger
2015 Sediment Accumulation

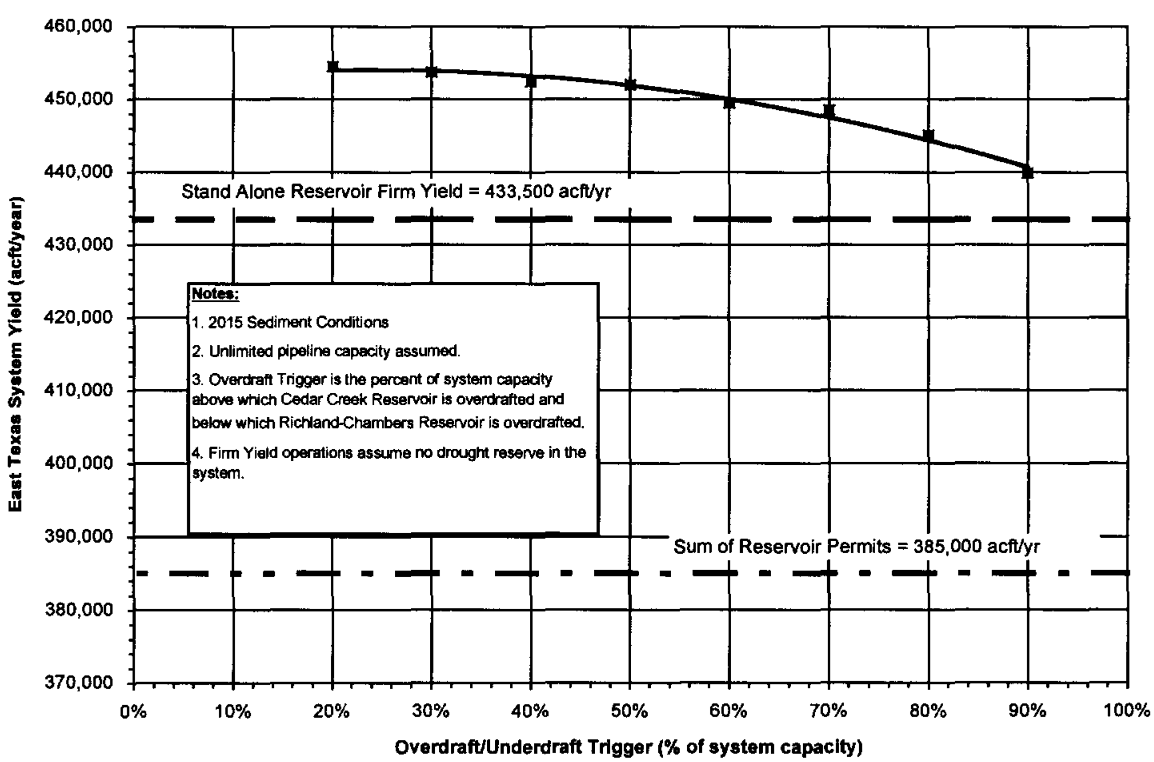

Figure 3-17. East Texas Reservoir System
System Firm Yield vs. Overdraft/Underdraft Trigger
2015 Sediment Accumulation

Table 3-19.
System Safe Yield at Various Overdraft/Underdraft Trigger Levels[1]
2050 Sediment Accumulation

Overdraft/ Underdraft Trigger[2] (% of system capacity)	System Yield (acft/yr)	Potential Increase in System Diversion Beyond Safe Yield[3] (acft/yr)	Potential Increase in System Diversion Beyond Permits[4] (acft/yr)	Maximum Monthly Diversion at Cedar Creek Reservoir (acft/mo)	Maximum Monthly Diversion at Richland-Chambers Reservoir (acft/mo)
90%	312,500	2,500 (1%)	0	16,559	19,709
80%	312,700	2,700 (1%)	0	16,574	20,062
70%	312,700	2,700 (1%)	0	16,580	20,181
60%	312,800	2,800 (1%)	0	16,589	20,977
50%	313,000	3,000 (1%)	0	16,604	21,893
40%	312,900	2,900 (1%)	0	15,928	23,580
30%	312,900	2,900 (1%)	0	15,694	24,695
20%	312,600	2,600 (1%)	0	15,272	25,680

1 Based on drought reserves of 157,000 acft and 197,000 acft in Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.
2 Percent of system storage above which Cedar Creek Reservoir is overdrafted and below which Richland-Chambers Reservoir is overdrafted.
3 Yield increase based on projected safe yield of 135,600 acft/yr and 174,400 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, under 2015 sediment conditions (see Section 3.2.2, Changes in Reservoir Drought Supply Reserves).
4 Yield increase based on permitted diversion of 175,000 acft/yr and 210,000 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.

Costs of the pump station and/or pipeline facilities necessary to deliver additional yield or permitted diversions are also key elements to be considered in determining the optimum overdraft/underdraft trigger. These costs will need to be addressed, should this option eventually be considered, as a part of the District's long-range plan.

3.2.4.2 Implementation Issues

While the option of overdrafting/underdrafting the East Texas Reservoirs appears to be a potentially favorable option, providing approximately 43,600 acft/yr additional yield over the sum of the current East Texas permits, there are two major implementation issues that must be discussed. First, in order to produce the additional water, the capacity of the raw water pipelines from each reservoir must be increased considerably. As shown in the fifth and sixth columns of

Table 3-20.
System Firm Yield at Various Overdraft/Underdraft Trigger Levels[1]
2050 Sediment Accumulation

Overdraft/ Underdraft Trigger[2] (% of system capacity)	System Yield (acft/yr)	Potential Increase in System Diversion Beyond Firm Yield[3] (acft/yr)	Potential Increase in System Diversion Beyond Permits[4] (acft/yr)	Maximum Monthly Diversion at Cedar Creek Reservoir (acft/mo)	Maximum Monthly Diversion at Richland-Chambers Reservoir (acft/mo)
90%	409,700	0	24,700 (6%)	24,873	24,534
80%	414,700	4,000 (1%)	29,700 (8%)	25,435	25,096
70%	422,600	11,900 (3%)	37,600 (10%)	26,313	26,539
60%	427,000	16,300 (4%)	42,000 (11%)	26,795	28,152
50%	428,600	17,900 (4%)	43,600 (11%)	26,978	30,596
40%	431,000	20,300 (5%)	46,000 (12%)	27,243	35,382
30%	431,400	20,700 (5%)	46,400 (12%)	27,287	38,817
20%	431,500	20,800 (5%)	46,500 (12%)	27,302	47,875

1 Based on drought reserves of 0 acft in both Cedar Creek Reservoir and Richland-Chambers Reservoir.
2 Percent of system storage above which Cedar Creek Reservoir is overdrafted and below which Richland-Chambers Reservoir is overdrafted.
3 Yield increase based on projected firm yield of 193,800 acft/yr and 216,900 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, under 2015 sediment conditions (see Section 3.2.2, Changes in Reservoir Drought Supply Reserves).
4 Yield increase based on permitted diversion of 175,000 acft/yr and 210,000 acft/yr at Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.

Table 3-19, the maximum monthly diversions needed when the associated reservoir is in overdrafting mode are very large. In fact, current capacity from East Texas would have to be increased by approximately 400 MGD to accommodate the peak pumping months. In addition to potentially expensive increases in pumping capacity, this option by its nature hinders the ability of the District to develop reuse water from the Trinity River by continually drawing down one of the two reservoirs. In order for the reuse project to meet it's operational criteria (Section 3.2.1), the reuse water is to be mixed with water in the reservoirs. In order to maintain the blending ratios (of reservoir water to reuse water) established by the operational criteria, the reservoirs should not be drawn down below the drought storage reserves. Under the overdrafting/ underdrafting operations, the ability of one or both of the reservoirs to accept reuse water would be limited most of the time. Other important implementation issues involve potential effect on recreation and fish habitat at the reservoir being overdrafted.

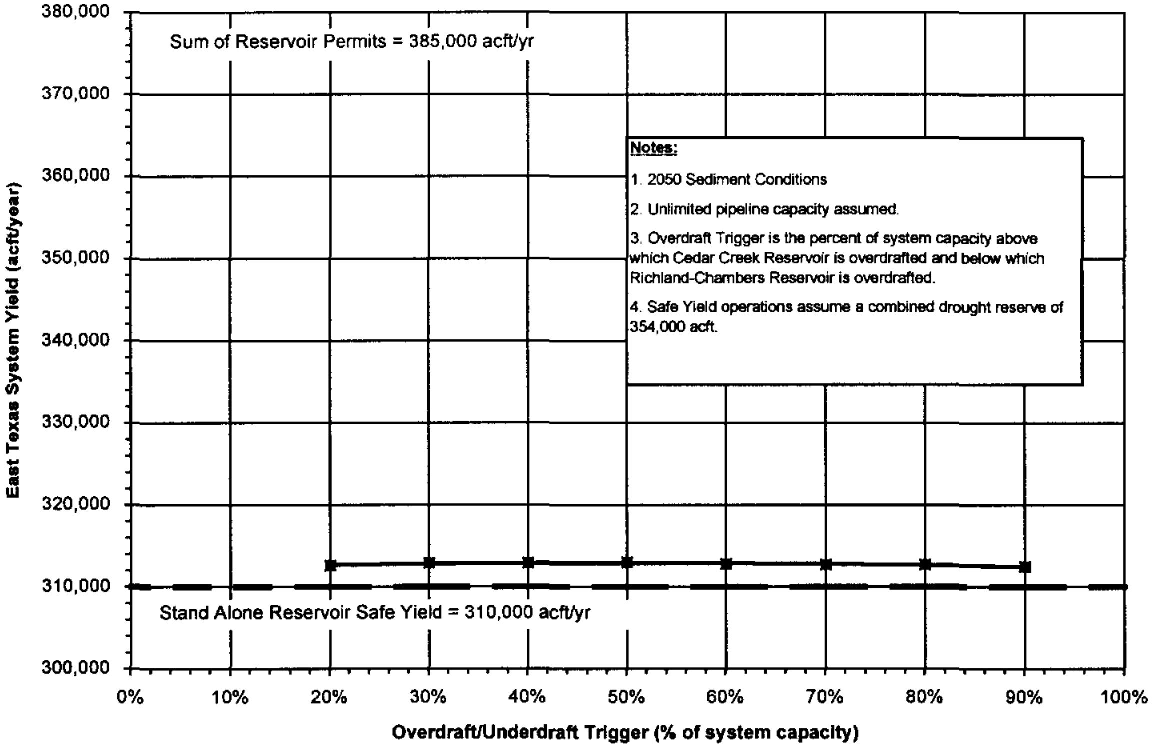

Figure 3-18. East Texas Reservoir System System Safe Yield vs. Overdraft/Underdraft Trigger 2050 Sediment Accumulation

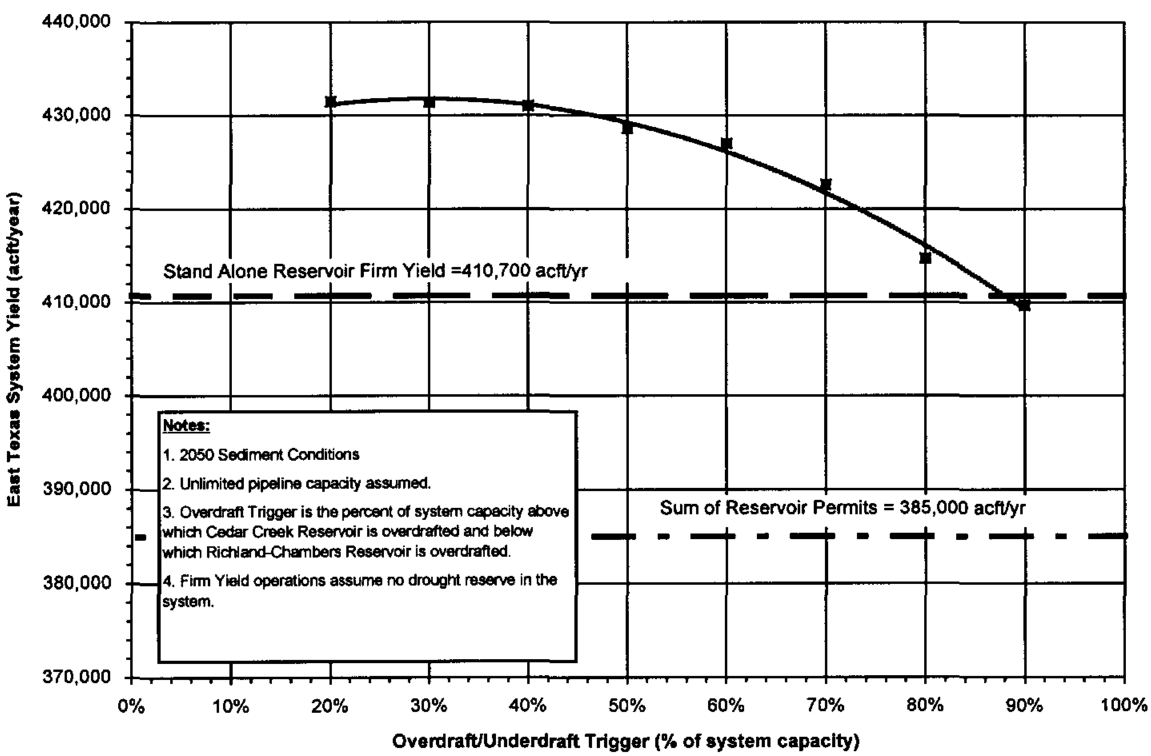

Figure 3-19. East Texas Reservoir System System Firm Yield vs. Overdraft/Underdraft Trigger 2050 Sediment Accumulation

3.2.5 Changes in Reservoir Drought Supply Reserves

It has been the policy of the District to operate Cedar Creek Reservoir and Richland-Chambers Reservoir under a safe yield plan. Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. The minimum volume of water remaining in the reservoir during the critical drought is referred to herein as the drought reserve. Under a firm yield operation plan, there is no drought reserve and the reservoir would be drawn down to approximately zero storage at the end of the critical month during the drought of record. It is generally understood that the District's West Fork System (Lake Bridgeport and Eagle Mountain Lake) is permitted for diversions in excess of its firm annual yield; however, permitted diversions from the East Texas Reservoirs (Cedar Creek Reservoir and Richland-Chambers Reservoir) provided for a drought reserve. Therefore, if the District chooses to reduce the drought reserves in the East Texas Reservoirs, there may be additional water available. If the gain in yield were sufficiently large, changes in drought reserves could delay the need for additional water supply sources. The purpose of this section is to quantify the potential yield increases available to the District should they reduce the drought reserves in the East Texas Reservoirs.

3.2.5.1 Modeling Methodologies and Data Refinement

In order to evaluate the yields potentially available if the drought reserves of Cedar Creek and/or Richland-Chambers Reservoirs are reduced, one must consider the fact that diversions in excess of the currently permitted amounts will require amendments to the existing water rights permits. Such amendments would necessitate evaluation of potential environmental impacts and of potential impacts to water rights junior to the original permit, but senior to the amendments. While evaluation of the latter is beyond the scope of this study, consideration of the former may be approximated using the Environmental Water Needs Criteria from the Consensus Planning Process conducted by the TWDB, TNRCC, and Texas Parks & Wildlife Department. A copy of the Environmental Water Needs Criteria and a memo to the TWDB explaining the method by which the criteria have been applied in this study can be found in Appendix F.

Review of the Environmental Water Needs Criteria indicates that pertinent streamflow statistics should be derived and reservoir operations should be simulated using a daily computational time interval. Since the District's existing model (TOM)[28] simulates system operations on a monthly timestep, it was necessary to use the TWDB's daily reservoir simulation model (SIMDLY) to complete the required yield analyses. SIMDLY input data includes an area-capacity table, daily inflows, monthly net evaporation rates, annual diversions, and a monthly diversion pattern. Current area-capacity tables for Cedar Creek Reservoir and Richland-Chambers Reservoir were obtained from reports[29,30] summarizing 1995 bathymetric surveys of the reservoirs. In addition, sediment accumulation rates reported in Appendix A and standard sediment distribution techniques[31] were used to develop estimated elevation-area-capacity tables for the years 2015 and 2050 for both reservoirs.

Total monthly inflows to the reservoirs adjusted for senior upstream water rights and monthly estimates of priority releases for downstream senior rights were obtained from detailed water rights analyses performed by R.J. Brandes Company[32] in conjunction with water rights permit applications being prepared for the District (see Appendix B). Priority releases are the waters that must be passed through upstream reservoirs during times of drought in order to allow senior water rights downstream to obtain as much of their full permitted diversion as possible. Hence, the total monthly inflows were adjusted to account for priority releases and prorated to daily inflows using available gaged streamflow records as summarized in Table 3-21.

Monthly net evaporation rates and diversion patterns used in SIMDLY for Cedar Creek Reservoir and Richland-Chambers Reservoir were obtained from the master datafiles for the TOM model. HDR confirmed that the net evaporation rates from the TOM model approximate those derived from the database maintained by the TWDB.

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[28] F&N, "Operation Model User's Manual," Tarrant County Water Control and Improvement District Number One, December, 1994.

[29] TWDB, "Volumetric Survey of Cedar Creek Reservoir," Tarrant County Water Control and Improvement District Number One, July 31, 1995.

[30] TWDB, "Volumetric Survey of Richland-Chambers Reservoir," Tarrant County Water Control and Improvement District Number One, March 31, 1995.

[31] Borland, W.M. and Miller, C.R., "Distribution of Sediment in Large Reservoirs," Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. HY2, April, 1958.

[32] RJ Brandes Company

Table 3-21.
Daily Proration of Monthly Inflows to
Cedar Creek Reservoir and Richland-Chambers Reservoir

Period of Record	USGS Gages Used to Prorate Monthly Data
Cedar Creek Reservoir	
Period of Record	**USGS Gages Used to Prorate Monthly Data**
Jan, 1941 to Jan, 1966	Gage No. 08063000, Cedar Creek @ Mabank
Feb, 1966 to Dec, 1981	Gage No. 08062800, Cedar Creek @ Kemp[1] Gage No. 08062900, Kings Creek @ Kaufman[1]
Richland-Chambers Reservoir	
Period of Record	**USGS Gages Used to Prorate Monthly Data**
Jan, 1941 to Feb, 1972	Gage No. 08063500, Richland Creek @ Richland[1] Gage No. 08064500, Chambers Creek @ Corsicana[1]
Mar, 1972 to Dec, 1981	Gage No. 08064600, Richland Creek @ Fairfield
1 For periods with two gages, the daily streamflow percent = $(Q1_{DAY} + Q2_{DAY}) * 100/ (Q1_{MONTH} + Q2_{MONTH})$	

3.2.5.2 Yield Analyses

Daily reservoir contents simulation models have been developed for both of the East Texas Reservoirs, Cedar Creek Reservoir and Richland-Chambers Reservoir. Current operation of the reservoirs is based on maintenance of drought reserve volumes of 157,000 acft and 197,000 acft in Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively, during the critical drought.[33,34] In order to set a baseline, contents simulations subject to full permitted diversions were performed and the resulting spills tabulated. These baseline spill files and the previously described daily priority releases were combined to represent daily flows below each reservoir. In accordance with the Environmental Water Needs Criteria discussed in Appendix F, daily flow statistics were computed for each month. Summaries of these statistics are presented in Tables 3-22 and 3-23 for Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively. In addition, the minimum water quality standard flows estimated as the two-year seven-day low flows (7Q2's) were computed for the stream reaches immediately downstream of both reservoirs. These flow rates were computed to be 0 cfs and 5 cfs for Cedar Creek Reservoir and Richland-Chambers Reservoir, respectively.

[33] F&N and APAI, Op. Cit., 1990.
[34] Letter to Mr. Tony Bagwell, TWDB, March 14, 1996, from James Oliver, Tarrant County WCID No. 1.

Table 3-22.
Daily Baseline Flow Statistics below Cedar Creek Reservoir[1]

Month	Minimum Flow (cfs)	25th percentile (cfs)	Median Flow (cfs)	75th Percentile (cfs)	Maximum Flow (cfs)
January	0	0	0	0	16,376
February	0	0	0	0	32,425
March	0	0	0	0	53,961
April	0	0	0	0	42,486
May	0	0	0	0	73,216
June	0	0	0	0	28,700
July	0	0	0	0	21,090
August	0	0	0	1.0[2]	54
September	0	0	0	0	6
October	0	0	0	0	8,427
November	0	0	0	0	20,732
December	0	0	0	0	36,992

1 Cedar Creek Reservoir operated for period of record 1941 to 1981 under current permitted diversion of 175,000 acft/yr. Flows include spills and priority releases.
2 Priority releases occur most frequently in August.

Using the data in Tables 3-22 and 3-23, the 7Q2's, and the environmental criteria (Appendix F) the release requirements for any additional yield above the permitted diversions from the East Texas Reservoirs were established. Review of the data presented in Table 3-22 shows that Cedar Creek flows downstream of the reservoir are zero at least 75 percent of the time. Therefore, no additional environmental flow passage would be required (under the assumed criteria) for Cedar Creek Reservoir yield greater than the currently permitted diversion. Likewise, at Richland-Chambers Reservoir, the environmental flows under the assumed criteria are equal to the minimum release currently required from the dam (5 cfs, as dictated in the U.S. Army Corps of Engineers' 404 Permit) at least 75 percent of the time. Therefore, only the existing minimum release requirement of 5 cfs for Richland-Chambers Reservoir was used in all simulations (even if the yield was greater than the permitted diversion).

Table 3-23.
Daily Baseline Flow Statistics below Richland-Chambers Reservoir[1]

Month	Minimum Flow (cfs)	25th percenti le (cfs)	Median Flow (cfs)	75th Percentile (cfs)	Maximum Flow (cfs)
January	5	5	5	5	46,529
February	5	5	5	5	26,420
March	5	5	5	12.0	80,035
April	5	5	5	36.0	62,266
May	5	5	5	688.0[2]	78,531
June	5	5	5	5	33,722
July	5	5	5	5	18,321
August	5	5	5	5	28
September	5	5	5	5	21,208
October	5	5	5	5	12,361
November	5	5	5	5	26,209
December	5	5	5	5	19,775

1 Richland-Chambers Reservoir operated for period of record 1941 to 1981 under current permitted diversion of 210,000 acft/yr. Flows include spills and priority releases.
2 Spills occur most frequently in May.

A series of reservoir contents simulations were run to evaluate the potential yields of Cedar Creek Reservoir and Richland-Chambers Reservoir at reduced volumes of drought reserve. The series of runs was bounded by the yield computed with the current drought reserves (157,000 acft for Cedar Creek Reservoir and 197,000 acft for Richland-Chambers Reservoir) and the yield with a drought reserve volume of 0 acft (firm yield). Tables 3-24 through 3-26 and Figures 3-20 through 3-22 summarize the estimated yields of Cedar Creek Reservoir for 1995, 2015, and 2050 sediment accumulation conditions, respectively. Similarly, the results of the yield calculations for Richland-Chambers Reservoir are summarized in Tables 3-27 through 3-29 and Figures 3-23 though 3-25 for 1995, 2015, and 2050 sediment accumulation conditions, respectively.

Table 3-24.
Reservoir Yields at Various Drought Reserve Storages
Cedar Creek Reservoir
1995 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
157,000	154,900	0
125,600	166,100	0
94,200	177,400	0
62,800	188,700	2,400 (1%)
31,400	200,000	13,700 (8%)
0	211,700	36,700 (21%)

1 Based on comparison with permitted diversion of 175,000 acft/yr.

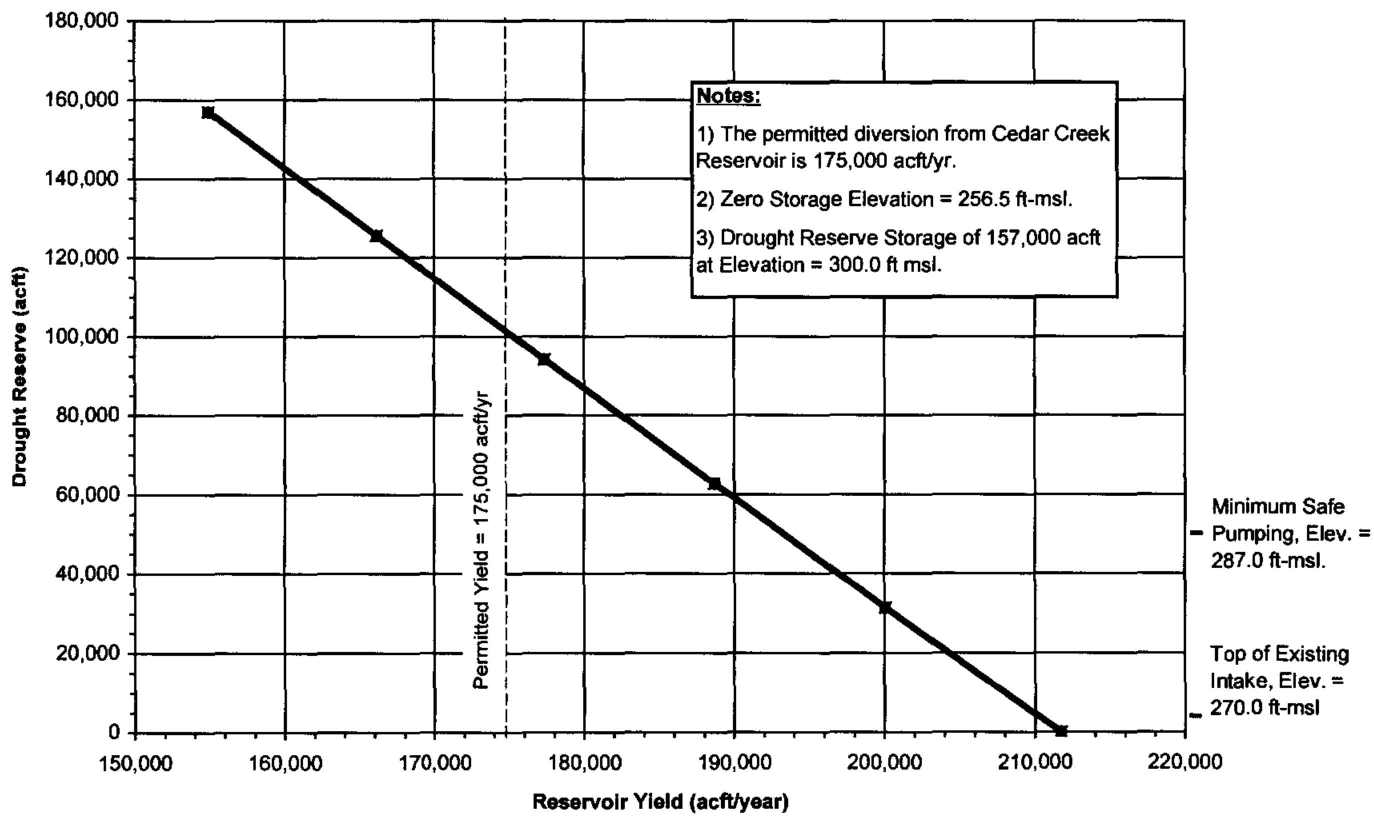


Figure 3-20. Reservoir Yield vs. Drought Reserve Cedar Creek Reservoir – 1995 Sediment Accumulation

Table 3-25.
Reservoir Yields at Various Drought Reserve Storages
Cedar Creek Reservoir
2015 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
157,000	148,000	0
125,600	159,300	0
94,200	170,600	0
62,800	182,000	7,000 (4%)
31,400	193,500	18,500 (11%)
0	205,200	30,200 (17%)

1 Based on comparison with permitted diversion of 175,000 acft/yr.

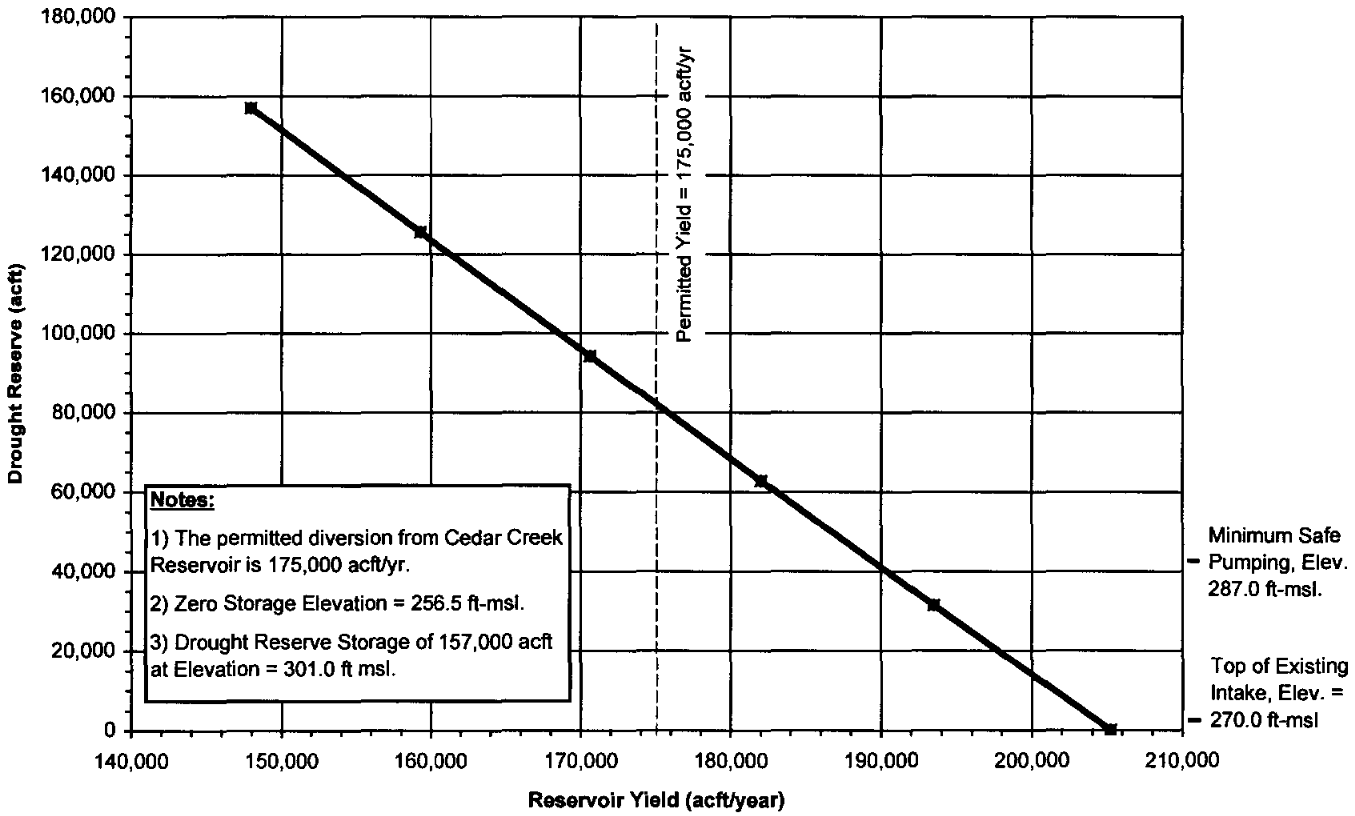


Figure 3-21. Reservoir Yield vs. Drought Reserve
Cedar Creek Reservoir – 2015 Sediment Accumulation

Table 3-26.
Reservoir Yields at Various Drought Reserve Storages
Cedar Creek Reservoir
2050 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
157,000	135,600	0
125,600	147,100	0
94,200	158,700	0
62,800	170,300	0
31,400	181,900	6,900 (4%)
0	193,800	18,800 (11%)

[1]Based on comparison with permitted diversion of 175,000 acft/yr.

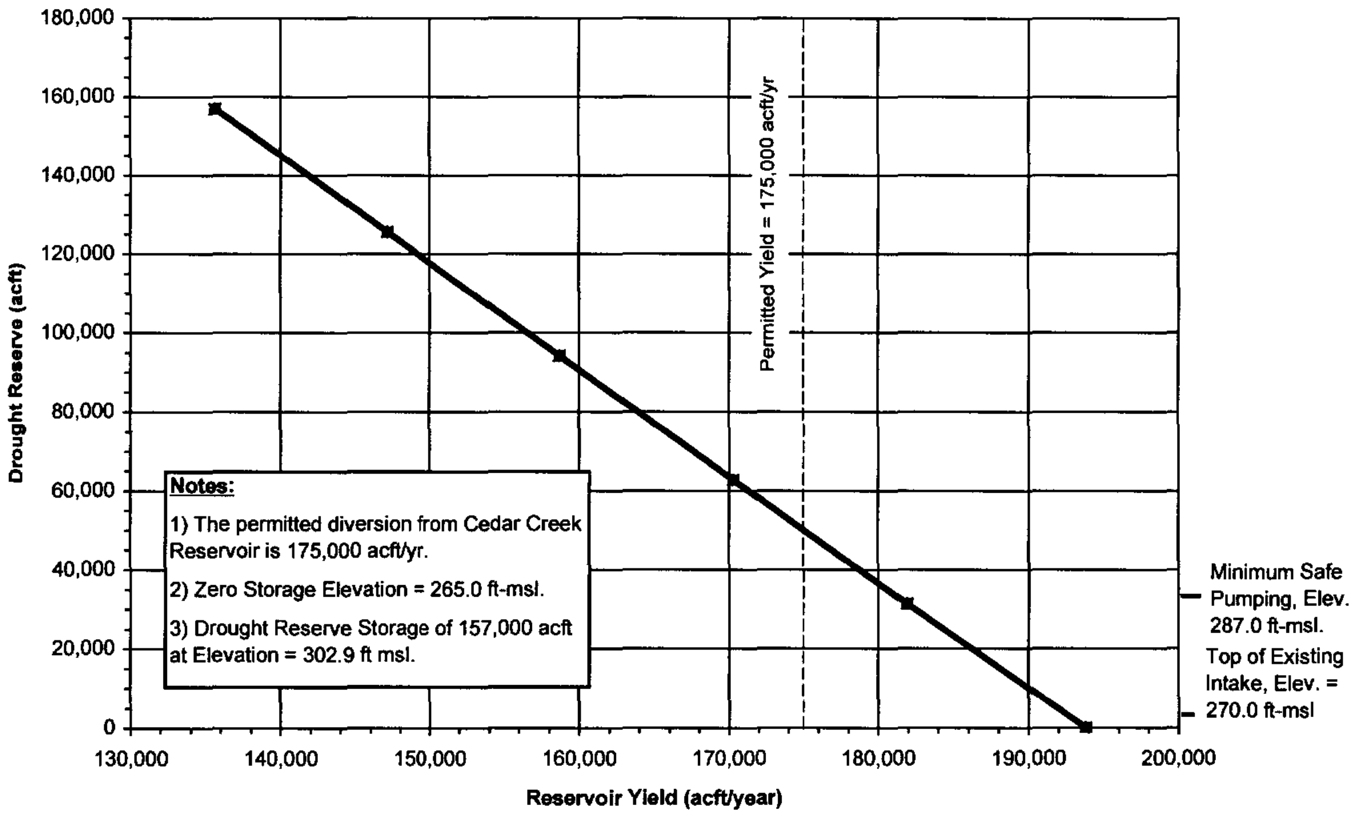


Figure 3-22. Reservoir Yield vs. Drought Reserve
Cedar Creek Reservoir – 2050 Sediment Accumulation

***Table 3-27.
Reservoir Yields at Various Drought Reserve Storages
Richland-Chambers Reservoir
1995 Sediment Accumulation***

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
197,000	202,100	0
157,600	208,400	0
118,200	214,800	4,800 (2%)
78,800	221,300	11,300 (5%)
39,400	227,900	17,900 (9%)
0	234,700	24,700 (12%)

1 Based on comparison with permitted diversion of 210,000 acft/yr.

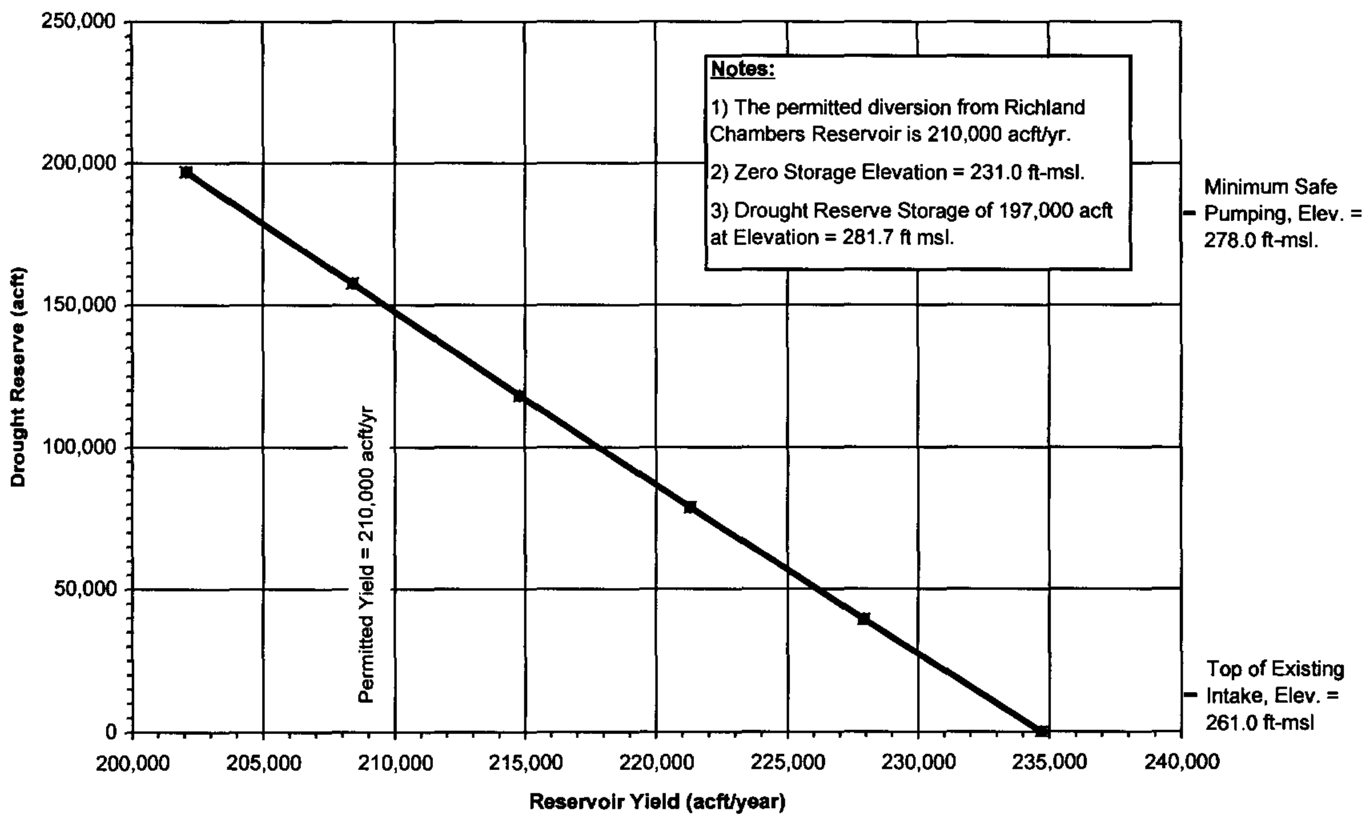


***Figure 3-23. Reservoir Yield vs. Drought Reserve
Richland-Chambers Reservoir – 1995 Sediment Accumulation***

Table 3-28.
Reservoir Yields at Various Drought Reserve Storages
Richland-Chambers Reservoir
2015 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
197,000	195,200	0
157,600	201,600	0
118,200	208,100	0
78,800	214,700	4,700 (2%)
39,400	221,400	11,400 (5%)
0	228,300	18,300 (9%)

[1] Based on comparison with permitted diversion of 210,000 acft/yr.

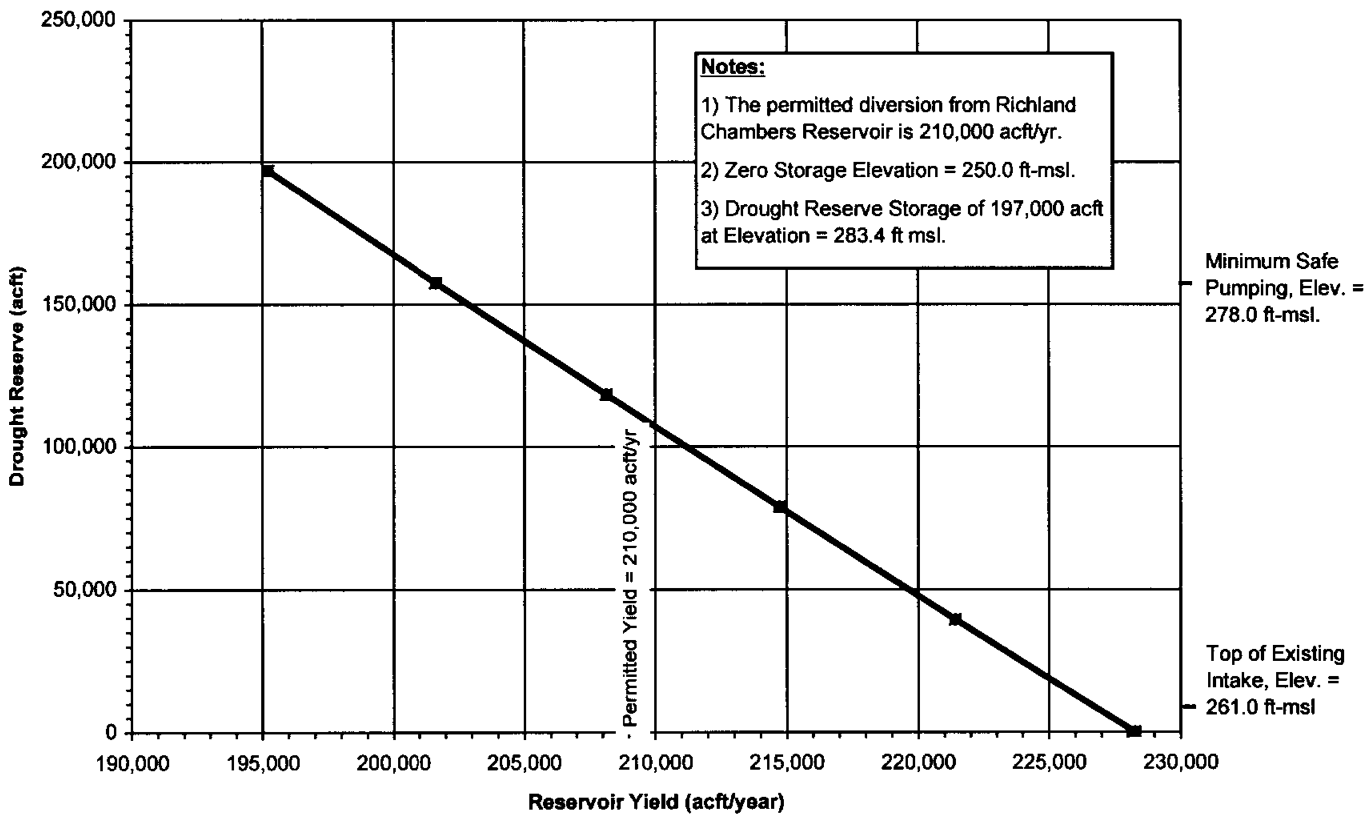


Figure 3-24. Reservoir Yield vs. Drought Reserve
Richland-Chambers Reservoir – 2015 Sediment Accumulation

Table 3-29.
Reservoir Yields at Various Drought Reserve Storages
Richland-Chambers Reservoir
2050 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield (acft/yr)	Potential Increase in Permitted Diversion (acft/yr) [1]
197,000	174,400	0
157,600	187,700	0
118,200	196,000	0
78,800	202,900	0
39,400	209,900	0
0	216,900	6,900 (3%)

[1] Based on comparison with permitted diversion of 210,000 acft/yr.

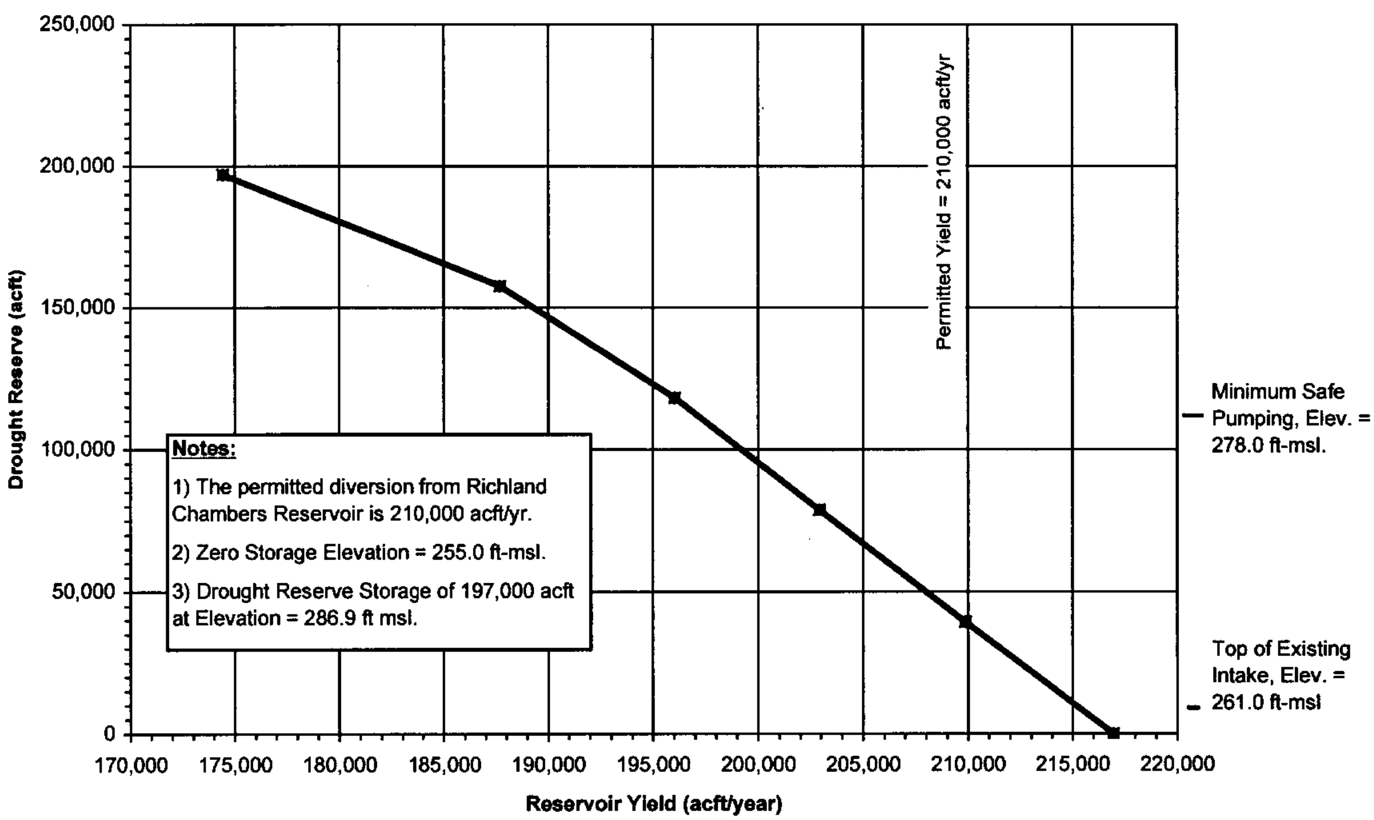


Figure 3-25. Reservoir Yield vs. Drought Reserve
Richland-Chambers Reservoir – 2050 Sediment Accumulation

As discussed in Appendix A, there is some uncertainty regarding the sediment accumulation rate in Richland-Chambers Reservoir due to the relatively short time Richland-Chambers Reservoir has been in operation, relatively wet conditions during that time period, and some questions about the original elevation-area-capacity relationship. The yields for Richland-Chambers Reservoir presented in Tables 3-27 through 3-29 were based on an "average" sediment accumulation rate of 2.65 acft per square-mile per year. This rate is comparable to those for other primarily Blackland Prairie watersheds controlled by reservoirs for which the interval between sediment surveys exceeds the period Richland-Chambers Reservoir has been in operation. Based on the TWDB 1995 bathymetric survey and the original elevation-area-capacity relationship, a higher sediment accumulation rate of 3.41 acft per square mile per year was computed. In order to evaluate the potential impact of this higher rate on the yield of Richland-Chambers Reservoir, a second series of yield computations were completed for Richland-Chambers Reservoir. The results of these computations are summarized in Tables 3-30 and 3-31 and in Figures 3-26 and 3-27.

As shown in Figure 3-26, the impact of the higher sediment accumulation rate on yield at various drought reserve volumes is relatively small over the next 15 to 20 years. However, by 2050, the difference ranges from approximately 14,200 acft/yr at a drought reserve volume of 197,000 acft to approximately 5,300 acft/yr with zero drought reserve (firm yield). An additional bathymetric survey should be performed at Richland-Chambers Reservoir within the next 15 to 20 years in order to refine the sediment accumulation rate, especially if the current policy of maintaining a drought reserve is continued.

The yield analyses summarized in this section indicate that the District may be unable to obtain the currently authorized diversion of 210,000 acft/yr from Richland-Chambers Reservoir by the year 2050, while still maintaining drought reserves. This conclusion is primarily the result of full consideration of upstream water rights and potential sediment accumulation rates (average or high) which are well in excess of those expected during project development. Intake facilities at Richland-Chambers Reservoir will likely need to be modified so that more of the reservoir pool is accessible during severe drought in order to ensure that diversions approximating the permitted amounts can be obtained in the future.

Table 3-30.
Reservoir Yields at Various Drought Reserve Storages
Richland-Chambers Reservoir
2015 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield Assuming Average Sediment Accumulation[1] (acft/yr)	Reservoir Yield Assuming High Sediment Accumulation[2] (acft/yr)	Difference in Reservoir Yield Due to Sediment Accumulation Rate (acft/yr)
197,000	195,200	193,200	2,000
157,600	201,600	199,700	1,900
118,200	208,100	206,200	1,900
78,800	214,700	212,900	1,800
39,400	221,400	219,600	1,800
0	228,300	226,500	1,800

1 Average Sediment Accumulation Rate = 2.65 acft per square-mile per year.
2 High Sediment Accumulation Rate = 3.41 acft per square-mile per year.

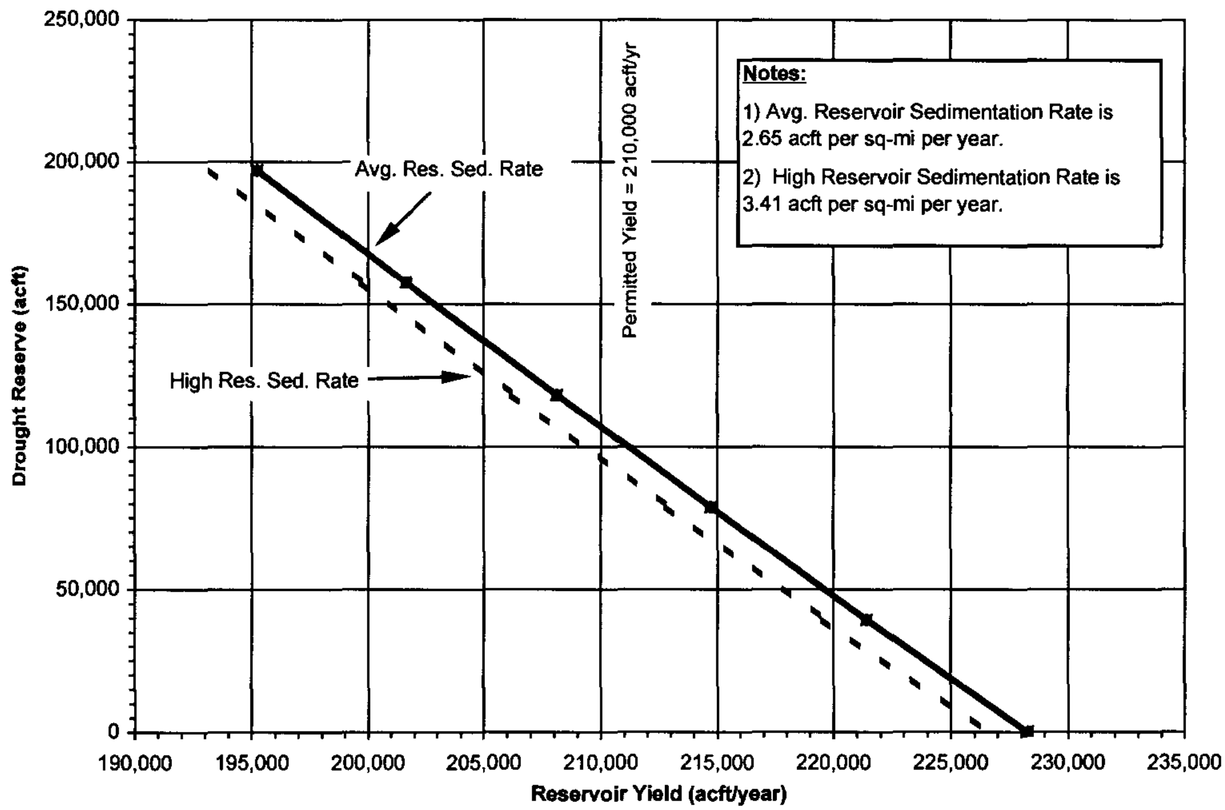


Figure 3-26. Reservoir Yield vs. Drought Reserve – Richland-Chambers Reservoir Sensitivity of Yield to Sedimentation Rate – 2015 Sediment Accumulation

Table 3-31.
Reservoir Yields at Various Drought Reserve Storages
Richland-Chambers Reservoir
2050 Sediment Accumulation

Drought Reserve Volume (acft)	Reservoir Yield Assuming Average Sediment Accumulation [1] (acft/yr)	Reservoir Yield Assuming High Sediment Accumulation [2] (acft/yr)	Difference in Reservoir Yield Due to Sediment Accumulation Rate (acft/yr)
197,000	174,400	159,800	14,600
157,600	187,700	173,300	11,400
118,200	196,000	186,700	9,300
78,800	202,900	197,100	5,800
39,400	209,900	204,300	5,600
0	216,900	211,600	5,300

[1] Average Sediment Accumulation Rate = 2.65 acft per square-mile per year.
[2] High Sediment Accumulation Rate = 3.41 acft per square-mile per year.

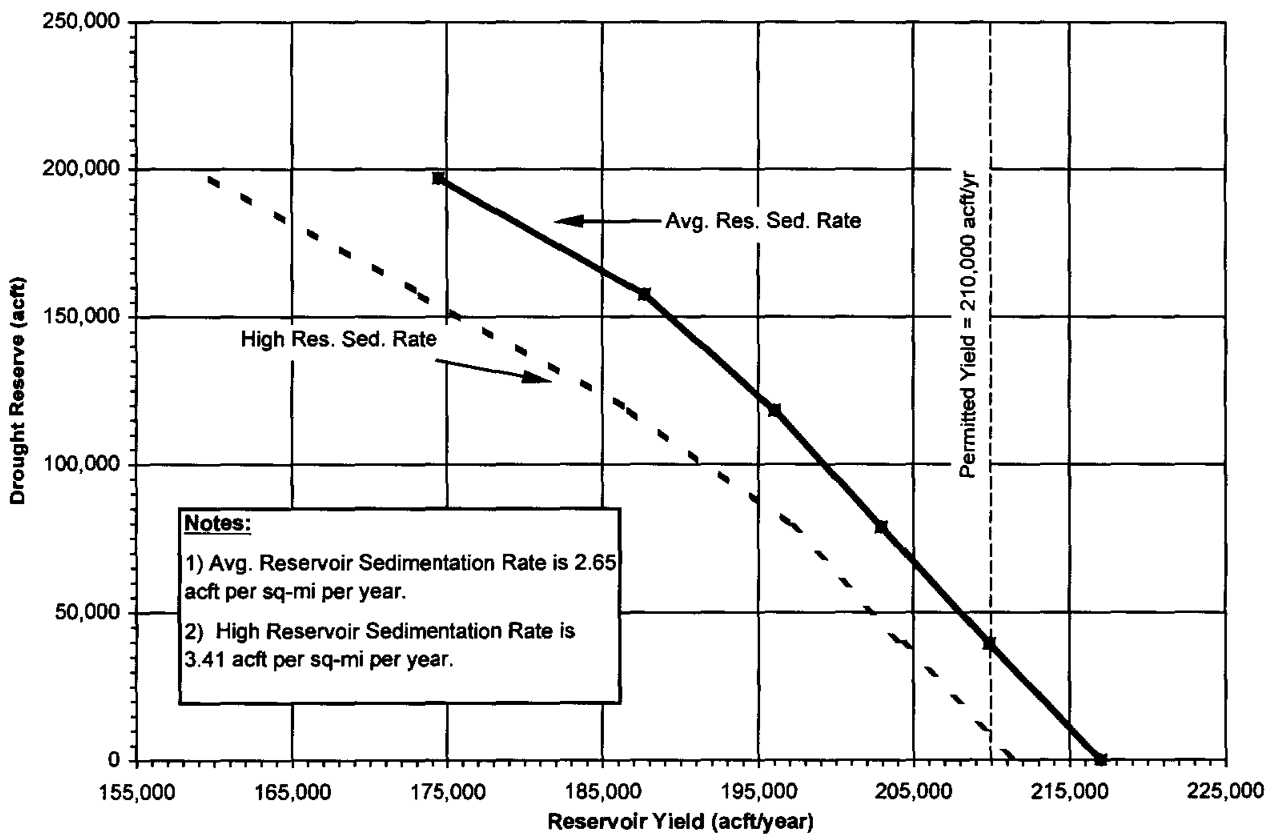


Figure 3-27. Reservoir Yield vs. Drought Reserve – Richland-Chambers Reservoir Sensitivity of Yield to Sedimentation Rate – 2050 Sediment Accumulation

By contrast, additional yield may be available from Cedar Creek Reservoir with the reduction of its drought reserve. Even with full consideration of upstream water rights senior to Cedar Creek Reservoir and higher than expected sediment accumulation rates, up to 18,800 acft/yr of additional yield might be available through 2050 with greater amounts potentially available in the interim. In order to access this additional supply, however, amendment of the Cedar Creek Reservoir permit and modification of the existing intake facilities would be required.

3.2.5.3 Implementation Issues

In order to develop the option of reducing drought reserves in the East Texas Reservoirs, the District will potentially need to modify the existing intakes at both Cedar Creek Reservoir and Richland-Chambers Reservoir. Currently, the crowns of the intake conduits are at elevations 270.0 ft-msl at Cedar Creek Reservoir and 261.0 ft-msl at Richland-Chambers Reservoir. In addition, the pumps at each facility need approximately 17 feet of submergence to safely operate. At these minimum elevations, the gains in yield from the reservoirs are less than the firm yield, but still greater than the permitted yield at Cedar Creek Reservoir. In this option, if it is decided that the intake facilities at Cedar Creek Reservoir would be modified to develop yields in excess of the permitted yield, the current East Texas pipeline capacities would need to be evaluated to ensure that they can deliver the increase. As with the overdraft/underdraft analysis, the costs associated with this option will need to be addressed if this option is ever pursued as part of the District's integrated plan development.

Section 4

Water Quality and Environmental Considerations

Section 4
Water Quality and Environmental Considerations

4.1 Water Quality Considerations

4.1.1 Safe Drinking Water Act Regulations

The Safe Drinking Water Act (SDWA) Amendments of 1996 establish the basis for many changes and new programs that will have a significant effect on the water treatment industry. The major parts addressed in these amendments are the following:

- Source Water Protection;
- Consumer Information;
- Regulatory Program; and
- Drinking Water State Revolving Fund.

The regulations required by these amendments are currently in proposed form, and the following discussion is based on these proposals and includes possible schedules for final implementation. Much of the guidance formulated by the Environmental Protection Agency (EPA) will then be directed to the states for legislation and implementation. Several of the Source Water Protection rules will directly affect the TRWD. Consumer Information, State Revolving Fund, and Regulatory Program regulations will more directly affect the District's customers. These amendments will be covered briefly in the following paragraphs with the majority of the discussion focused on the Regulatory Program and particularly the expected effects of what is currently being called the Microbial/ Disinfection Byproduct (M/DBP) rule.

4.1.1.1 Source Water Protection

This part of the amendments is preventive in emphasis. The main focus is on source water assessments. These assessments incorporate the delineation of the source water area for both surface and ground waters used for public consumption, and the effect on source water quality and the corresponding effect on water treatment. The EPA issued the final guidance document to the states in August 1997. The states will be required to submit a plan to the EPA by February 1999. The District, through its existing water quality sampling and watershed management activities, has a program in place that directly addresses the proposed requirements covered under the source water protection program.

Two other provisions of this part of the amendments, which will affect District customers, are requirements for capacity development of water treatment plants and for water treatment plant operators certification. Capacity development includes determining that new water treatment plants have the technical, financial, and managerial capacity to meet the National Primary Drinking Water Regulations (NPDWR) and that existing plants, particularly those with a past record of noncompliance, be aided by the state in these areas. Texas already has a water treatment plant operators' certification program.

4.1.1.2 Consumer Information

This part of the amendments establishes the publication of consumer confidence reports and clarifies the requirements for public notification for violations of treated water quality standards. The consumer confidence report will be established to inform water customers of raw water quality, treated water quality, and water treatment issues and the intent is that these reports will be sent in the water bill at a minimum of once a year. The first consumer confidence reports will be required to be published by the end of 1999. This part of the amendments also requires the Food and Drug Administration (FDA) to publish a consumer study on the contents of bottled water by February 1998.

4.1.1.3 Drinking Water State Revolving Fund

This fund is established to make grants available to the state to further the health protection objectives of these amendments. There are very specific rules to the states for the use of these funds and portions of this funding can be withheld from states whose programs do not comply with the other amendments. A major use of these funds is to provide low interest loans for water projects.

4.1.1.4 Regulatory Program

This part of the regulations is primarily directed at the quality of treated water. The major areas addressed in this part of the amendments are as follows:

- Contaminant Selection;

- Standards and Regulation Development;
- Arsenic, Sulfate, Radon, and Disinfection Byproducts;
- Drinking Water Studies and Research;
- Small System Exemptions;
- Monitoring; and
- Enforcement.

4.1.1.4.1 Contaminant Selection, and Standards and Regulation Development

These areas pertain to the criteria for the selection of substances not already regulated by the NPDWR and the determination to regulate these substances, including concentration or maximum contaminant levels (MCLs) for the regulated substances, in drinking water. These criteria include occurrence, risk analysis, and cost benefit analysis. The EPA must publish a list of contaminants by February 1998 and then every 5 years thereafter. The requirement to regulate 25 contaminants every 3 years has been eliminated. EPA is now required to determine whether or not to regulate at least five contaminants ever 5 years beginning in August 2001. Also included in this portion of the amendments are future regulations for ground water disinfection, recycling of filter backwash, and standards for bottled water.

4.1.1.4.2 Arsenic, Sulfate, Radon, and Disinfection Byproducts

EPA has separated these four substances for first priority consideration to be regulated as contaminants. The following is the schedule for these regulations.

- Disinfection Byproducts: Promulgation of the Enhanced Surface Water Treatment Rule (ESWTR) and Stage 1 Disinfectants/Disinfection Byproducts (D/DBP) rule is due by November 1998.
- Radon: A health risk reduction and cost analysis associated with possible MCL levels will be published by February 1999. A proposed rule by August 1999 and a final rule by August 2000.
- Sulfate: A dose response study will be completed by February, 1999, and sulfate will be on the list of the first contaminants to be considered for regulation in 2001.
- Arsenic: A proposed NPDWR will be issued by January 1, 2000 and a final rule issued by January 1, 2001.

The ESWTR and the Stage I D/DBP rule have been combined and are currently being called the Microbial/Disinfection Byproduct (M/DBP) rule. They have been combined so that the regulations developed will consider and balance all of the water treatment goals: Disinfection Byproduct Control, Disinfection Requirements, and Turbidity Standards. These three goals are discussed below.

Disinfection Byproduct Control.

The proposed rule contains the following MCLs for four disinfection byproducts (DBPs):

- Total Trihalomethanes (TTHMs) 80 ug/l,
- Five Haloacetic Acids (HAA5) 60 ug/l,
- Bromate 10 ug/l,
- Chlorite 1.0 mg/l.

In addition to these required limits, there are proposed rules for treatment techniques to reduce the production of DBPs. This focuses on the removal of precursor organics prior to disinfection. These precursor organics are quantified by the measurement of total organic carbons (TOC). Enhanced coagulation is the term used for the coagulation treatment process with emphasis on TOC removal. This term also includes the idea that the level of turbidity removal must also be maintained. There are two ways for a plant to determine the required TOC removal. First is the "3x3" matrix which is included in the rule and requires a 15 to 50 percent TOC removal based on raw water TOC concentration and alkalinity. This matrix is the same for plants that also practice softening. If a plant can obtain the percent removal required in this matrix, then this will be their requirement. If a plant cannot meet the percent removal requirement, then they can do a series of jar tests increasing the alum dose by 10 mg/l (or other coagulant by the same weight ratio) until the increased amount of TOC removed each time is below 0.3 mg/l. The TOC removal determined by the jar tests will be their requirement.

Exemptions from enhanced coagulation requirements are based on running annual average and include:

- If a plant can show that their raw water TOC level, as measured by specific UV absorbency, is below 2.0 liter/mg-m.
- If settled water TOC is less than 2.0 mg/l.
- Complete lime softening plants.
- TTHM less than 40 ug/l and HAA5 less than 30 ug/l using only free chlorine for disinfection.
- TTHM less than 40 ug/l and HAA5 less than 30 ug/l and raw water TOC less than 4.0 mg/l and alkalinity greater than 60 mg/l as $CaCO_3$.

Disinfection Requirements.

These requirements include a Maximum Disinfection Residual Level (MDRL) based on a running annual average as follows:

- Chlorine 4.0 mg/l,
- Chloramine 4.0 mg/l, and
- Chlorine dioxide 0.8 mg/l.

Ozone and UV are also used for disinfection in water treatment. These disinfection processes do not carry a residual, but they may still play a part in the generation of DBP.

The currently proposed M/DBP rule is allowing disinfection credit prior to filtration to be retained. If a plant is not meeting the MCLs for disinfection byproducts, they may need to consider other options. This may include not starting disinfection until after precursor TOC has been removed. They may need to consider enlarging or baffling their clearwell to increase the disinfection contact time. If a plant exceeds 80 percent of the DBP levels (64 mg/l TTHM and 48 ug/l HAA5), then they will have to do disinfection benchmarking. This will lock the plant into a specific disinfectant and dose, and may force them to have to consider other treatment processes for removal of DBP.

Turbidity Standards.

These standards are an important measure of water treatment effectiveness. This has taken on even more importance because of the link between turbidities below 0.1 NTU and the removal of cryptosporidium. The proposed turbidity standards for water from combined filters is required to be below 0.3 NTU in 95 percent of samples. This is more stringent than the previous requirement of 0.5 NTU. Levels must always be below 1 NTU, down from the 5 NTU previously required.

Continuous turbidity monitoring is required for individual filters and the requirements are proposed:

- State notification if greater than 1.0 NTU.
- Filter profile if turbidity is greater than 1.0 NTU for 3 months.
- Third-party evaluation if turbidity is greater than 2 NTU for 2 months.

The District should continue to monitor the progress of these regulations in order to be aware of the requirements being applied to their customers.

4.1.2 Water Quality Conditions

The District has developed a long-term approach for determining water quality conditions of their water supplies. Elements of this program include monitoring, modeling, and management activities. These activities are discussed below.

4.1.2.1 Monitoring Program

The District's water quality monitoring program has been in place since 1989. The program involves a combination of routine quarterly sampling of all reservoirs and intensive monthly sampling of one reservoir approximately each year on a rotating basis. The program includes multiple sampling stations located within the main lake and cove areas of each reservoir. In recent years, the District has also begun sampling at additional stations located on the tributaries just upstream of the reservoirs. Data for approximately 25 different water quality parameters have historically been collected at these stations. These parameters are listed in Table 4-1.

4.1.2.2 Modeling Program

The District has developed eutrophication models for four of their water supply reservoirs (Eagle Mountain, Cedar Creek, Richland-Chambers, and Benbrook) using the U.S. Environmental Protection Agency's Water Quality Analysis Simulation Program (WASP). The parameters marked with an asterisk in Table 4-1 are modeled with the WASP models. Additional parameters considered in the modeling include organic nitrogen and organic phosphorus. The WASP models are useful tools for managing the water quality of these reservoirs as they provide a means for investigating the effects from various hydrologic and watershed development scenarios. Specifically, these tools provide support for making decisions regarding the alternatives for managing various point and non-point source loading conditions based on the simulated impacts to the water bodies. The models allow finite management resources to be targeted toward the areas and issues estimated to be of most significance with regard to water quality. The data collected through the District's sampling program are critical to the development of reliable models. Data from different time periods are required to calibrate and verify the models. A long-term sampling program also provides information required to

Table 4-1.
Tarrant Regional Water District
Water Quality Sampling Data

Parameter	*Units*	*Parameter*	*Units*
Algae	cells/ML	OPO4-P	mg/L
Alkalinity	mg/L	ORP	mv
BOD20	mg/L	pH	std. units
*BOD5	mg/L	Potassium	mg/L
Calcium	mg/L	SECCHI Depth	m
Chloride	mg/L	Silica	mg/L
*CHL_{-a}	ug/L	Sodium	mg/L
Color	Units	SPC	umhos/cm
*Dissolved Oxygen	mg/L	STKN	mg/L
OEC	mg/L	Sulfate	mg/L
Fecal Coliform	Col/100ml	TDS	mg/L
Iron	mg/L	Temperature	degree C
Ke	1/m	TKN	mg/L
Lead	mg/L	TOC	mg/L
Magnesium	mg/L	TOX	mg/L
Manganese	mg/L	TPO4-P	mg/L
*NH3-N	mg/L	TSS	mg/L
NO2+NO3-N	mg/L	TTHMF	
NO2-N	mg/L	VSS	mg/L
*NO3-N	mg/L		

***State variable in WASP model.**

begin to understand the seasonal phenomena at work, and to identify any trends that may be developing.

The District has conducted some evaluations of water quality conditions in two of their reservoirs under drought conditions. The analysis was primarily on data collected during the recent drought period from October 1995 through September 1996. Input files were developed for the existing WASP models for Eagle Mountain Lake and Richland-Chambers Reservoir, which reflected, flows, loads, temperature, and light conditions for this time period. The observed chlorophyll-a levels in the reservoirs where only slightly lower during the drought period as compared to data collected in recent years under more normal hydrologic conditions. The initial WASP drought models tended to under-predict chlorophyll-a concentrations due to the drastic reduction in nutrient loading from non-point sources. Appropriate adjustments were made to the tributary inflow loads in the models to achieve satisfactory calibrations of the models to the observed data. The District is currently utilizing these drought models to evaluate the water quality impacts from various future development and loading scenarios.

During the past several years, the District has also undertaken a program to develop watershed runoff models to investigate the quality of runoff, the potential impacts upon reservoir water quality, and the possible use of structural and non-structural controls. One important element of this program has been the application of the basin simulation model SWAT as part of a cooperative program with the Natural Resources Conservation Service (NRCS). SWAT is being used as a tool to assess the non-point source pollution in the watersheds contributing to the District reservoirs. By identifying the source and non-point source loadings from subwatersheds and basins, the District can prioritize the best management practices for improving or protecting water quality. This program has been linked to the District's reservoir water quality models. Refinements to these models are presently being made as part of an ongoing project.

4.1.2.3 Water Quality Management

The District has approached the management of water quality on several fronts including water quality monitoring and wetland management pilot programs. As discussed previously, the water quality monitoring program has assessed the concentrations of conventional organic and inorganic constituents, nutrients, metals, disinfection byproducts, and bacteria. The District has sampled for cryptosporidium and giardia at water intakes for their customers even before this practice was required by the information collection rule. The basin-wide and reservoir modeling programs have utilized the data collected by the District to determine the trends in water quality and the impacts of various management practices.

The District is also carrying out a multi-year program to investigate the effectiveness of wetlands for removing pollutants from potential water supply sources such as the Trinity River in the vicinity of Richland-Chambers and Cedar Creek reservoirs. The District has been operating a pilot-scale wetland for several years. The next step in the program is to construct a field-scale wetland for additional testing. If the results of these tests are favorable, full-scale wetlands could be developed at Richland-Chambers and Cedar Creek reservoirs to improve the water quality of Trinity River diversions before the water enters the reservoirs. Thus far, the pilot-scale wetland has been studied for the ability to remove suspended sediments, nutrients, metals, pesticides, arsenic, total organic carbon, and several other constituents. Future plans include investigating the ability of the wetlands to remove cryptosporidium, giardia, and disinfection byproducts.

The combination of monitoring, modeling, and pilot studies being carried out by the District is a reasonable and thorough approach to the protection and management of the water quality of their water supplies.

4.2 Customer Water Treatment Facility Considerations

The water quality of Richland-Chambers Reservoir and Cedar Creek Reservoir differ, and the cost to treat the water differs accordingly. Managers of the water treatment plants on the Richland-Chambers and Cedar Creek supply system were interviewed regarding the cost difference of treating water from the two reservoirs and about the effect on water treatment operations. An initial interview was followed by a survey that solicited additional information regarding treatment processes used to treat Richland-Chambers and Cedar Creek water, and the resulting costs. This chapter summarizes the information provided by the treatment plant managers. A copy of the survey responses is provided in Appendix E.

4.2.1 System Description

Water from Richland-Chambers and Cedar Creek reservoirs is a major source of water supply for five treatment plants in Tarrant County: Mansfield Water Treatment Plant (WTP), Trinity River Authority Tarrant County WTP, Arlington J.F. Kubala WTP, Arlington Pierce-Burch WTP, and Fort Worth Rolling Hills WTP. The process flow diagrams for each of these plants are presented in Figures 4-1 through 4-5.

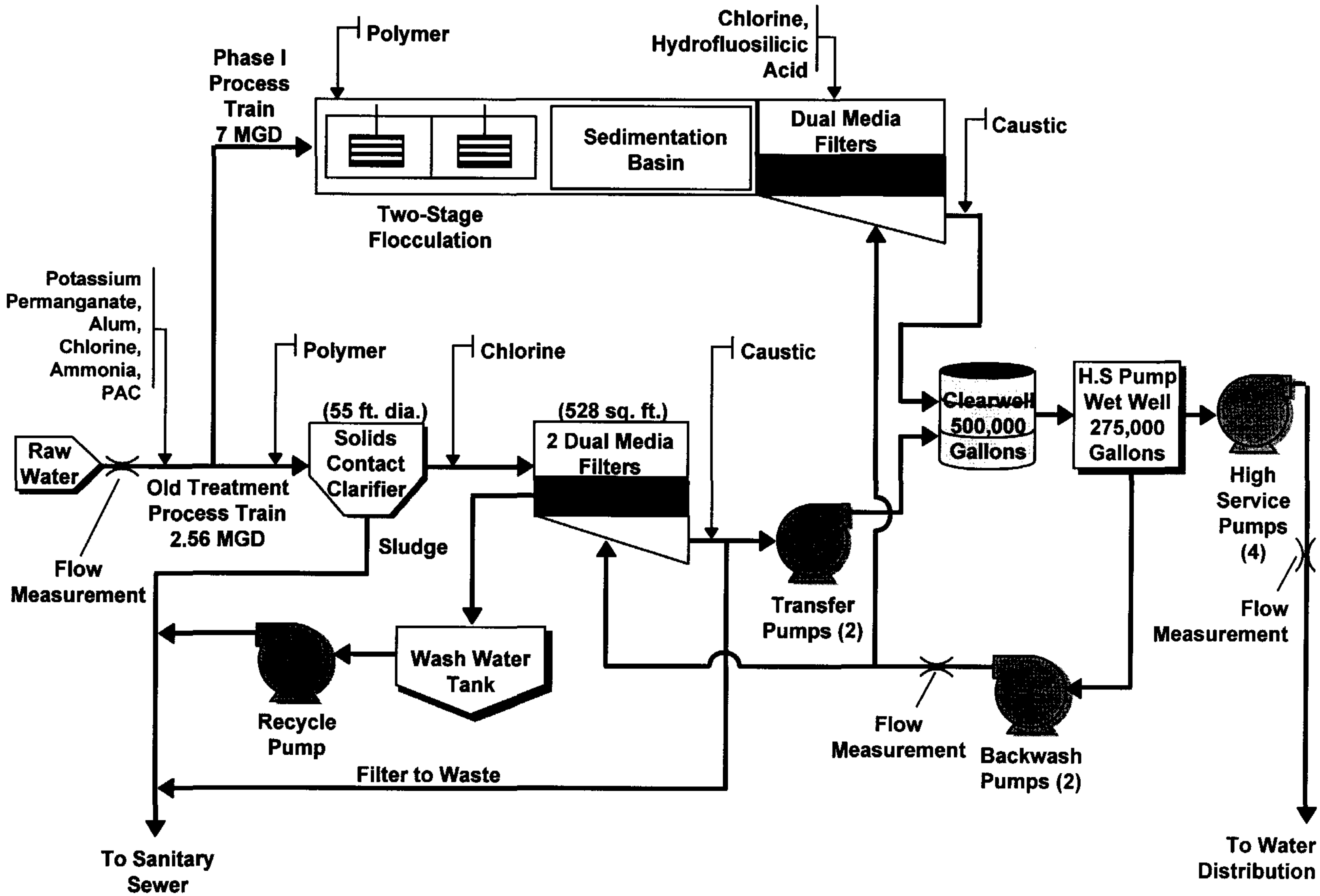
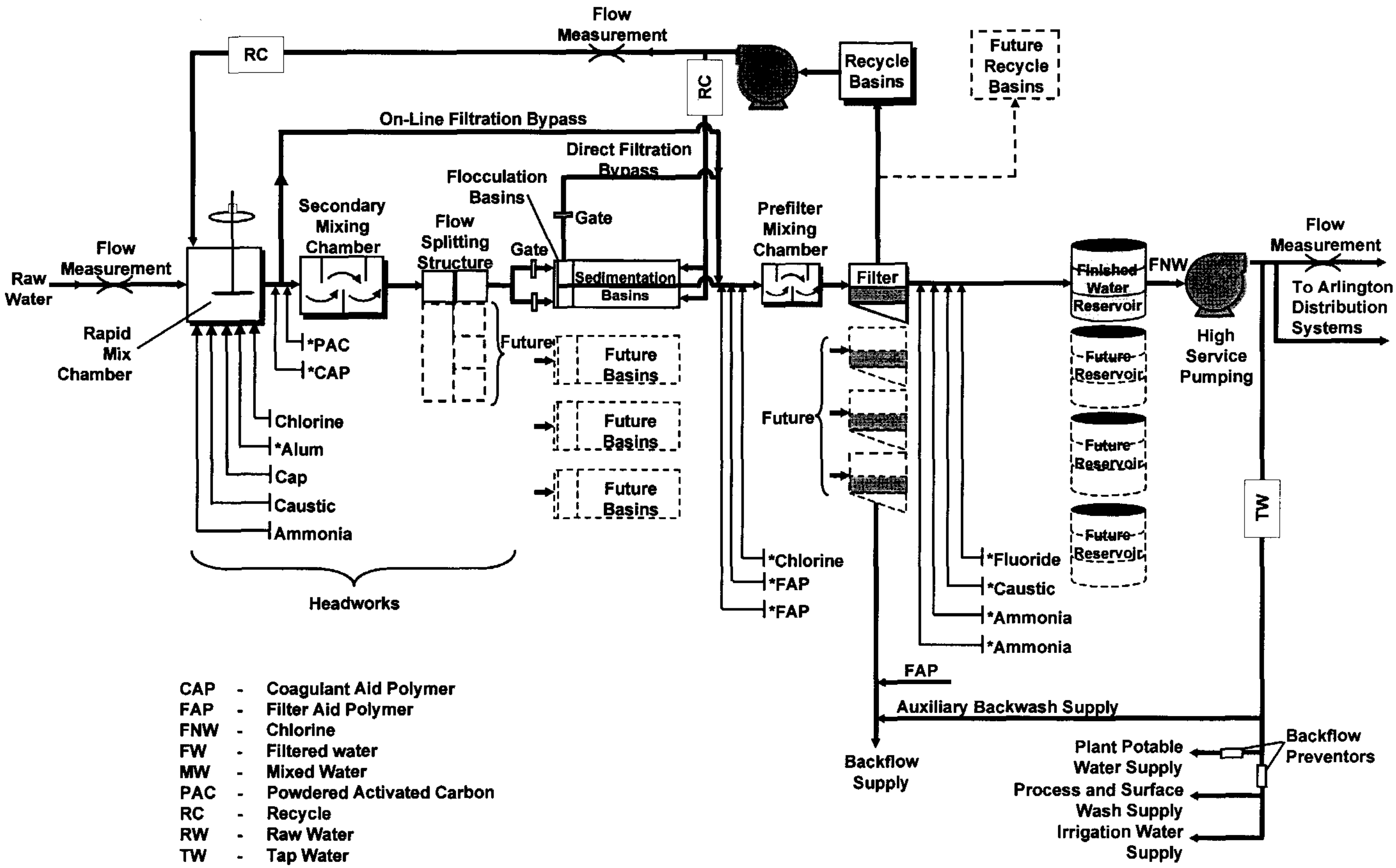


Figure 4-1. Treatment Schematic — City of Mansfield WTP



CAP - Coagulant Aid Polymer
FAP - Filter Aid Polymer
FNW - Chlorine
FW - Filtered water
MW - Mixed Water
PAC - Powdered Activated Carbon
RC - Recycle
RW - Raw Water
TW - Tap Water
* - Chemical Typically Fed at Each Location

Figure 4-2. Treatment Schematic — City of Arlington — J.F. Kubala WTP

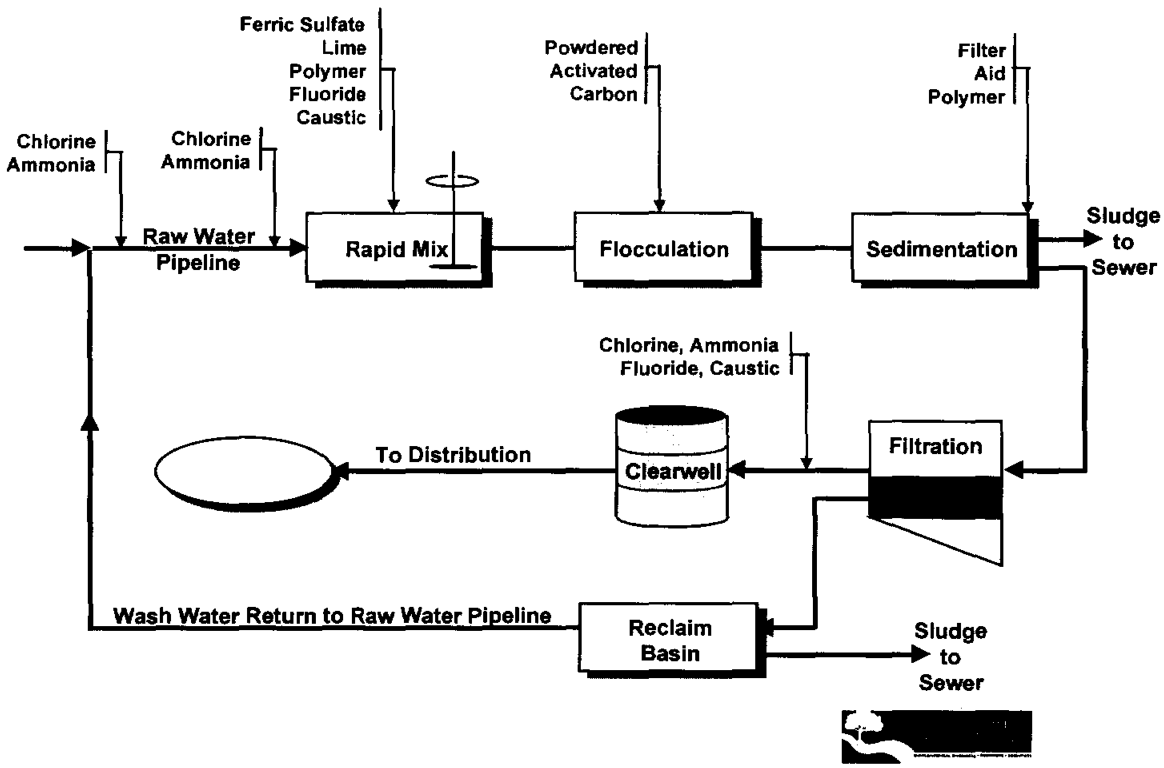


Figure 4-3. Treatment Schematic — City of Fort Worth — Rolling Hills WTP

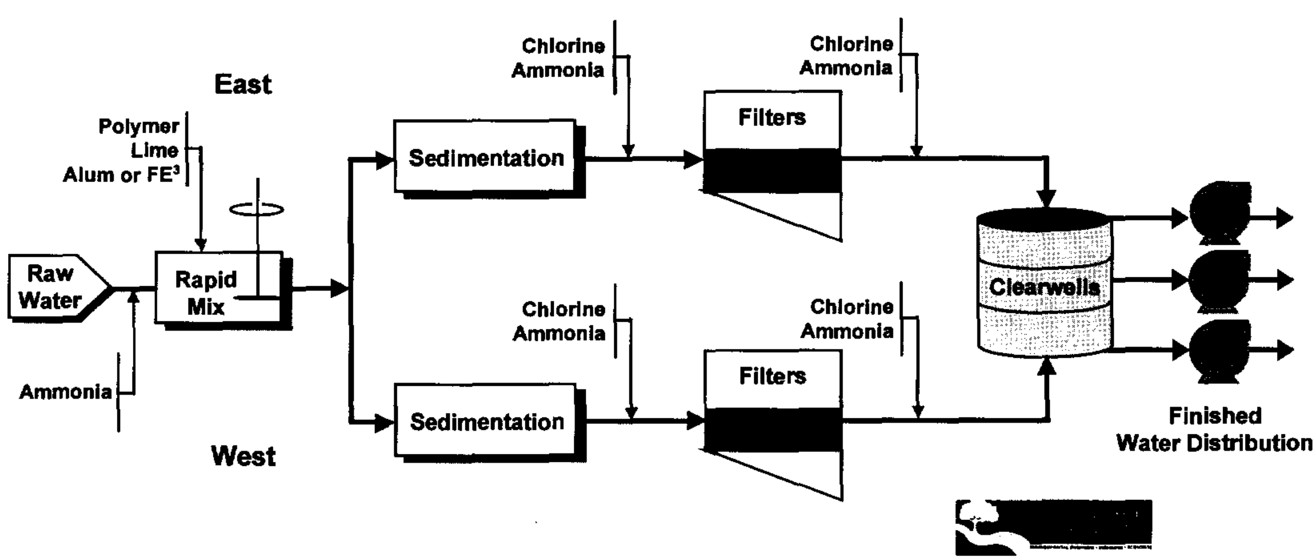


Figure 4-4. Treatment Schematic — Trinity River Authority — Tarrant County WTP

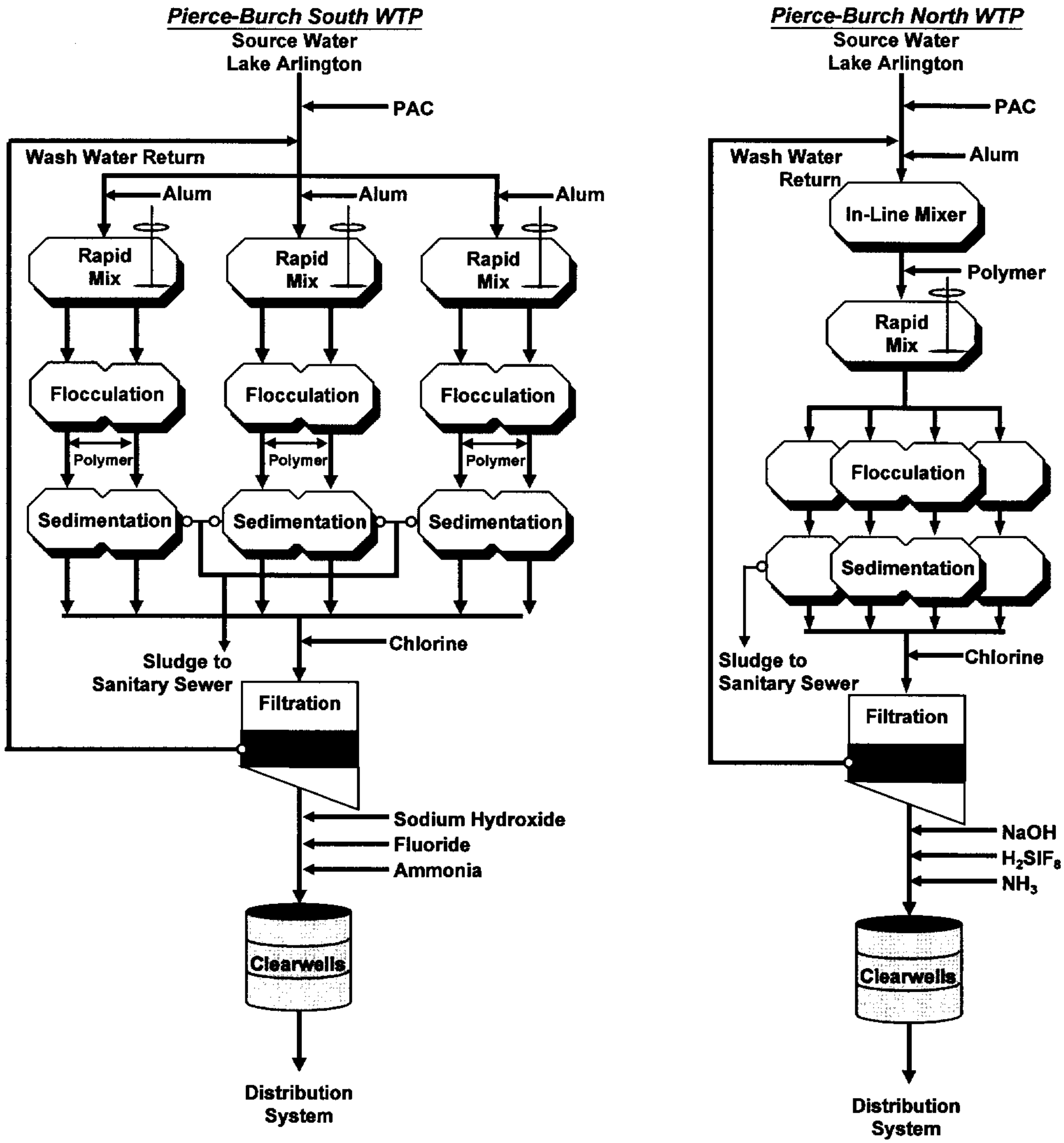


Figure 4-5. Treatment Schematics — Arlington Water Utilities

A review of the processes shows that each of the plants use some type of chemical addition followed by settling, filtration, and disinfection. The chemicals used at each plant are shown in Table 4-2. Variations in source water quality affect the amount and type of water treatment chemicals used to produce finished water of a high quality.

Table 4-2.
Tarrant Regional Water District
Richland-Chambers/Cedar Creek Reservoir Supply System
Customer Water Treatment Plant Chemicals

Arlington — J.F. Kubala Water Treatment Plant	
Aluminum Sulfate	Coagulant
Sodium Hydroxide	pH Adjustment
Powdered Activated Carbon	Taste and Odor
Potassium Permanganate	Taste and Odor
Coagulant Aid Polymer	Coagulation
Chlorine	Taste and Odor/Disinfection
Filter Aid Polymer	Filtration
Ammonia	Disinfection
Fluoride	Fluoridation
Arlington — Pierce Burch Water Treatment Plant	
Aluminum Sulfate	Coagulant
Sodium Hydroxide	pH Adjustment
Powdered Activated Carbon	Taste and Odor
Coagulant Aid Polymer	Coagulation
Chlorine	Taste and Odor/Disinfection
Ammonia	Disinfection
Fluoride	Fluoridation
Fort Worth Rolling Hills Water Treatment Plant	
Ferric Sulfate	Coagulant
Chlorine	Disinfection
Ammonia	Disinfection
Lime	Flocculation
Polymer	Coagulation
Fluoride	Fluoridation
Caustic	pH Adjustment
Powdered Activated Carbon	Taste and Odor
Filter Aid Polymer	Filtration

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Table 4-2.
Tarrant Regional Water District
Richland-Chambers/Cedar Creek Reservoir Supply System
Customer Water Treatment Plant Chemicals (Concluded)

Trinity River Authority — Tarrant County Water Treatment Plant	
Aluminum Sulfate	Coagulant
Lime	Coagulant Aid
Ferric Chloride	Coagulant
Polymer	Coagulant Aid
Ammonia	Disinfection
Chlorine	Disinfection
Mansfield Water Treatment Plant	
Potassium Permanganate	Taste and Odor
Aluminum Sulfate	Coagulant
Chlorine	Disinfection
Ammonia	Disinfection
Powdered Activated Carbon	Taste and Odor
Polymer	Coagulant Aid
Hydrofluorosilicic Acid	Fluoridation
Caustic	pH Control

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4.2.2 Impact of Water Quality Variations

Of the five plants surveyed, only three were directly affected by changing the source of water from the Richland-Chambers to the Cedar Creek Reservoirs. The plants affected include Arlington J.F. Kubala, Fort Worth Rolling Hills, and Mansfield. Each of these plants draws water directly from the transfer line or from the balancing reservoirs. The other two plants surveyed, Arlington Pierce-Burch and Trinity River Authority Tarrant Country, draw water from Lake Arlington. Lake Arlington, which receives considerable runoff from tributaries, serves as a buffer to raw water quality coming from the District's East Texas reservoirs. The following discussion will focus primarily on responses from the operators of the three plants that receive water directly from the system.

Each of the respondents from treatment plants which receive water directly from the transmission line or balancing reservoirs indicated that there was a difference in treatment requirements for water from Richland-Chambers and Cedar Creek Reservoirs. They indicated that water from Cedar Creek was the more costly water to treat. They also indicated that the higher costs were not occasional, but consistent occurrences when Cedar Creek raw water was the predominant water source.

The City of Fort Worth has developed costs for treating the different source waters and source water blends. These costs are presented in Table 4-3.

With regard to the impact of the raw water quality on chemical dosages, the increases in chemical dosages were required for treatment of Cedar Creek water compared to the dosage required for Richland-Chambers water (Table 4-4).

The cost of treated water is directly related to the cost of the chemicals used in treatment and the cost of disposing of sludges.

Table 4-3.
City of Fort Worth Water Treatment Plant
Costs of Treating Different Source Waters

Water Source	Chemical Costs/MG	Operations Costs/MG	Sludge Management Costs/MG
RC — 100%	$26.54	$11.43	$29.49
RC — 70% CC — 30%	$21.91	$10.55	$16.25
RC — 35% CC — 65%	$34.47	$16.57	$40.34
CC — 100%	$36.00	$14.49	$39.85
Note: RC = Richland-Chambers Reservoir, CC = Cedar Creek Reservoir			

Table 4-4.
Approximate Increase in Chemical Dosage Required to Treat Cedar Creek Water Compared to Richland-Chambers

Aluminum Sulfate, 15 mg/L	Ferric, 63 mg/L
Caustic, 2.5 mg/L	Polymer, 0.45 mg/L
Carbon, 5 m/L	Lime, 4.9 mg/L

4.2.3 Raw Water Characteristics Affecting Treatment

With regard to the raw water characteristics that most affect treatment, unexpected changes in the source of raw water, and taste and odor were the top two problems. Particle sizes in the 5 to 20 *u*m range were noted as a problem in Cedar Creek water. Rapid changes in alkalinity and pH, and turbidity also cause problems. Turbidity problems have occurred year round; taste and odor problems tend to be seasonal. For the City of Fort Worth, the low alkalinity encountered in the Cedar Creek water resulted in complaints from some of their commercial customers.

4.2.4 Management Issues Affecting Water Treatment

All of the customers taking water directly from the transmission line commented on management issues that affect their ability to effectively and efficiently produce high-quality finished water. A significant operational problem occurs for the water treatment plants when unexpected changes occur in the source water quality. It is beneficial for the treatment plants to receive notice of changes in raw water source or quality before it occurs in order to prepare for the different treatment requirements. Early notices provide the opportunity to get samples of the water quality as a switch in source occurs in order to perform jar testing and obtain an indication of chemical dosages needed.

Treatment plant operators suggested that a gradual switch involving blending from one raw water source to the other would provide the water customers some acclimation time for the new water characteristics, and would cut down on complaints.

4.2.5 Summary

The water treatment plants being supplied by Richland-Chambers and Cedar Creek Reservoirs have the capability of treating the variable water qualities associated with the two water sources. Water from Cedar Creek Reservoir is more costly to treat. Unexpected changes in the source of the water causes complications in treatment. Treatment plant operators have indicated that to efficiently and cost-effectively treat the water, the District should implement a more effective system of communication regarding changes in water supply and should consider adding flexibility to their raw water delivery system.

Section 5

Integrated Supply Plans and Long-Range Supply Planning

Section 5
Integrated Water Supply Planning

Integrated water supply planning provides the District a framework and methodology in which to incorporate the diverse elements that must be considered in today's water supply business environment. Previous planning programs of the District have successfully met the growing water demands of the Tarrant County area and provide a strong foundation as the District looks forward into the next century. The planning horizon is 50 years, from year 2000 to 2050, although the District must always take into consideration its water needs on an even larger horizon. Prudent planning, both for near-term and long-term actions, provides ample time for the District to make wise decisions regarding permitting, operational methods for existing facilities, and investment in new facilities.

The supply elements to be integrated into water supply planning for the District include:

- Customer involvement (i.e., review and input to the integrated planning);
- Water conservation and demand management;
- Maximization of supply from existing sources;
- Delivery system capabilities; and
- Supply side alternatives.

The need for new water supplies to meet the District's growing demands was discussed in Section 3.1.4. In Section 3.2, the water management options and supply elements available to the District to meet projected demands were discussed. Presented in this section are the current capacity of District facilities to deliver water, the management options and supply elements to be included in the integrated plans, and two integrated water supply plans. For each of the integrated plans the water supply available from each element is summarized, the new delivery facilities needed to implement the plans are identified, and cost estimates for plan elements needed in the near- to mid-term (i.e., next 25 years) are presented. Costs for new supply reservoirs and associated delivery facilities need further study before estimates can be made.

5.1 Existing Facilities and Capacities

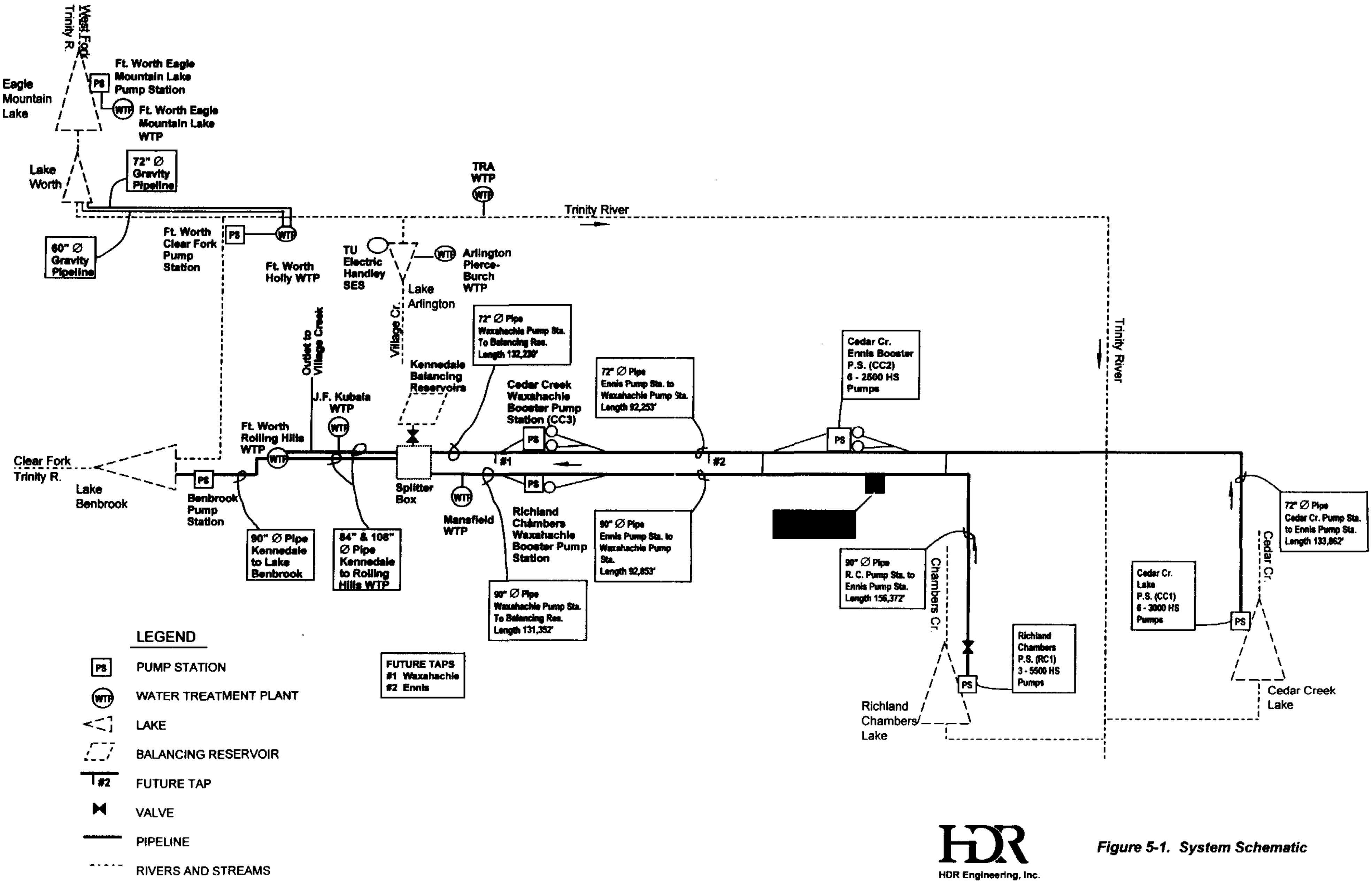
5.1.1 West Fork Facilities

The District's water supply system is divided geographically into the West Fork facilities (Eagle Mountain Lake, Lake Bridgeport, Lake Benbrook, and Lake Worth) and the East Texas facilities (Cedar Creek Reservoir and Richland-Chambers Reservoir). The District's water supply facilities are shown on an area map in Figure 1-1. A system schematic of the District facilities is provided in Figure 5-1.

The West Fork System supplies water to the Eagle Mountain WTP and the Holly WTP. The Eagle Mountain WTP is supplied water from a pump station located just downstream of Eagle Mountain Lake, and can receive water from Eagle Mountain Lake and from Lake Bridgeport. The Holly WTP receives water from the West Fork through an intake on Lake Worth. Water flows by gravity through two pipelines (60-inch and 72-inch diameter) from Lake Worth to Holly WTP. Holly WTP can also receive water from Lake Benbrook on the Clear Fork. Water is released from Lake Benbrook and flows down the Clear Fork channel to an intake structure and pump station just upstream of the confluence with the West Fork. These facilities are shown in schematic form in Figure 5-1. Delivery capacities of the West Fork delivery facilities are listed in Table 5-1.

5.1.2 East Texas Facilities

Water from the East Texas reservoirs must be pumped about 75 miles against a 400-foot static lift to reach Tarrant County. Currently, pumping capacity from each of the East Texas reservoirs is less than the safe yield of the reservoirs. Water from Cedar Creek Reservoir is pumped through a 72-inch diameter pipeline and discharges into the splitter box at the balancing reservoirs at Kennedale. The Cedar Creek pipeline has a pump station at the lake and two booster pump stations, one at Ennis and one at Waxahachie, as shown in Figure 5-1. The pipeline has two operational modes: low capacity operation and high capacity operation. Under low capacity operation, the Ennis booster station is not operated. The capacities of the Cedar Creek delivery facilities are provided in Table 5-2. The Cedar Creek pipeline supplies the Arlington J.F. Kubala WTP directly from a tap on the pipeline. Interconnects to the Richland-



HDR Engineering, Inc.

Figure 5-1. System Schematic

Table 5-1
West Fork Supply and Water Delivery Facility Capacities

West Fork Supply Current Year 2015 Year 2050	 78,000 acft/yr 74,000 67,000
Eagle Mountain Lake	
Raw Water Pump Station to Eagle Mountain WTP (capacity after planned expansion will be 190 MGD)	30 MGD (33,600 acft/yr)
Lake Worth	
to Holly WTP Intake and Gravity Pipelines 60-in dia. pipeline 72-in dia. pipeline	 160 MGD (179,000 acft/yr)
Lake Benbrook	
to Holly WTP Clear Fork Pump Station	 60 MGD (67,000 acft/yr)

Table 5-2
East Texas Yield and Water Delivery Facility Capacities

Cedar Creek Reservoir	
Reservoir Safe Yield Current year 2015 year 2050	 154,900 acft/yr 148,000 acft/yr 135,600 acft/yr
72-in pipeline pumping capacity Low Capacity Operation High Capacity Operation	 78 MGD 147 MGD (165,000 acft/yr)
Richland-Chambers Reservoir	
Reservoir Safe Yield Current year 2015 year 2050	 202,100 acft/yr 195,200 acft/yr 174,400 acft/yr
90-in pipeline pumping capacity Low Capacity Operation Future High Capacity Operation[1]	 146 MGD (163,500 acft/yr 244 MGD (273,000 acft/yr)
1 Additional pumps must be installed at existing pump stations to operate in high capacity mode.	

Chambers pipeline allow Cedar Creek water to be pumped through the Richland-Chambers pipeline or Richland-Chambers water to be pumped through the Cedar Creek pipeline as shown in Figure 5-1.

Water from Richland-Chambers Reservoir is pumped through a 90-inch diameter pipeline and discharges into the splitter box at the balancing reservoirs at Kennedale. The Richland-Chambers pipeline has a pump station at the lake and two booster pump stations, one at Ennis and one at Waxahachie, as shown in Figure 5-1. The pipeline has two planned operational modes: low capacity operation and high capacity operation. Under low capacity operation, the Ennis booster station would not be operated. Currently, the booster pumps at the Ennis booster pump station that are necessary to operate the pipeline in high capacity mode are not installed. Therefore, the Richland-Chambers pipeline currently can only be operated in low capacity mode. The capacities of the Richland-Chambers delivery facilities are provided in Table 5-2. The Richland-Chambers pipeline supplies the Mansfield WTP directly from a tap on the pipeline. Interconnects to the Cedar Creek pipeline allow Cedar Creek water to be pumped through the Richland-Chambers pipeline or Richland-Chambers water to be pumped through the Cedar Creek pipeline, as shown in Figure 5-1.

From the splitter box at the Kennedale balancing reservoirs, 84-inch and 108-inch pipelines supply water to the Arlington outlet and to the Rolling Hills WTP. The Arlington outlet discharges water to Village Creek at the upper end of Lake Arlington. Three customers draw water from Lake Arlington: the Arlington Pierce-Burch WTP, the Trinity River Authority WTP, and the TU Electric Handley generating station. Connected to the splitter box at the Rolling Hills WTP reservoirs is a 90-inch pipeline that discharges to Lake Benbrook, allowing water from the East Texas reservoirs to be delivered to Holly WTP. An intake and pump station at Lake Benbrook allows water stored in Lake Benbrook (typically, East Texas reservoir water) to be pumped in the 90-inch pipeline back to the Rolling Hills WTP.

5.2 Need for New Water Supplies and Facilities

A comparison of projected water demands and supplies was presented in Section 3.1, which indicates that presently available supplies (about 430,000 acft/yr) can meet projected demands through year 2009 (Table 3-5). By 2020, demands are projected to exceed current supplies by 67,051 acft/yr, and in year 2050, demand would exceed supply by 208,083 acft/yr (Table 3-5 and Figure 3-2).

5.3 Integrated Water Supply Plan

An integrated water supply plan for the District will consist of an integrated approach to demand side and supply side issues. On the demand side, achievement of conservation goals by each of the customers will be an important element to defer investment in new supply side projects. On the supply side, the integrated plan elements involve not only water supply at the source, but also delivery system items (i.e., pipeline and pump station expansions).

5.3.1 Maximizing Existing Water Supply Resources

Several options are available to the District to maximize existing water supply resources and potentially delay construction of additional water supply projects. Options available involve operational changes of the East Texas reservoirs or augmentation with reuse water. Water supply options include:

- Water conservation (Section 2);
- Overdraft/underdraft of East Texas reservoirs (Section 3.2.4);
- Changes in reservoir drought reserves (Section 3.2.5); and
- Water reuse (Section 3.2.1).

5.3.1.1 Water Conservation

Water conservation is a demand-side component that should be a part of the integrated water management plan. As described in Section 2, it is planned that organized water conservation programs will be used in the District's customer cities and water supply districts to reduce water demand. These organized programs will be in addition to water conservation achieved through the use of low-flow plumbing fixtures. Such programs could include incentives to replace existing fixtures with low-flow fixtures, use of drought tolerant landscaping to reduce lawn water, leak detection and repair, and water conservation pricing. The District has worked with the major wholesale municipal customers to establish conservation goals, as shown in Table 5-3.

Table 5-3
Water Conservation Goals for Tarrant Regional Water District
(acft/yr)

	2000	2010	2020	2030	2040	2050
Water Conservation Goal for Wholesale Customers	5,788	13,359	24,099	25,202	25,049	23,082
From Table 2-4.						

5.3.1.2 Water Reuse

The District is proposing to increase its available raw water supply by developing reuse projects at Richland-Chambers and Cedar Creek Reservoirs. These projects involve diverting wastewater return flows from the Trinity River into Cedar Creek Reservoir and Richland-Chambers Reservoir, thereby increasing the yield of the reservoirs. The wastewater return flows to be diverted originate from the District's raw water customers as treatment plant discharges into primarily the West Fork of the Trinity River. The source of the diverted wastewater return flows will be raw water initially supplied by the District to its customers from either Richland-Chambers and Cedar Creek reservoirs, or from other District reservoirs in the upper Trinity River Basin. Yields available from the reuse project are reported in Table 5-4.

Table 5-4
Trinity River Project Available Yield

	Yield Increase Due to Reuse Project[1] (acft/yr)	Total Yield (acft/yr)	Minimum Drought Storage Reserve (acft)
Richland-Chambers Reservoir	63,000	273,000	147,896
Cedar Creek Reservoir	52,500	227,500	106,739
Combined Project	115,500	500,500	254,635
1 Yield increase is predicated on adjusting minimum drought supply reserves from 197,000 acft to 147,896 acft in Richland-Chambers and from 157,000 acft to 106,739 acft in Cedar Creek Reservoir.			

Source: R.J. Brandes Co., "Yield Analysis of Trinity River Project", prepared for Tarrant Regional Water District, June 1998.

5.3.1.3 Systems Operation of East Texas Reservoirs

As described in Section 3.2.4, a potential increase in system yield is available if the East Texas Reservoirs are operated as a system[1].

While the option of systems operation of the East Texas reservoirs appears to be a potentially favorable option, providing approximately 43,600 acft/yr (Table 3-31) additional yield over the sum of the current East Texas permits, there are two major implementation issues resulting in this option not being included in the integrated plan. First, in order to produce the additional yield, the capacity of the raw water pipelines from each reservoir must be considerably increased. The maximum monthly diversions needed when the associated reservoir is in overdrafting mode are large. Current capacity from East Texas would have to be increased by approximately 400 MGD (equivalent of a 120-inch pipeline) to accommodate the peak pumping months. In addition to potentially expensive increases in pumping capacity, this option, by its nature, hinders the ability of the District to develop reuse water from the Trinity River by continually drawing down one of the two reservoirs. Under systems operation, the ability of one or both of the reservoirs to accept reuse water would be limited much of the time if the operational blending criteria are to be met. Other important implementation issues include the potential effects on recreation and fish habitat at the reservoir being overdrafted.

5.3.1.4 Reservoir Drought Reserves

As described in Section 3.2.5, there is a potential increase above permitted diversions in 2050 of 18,800 acft/yr at Cedar Creek Reservoir (Table 3-10) if drought reserves are reduced to zero. At Richland-Chambers Reservoir, reducing the drought reserve to zero results in a potential increase above permitted diversions of 6,900 acft/yr in 2050 (Table 3-13). For the two reservoirs combined, the potential increase above permitted diversion is 25,700 acft/yr.

Safe yield is defined as the volume of water that can be diverted each year such that the minimum volume remaining in the reservoir during the most severe drought on record approximates a one-year supply if diverted at the safe annual yield. Under a firm yield operation

[1] System operation would involve overdrafting Cedar Creek Reservoir in wet and average years, and subsequently underdrafting during a drought when Richland-Chambers reservoir would be overdrafted.

plan, there is no drought reserve and the reservoir would be drawn down to approximately zero storage at the end of the critical month during the drought of record.

Maintaining a drought reserve in the reservoir assures that water would be available in the occurrence of a drought more severe than the drought of record. A drought reserve also provides a "shock absorber" in the event water demand increases faster than projected, or unforeseen delays are experienced bringing a supply project on-line.

If chosen to be implemented, reduction of drought reserves should be instituted as a reservoir operations change toward the end of the program and just prior to construction of a new water supply source. Reduction of the drought supply reserve can be implemented gradually as needed to maintain sufficient system yield. The wetlands reuse project yield is predicated on adjusting minimum drought storage amounts from 197,000 acft to 147,896 acft in Richland-Chambers Reservoir and from 157,000 acft to 106,739 acft in Cedar Creek Reservoir. Reducing drought supply reserves below these amounts would increase the ratio of reuse water to natural inflow and potentially affect water quality in the reservoirs. Following construction of a new water supply project, operation of the District reservoirs can be returned to a higher drought supply reserve (i.e., back to safe yield operation).

5.3.2 New Supply Reservoirs

There are a number of existing or new water supply reservoirs that could potentially provide a new water supply to the District. These projects are described in Section 3.2.3. One of these projects, Tehuacana Reservoir, has been in the long-range plan of the District, since Richland-Chambers Reservoir was conceptualized. Tehuacana Reservoir would be adjacent to Richland-Chambers Reservoir and interconnected with it by a canal.

A second reservoir that could potentially be included in the long-range planning of the District is Marvin Nichols I Reservoir in the Sulphur River Basin.

5.3.2.1 Tehuacana Reservoir (Trinity River Basin)

The 1997 Texas Water Plan[2] recommends that Tehuacana Reservoir be constructed and this project is the only recommended water supply reservoir in the upper Trinity River Basin.

[2] Texas Water Development Board (TWDB), "Water for Texas", August 1997.

Tehuacana Reservoir would be located on Tehuacana Creek in Freestone County and is immediately south of Richland-Chambers Reservoir. The reservoir is planned to be interconnected with Richland-Chambers Reservoir by an open channel to allow water from Tehuacana to flow into Richland-Chambers and the Richland-Chambers spillway is sized to handle flow from Tehuacana Creek. This project has been a part of the District's water supply planning since it was first proposed[3] in the 1950s. Yield available from the project would be 65,547 acft/yr[4]. This project could also be developed in conjunction with the Trinity River Reuse Project (Section 3.2.1), which would increase the yield available from the reservoir.

5.3.2.2 Sulphur River Basin Reservoirs

The 1997 Texas Water Plan[5] recommends two new water supply projects be built in the Sulphur River Basin, Marvin Nichols I Reservoir, and George Parkhouse II Reservoir. These projects could be used to meet local needs as well as the needs of the Fort Worth area and perhaps the Dallas area as well.

The Marvin Nichols I project would be located on the Sulphur River in Red River, Morris, and Titus counties and is about 160 miles northeast of Tarrant County (Figure 3-16). (Note: Marvin Nichols II reservoir would be a project adjacent to Nichols I, but on White Oak Creek.) The Nichols I project is downstream of the Parkhouse II site and the yield of the Nichols I project would be lower if built after Parkhouse II. The Nichols I project yield, without Parkhouse II being constructed would have a yield[6] of 560,151 acft/yr. If Parkhouse II is constructed first, then Nichols I would have a yield of 470,413 acft/yr. The district has indicated an interest in contracting for approximately one-third of the yield of Marvin Nichols I Reservoir, or about 187,000 acft/yr.

5.3.3 West Fork Improvements

The District is considering methods to increase raw water availability in the West Fork of the Trinity River. Additional water supplies would result in significant benefits to the District

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[3] Freese & Nichols, Inc. and Alan Plummer Associates, Inc. "Regional Water Supply Plan for Tarrant County Water Control and Improvement District Number One", 1990.
[4] TWDB, Op. Cit., August 1997.
[5] Ibid.
[6] Ibid.

and its customers through operational flexibility, system reliability, treatability (raw water blending), recreation, and meeting the needs of a high-growth area. One potential method to increase raw water availability in the District's West Fork resources would be to construct facilities to deliver water from the East Texas reservoirs (through the Benbrook connection and Lake Benbrook) to Eagle Mountain Lake. This would also increase the flexibility of all of the District's supply resources by providing a means of transferring water from the West Fork resources to Lake Benbrook and thereby supplementing the East Texas supply. These potential improvements were described in more detail in Section 3.2.2.

5.4 Integrated Supply Plans

The integrated water supply plans of the District include these components:

- Water conservation;
- Augmentation of the East Texas reservoirs with the Trinity River Project;
- Reservoir operation changes (only as needed to meet conditions worse than drought of record or to meet short-term needs prior to implementation of a follow-on project); and
- New supply source – Tehuacana Reservoir or Marvin Nichols I.

Two alternative integrated plans have been developed.[7] Plan 1 includes water conservation, the Trinity River Project, Tehuacana Reservoir, and interim reservoir operation changes (i.e., reduced drought reserves). Plan 2 includes water conservation, the Trinity River Project, and Marvin Nichols I Reservoir in the Sulphur River Basin.

The components of each plan are specified in more detail in Table 5-5, along with the water supply to be obtained from each component.

Figure 5-2 is a plot of projected water demand in the District and existing system supply. Superimposed onto Figure 5-2 is a step-diagram of increased supply with implementation of integrated water supply Plan 1.

As shown in Figure 5-2, achieving water conservation goals would be accomplished gradually throughout the 50-year planning period. The Richland-Chambers portion of the Trinity

[7] The order presented for Plan 1 and Plan 2 is not indicative of a recommended alternative, as elements of each plan will require additional study before plan adoption by the District.

Table 5-5
Integrated Water Supply Plan Components

Plan 1		Plan 2	
Component	**2050 Yield (acft/yr)**	**Component**	**2050 Yield (acft/yr)**
Safe yield operation of existing system	383,000	Safe yield operation of existing system	383,000
Achieve water conservation goals	23,082	Achieve water conservation goals	23,082
Trinity River Project Reuse		Trinity River Project Reuse	
Richland-Chambers Reuse	63,000	Richland-Chambers Reuse	63,000
Cedar Creek Reuse	52,500	Cedar Creek Reuse	52,500
Tehuacana Reservoir	65,547	Marvin Nichols I Reservoir**	187,000
Total 2050 Supply	587,129	Total 2050 Supply	708,582
Projected 2050 Demand	591,083	Projected 2050 Demand	591,083
Potential Shortage*	(3,954)	Potential Shortage	0
* Shortage can be supplied by temporarily reducing drought reserves or by implementing reuse at Tehuacana Reservoir.		** Full project yield is 560,151 acft/yr. TRWD has indicated an interest in contracting for up to 187,000 acft/yr from the project.	

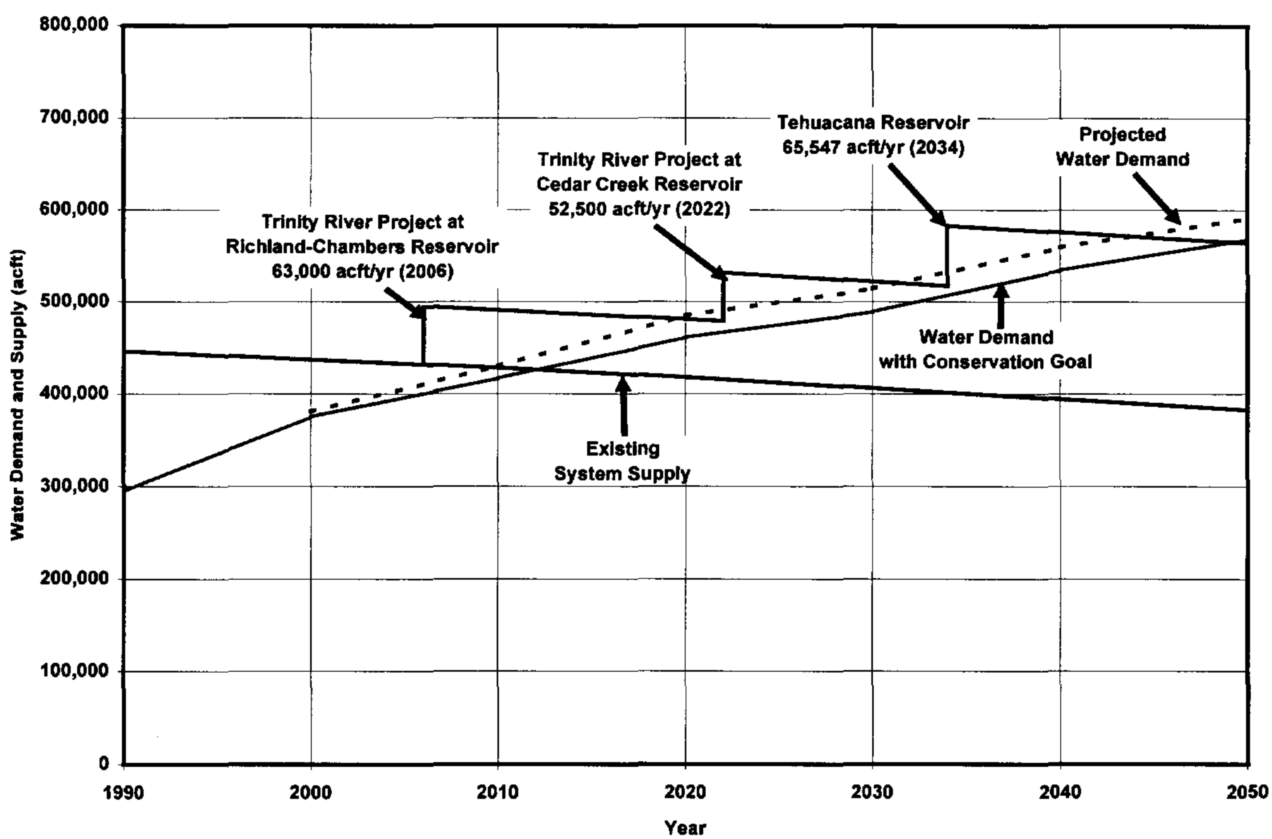

Figure 5-2. Water Demand and Supply with Integrated Water Supply Plan 1

River Project would need to be completed[8] by the end of 2006, and the Cedar Creek portion would be needed by 2022. Supply from the Tehuacana Reservoir Project would be needed by 2034.

Figure 5-3 is a similar graph to Figure 5-2, showing a step-diagram from implementation of integrated water supply Plan 2.

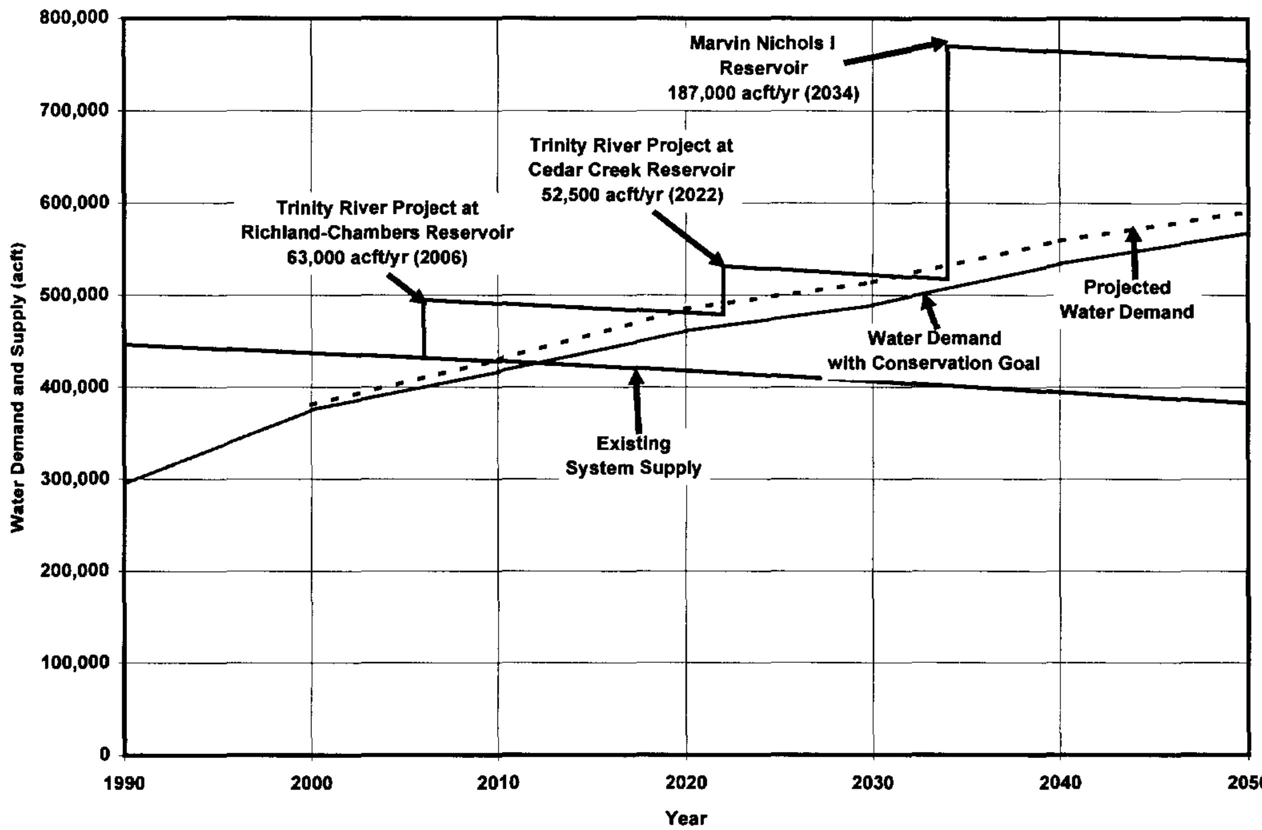

Figure 5-3. Water Demand and Supply with Integrated Water Supply Plan 2

As shown in Figure 5-3, achieving water conservation goals would be accomplished gradually throughout the 50-year planning period.

Also as shown in Figure 5-3, the key dates for implementing the reuse projects are the same as for Plan 1. Supply from the Marvin Nichols I Reservoir project would be needed by 2034. The key implementation dates for each plan are listed in Table 5-6.

[8] Project implementation year is set 3 years prior to date of projected shortage to allow for potential delays or needs greater than projected.

Table 5-6
Implementation Dates for Integrated Water Supply Plan Components

Plan 1		Plan 2	
Component	**Date Needed**	**Component**	**Date Needed**
Achieve water conservation goals	implement by 2005 with gradual increase thereafter	Achieve water conservation goals	implement by 2005 with gradual increase thereafter
Trinity River Project Reuse		Trinity River Project Reuse	
Richland-Chambers Reuse	2006	Richland-Chambers Reuse	2006
Cedar Creek Reuse	2022	Cedar Creek Reuse	2022
Tehuacana Reservoir	2034	Marvin Nichols I Reservoir	2034
Modify Reservoir Operations (reduce drought supply reserves)	2045		

5.4.1 Delivery Facilities Needed

5.4.1.1 Richland-Chambers Facilities

Current delivery facilities have a delivery capacity less than the safe yield of the reservoir. Increased capacity is needed to deliver the safe yield and augmented yield from the reuse project. The increased delivery capacity needed can be estimated as shown in Table 5-7.

Table 5-7
Richland-Chambers Reservoir Delivery System

	Required Pumping Capacity	
Estimated safe yield[1]	195,200 acft/yr 23,400 acft/month[2]	251 MGD
Reuse project yield	63,000 acft/yr 7,600 acft/month[2]	81 MGD
Tehuacana Reservoir Yield	65,547 acft/yr 7,900 acft/month	84 MGD
Total required pumping capacity	38,900 acft/month	416 MGD
Current pumping capacity with 90" pipeline at high capacity		244 MGD
Increased pumping capacity needed		172 MGD
Pipeline diameter from Richland-Chambers Reservoir to Ennis Booster Pump Station (at 9 fps and 5 percent downtime)		84-inch

1 Estimated safe yield in year 2015.
2 Monthly pumping volume is estimated using a maximum summer month delivery factor of 12 percent of annual volume.

The estimated safe yield of Richland-Chambers Reservoir in year 2015 is 195,200 acft/yr. Using a peak month demand factor of 12 percent of annual deliveries, results in a peak month delivery of 23,400 acft/month, or about 251 MGD. With implementation of the reuse project, an additional 63,000 acft/yr is available, and with construction of Tehuacana Reservoir, an additional 65,547 acft/yr is available, for a total yield at Richland-Chambers of 323,747 acft/yr. The peak monthly pumping demand (i.e., 12 percent of annual demand) would be 38,900 acft/yr, or about 416 MGD (Table 5-7). The current pumping capacity of the 90-inch diameter Richland-Chambers pipeline at high capacity operation is 244 MGD, which results in a required pumping and pipeline capacity expansion of 172 MGD (Table 5-7). For a pipeline design velocity of 9 fps and 5 percent downtime, the required pipeline diameter would be 84 inches. If the pipeline were to be built without capacity for Tehuacana Reservoir yield, the increased pumping capacity would need to be 88 MGD, requiring a 54-inch pipeline (at 9 fps and 5 percent downtime).

5.4.1.2 Cedar Creek Facilities

Current delivery facilities at Cedar Creek Reservoir have a delivery capacity about equal to the safe yield of the reservoir (Table 5-2). With implementation of the reuse project, delivery capacity from Cedar Creek Reservoir will need to be increased by about 108 MGD, as shown in Table 5-8. The estimated safe yield of Cedar Creek Reservoir in year 2015 is 145,500 acft/yr. Using a peak month demand factor of 12 percent of annual deliveries, results in a peak month delivery of 17,500 acft/month, or about 187 MGD. With implementation of the reuse project, an additional 52,500 acft/yr is available, for a total yield at Cedar Creek of 198,000 acft/yr. The peak monthly pumping demand (i.e., 12 percent of annual demand) is 23,800 acft/yr, or about 255 MGD (Table 5-8). The current pumping capacity of the 72-inch diameter Cedar Creek pipeline at high capacity operation is 147 MGD, which results in a required pumping and pipeline capacity expansion of 108 MGD (Table 5-8). For a pipeline design velocity of 9 fps and 5 percent downtime, the required pipeline diameter would be 60 inches.

Table 5-8
Cedar Creek Reservoir Delivery System

	Required Pumping Capacity	
Estimated safe yield[1]	145,500 acft/yr 17,500 acft/month[2]	187 MGD
Reuse project yield	52,500 acft/yr 6,300 acft/month[2]	67.5 MGD
Total required pumping capacity	23,800 acft/month	255 MGD
Current pumping capacity with 90" pipeline at high capacity		147 MGD
Increased pumping capacity needed		108 MGD
Pipeline diameter from Cedar Creek Reservoir to Ennis Booster Pump Station (at 9 fps and 5 percent downtime)		60-inch

1 Estimated safe yield in year 2015.
2 Monthly pumping volume is estimated using a maximum summer month delivery factor of 12 percent of annual volume.

5.4.1.3 Facilities Needed and Cost Estimates for Plan 1

The facilities needed to implement integrated water supply Plan 1, their respective sizes or capacities, and estimated costs are listed in Table 5-9. The location of the major supply facilities and size of the pipelines is shown in Figure 5-4. The first capacity improvement needed (by 2006) would be implementation of high capacity operation of the Richland-Chambers pipeline. To do this, three pumps would be installed at the Richland-Chambers intake pump station and six booster pumps at the Ennis booster pump station. This would increase capacity by 98 MGD for a total pumping capacity of 244 MGD. The estimated cost of the pumping improvements is $16,350,000.

In parallel with the pumping system improvements, the Trinity River Reuse Project at Richland-Chambers Reservoir should also be implemented by 2006. This project would consist of a 112.5 MGD river intake, pump station, and pipeline, the treatment system ponds, treated water pump station and pipeline. The cost for the Richland-Chambers portion of the reuse project is estimated to be $24,087,000.

Table 5-9
Integrated Water Supply Plan 1 Component Sizes and Estimated Costs

Component (date needed)	*Capacity[1] and Size*	*Estimated Cost[2]*
Richland-Chambers Pipeline High Capacity Operation (2006)		
Add pumping units at lake pump station	**98 MGD**	**$4,350,000**
Booster pump station at Ennis	**98 MGD**	**$12,000,000**
Trinity River Reuse Project – Richland-Chambers Reservoir		
Wetland Treatment System (2006)		**$24,087,000**
a. river intake and pump station[2]	**107 MGD**	
b. raw water pipeline[3,4]	**107 MGD**	
c. wetlands and sedimentation ponds[4]		
d. treated water pump station[3]	**122 MGD**	
e. treated water pipeline[3,4]	**122 MGD**	
R/C Raw Water Pipeline No. 2 from R/C to Ennis Booster Pump Station (2014)		
a. lake pump station expansion	**172 MGD**	**$15,732,000**
b. raw water pipeline (includes 84 MGD capacity for future Tehuacana Resv. yield)	**84" dia., 29.8 miles**	**$111,714,000**
Additional Delivery Capacity – Ennis Booster to Lake Benbrook		
Raw Water Pipeline, Ennis to Kennedale (2014)	**280 MGD**	
a. raw water pipeline (includes 84 MGD capacity for future Tehuacana Resv and 108 MGD capacity for reuse project at Cedar Creek)	**96"**	**$180,695,000**
		$36,720,000
b. booster pump stations	**2**	
Kennedale Balancing Reservoir Improvements (2022)		**$6,600,000**
a. additional balancing reservoir	**1 or 2**	**$9,771,000**
b. pump station to increase delivery capacity to Lake Benbrook	**280 MGD**	
Trinity River Reuse Project – Cedar Creek Reservoir		
Wetland Treatment System (2022)		**$28,600,000**
a. river intake and pump station[3]	**96 MGD**	
b. raw water pipeline[3,4]	**96 MGD**	
c. wetlands and sedimentation ponds[4]		
d. treated water pump station[3]	**99 MGD**	
e. treated water pipeline[3,4]	**99 MGD**	
Cedar Creek Raw Water Pipeline No. 2 from Cedar Creek to Ennis Booster Pump Station (2022)		
a. lake pump station expansion	**108 MGD**	**$14,445,000**
b. raw water pipeline	**60"dia., 25.6 miles**	**$45,281,000**
Tehuacana Reservoir (2034)		
a. dam, reservoir, and open channel to connect Tehuacana to Richland-Chambers	**65,547 acft/yr**	**Costs dependent on further study**
b. R/C lake pump station expansion	**84 MGD**	
c. booster pump station expansions	**2**	

1 Pumping capacities include a max summer month delivery factor of 12 percent of annual volume.
2 Estimated costs are in 1998 dollars.
3 Pumping capacities obtained from "Yield Analysis of Trinity River Project," R. J. Brandes Company, June 1998, Table 3-1.
4 Facility sizes and estimated costs obtained from "Wetland Treatment System Conceptual Plan," Alan Plummer Associates, Inc., January 1997, Appendix B, Table III-9, and Section IV.

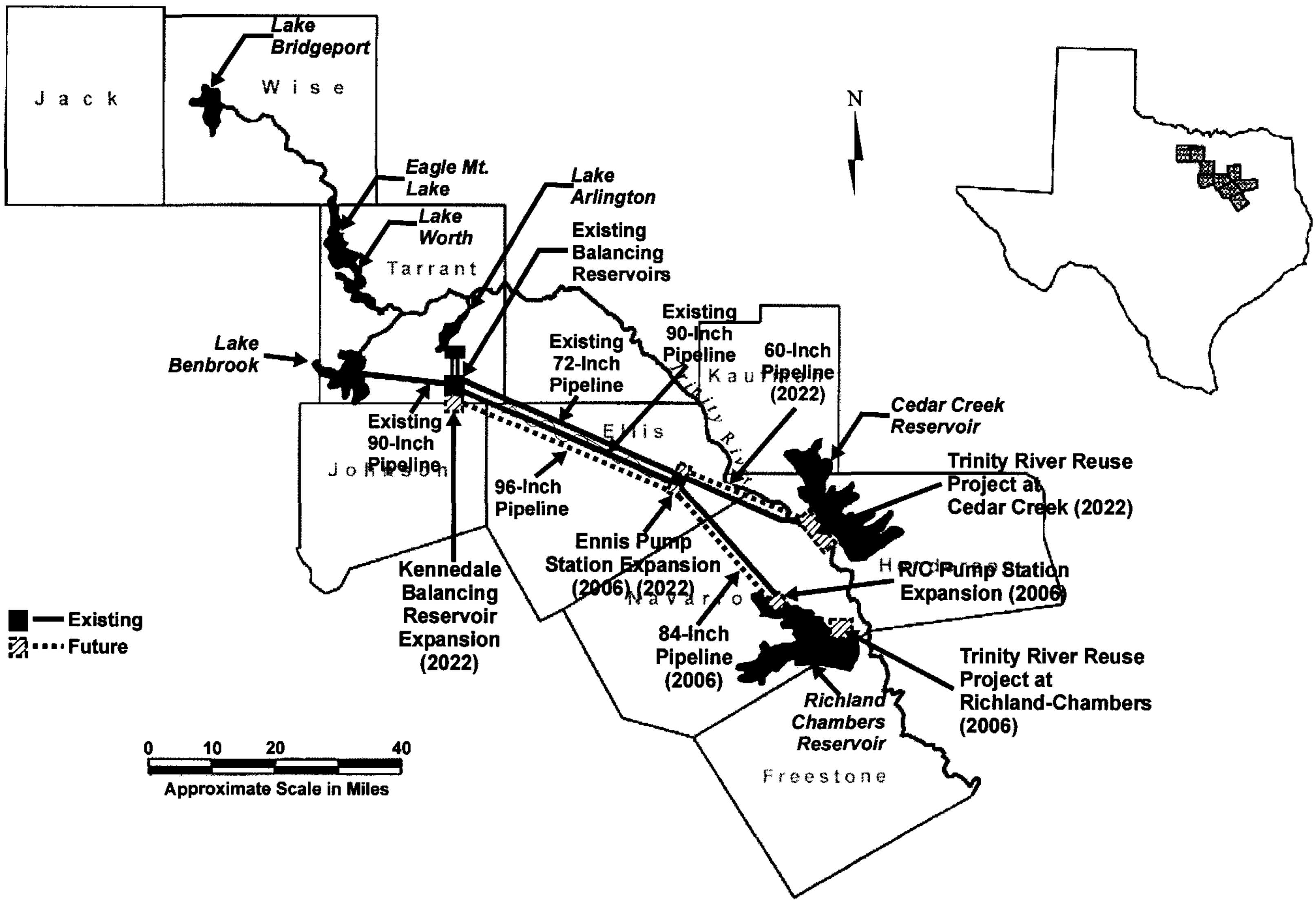

Figure 5-4. Integrated Water Supply Plan 1 — Delivery System Improvements

In order to deliver the increased water supply resulting from the reuse project to the Ennis booster pump station, a new 84-inch diameter pipeline would be needed as described earlier in Section 5.4.1.1 and Table 5-7. This pipeline size also has sufficient capacity to convey the yield from the planned Tehuacana Reservoir. If Tehuacana Reservoir is not constructed (i.e., Plan 2 would be implemented, not Plan 1), then the required pipeline size from Richland-Chambers to Ennis would be 54-inch diameter. The cost for the 84-inch diameter pipeline and pump station at Richland-Chambers is estimated to be $127,446,000.

Once the new 84-inch diameter pipeline is constructed from Richland-Chambers Reservoir to the Ennis booster pump station, additional pipeline and pumping capacity will be needed to deliver the water to the Kennedale balancing reservoirs. The pipeline from Ennis to Kennedale would be sized to convey 172 MGD supply from Richland-Chambers (Table 5-7) combined with the 108 MGD from the Cedar Creek portion of the Trinity Reuse Project that is in excess of the existing 72-inch pipeline capacity (Table 5-8). The total additional delivery capacity needed is 280 MGD. This would require a 96-inch diameter pipeline (for 9 fps and 5 percent downtime). The cost for the 96-inch diameter pipeline, booster pump stations and storage at Ennis and Waxahachie, and terminus structure at Kennedale is estimated to be $217,415,000.

At Kennedale, an additional balancing reservoir would be needed as well as a booster pump station to increase the delivery capacity through the existing 90-inch diameter pipeline from 120 MGD to 280 MGD to Lake Benbrook. The estimated cost of the improvements at Kennedale and the pipeline to Lake Benbrook is $16,371,000.

The Trinity River Reuse Project at Cedar Creek Reservoir should be implemented by 2022. This project would consist of a 96 MGD river intake, pump station, and pipeline, the treatment system ponds, treated water pump station and pipeline. The cost for the Cedar Creek portion of the reuse project is estimated to be $28,600,000. In order to deliver the increased water supply resulting from the reuse project to the Ennis booster pump station, a new 60-inch diameter pipeline would be needed as described earlier in Section 5.4.1.2 and Table 5-8. The estimated cost for the 60-inch diameter pipeline and pump station at Cedar Creek Reservoir is $59,726,000.

The final component of integrated water supply Plan 1 would be construction of Tehuacana Reservoir and the open channel to connect it to Richland-Chambers Reservoir. Also required at this point would be pumping improvements at the Richland-Chambers intake pump station and each of the booster pump stations to convey the supply originating from Tehuacana Reservoir. The estimated costs for the Tehuacana Project are dependent on further study of project components and possible purchase of mining rights to lignite deposits.

5.4.1.4 Facilities Needed and Cost Estimates for Plan 2

The facilities needed to implement integrated water supply Plan 2, their respective sizes or capacities, and estimated costs are listed in Table 5-10. The location of the major supply facilities and size of the pipelines is shown in Figure 5-5. The first capacity improvement needed (by the end of 2006) would be implementation of high capacity operation of the Richland-Chambers pipeline. To do this, three pumps would be installed at the Richland-Chambers intake pump station and six booster pumps at the Ennis booster pump station. This would increase capacity by 98 MGD for a total pumping capacity of 244 MGD. The estimated cost of the pumping improvements is $16,350,000.

In parallel with the pumping system improvements, the Trinity River Reuse Project at Richland-Chambers Reservoir should also be implemented by 2006. This project would consist of a 107 MGD river intake, pump station, and pipeline, the treatment system ponds, treated water water pump station and pipeline. The cost for the Richland-Chambers portion of the reuse project is estimated to cost $24,087,000.

In order to deliver the increased water supply resulting from the reuse project to the Ennis booster pump station, a new 54-inch diameter pipeline would be needed. The cost for the 54-inch diameter pipeline and pump station at Richland-Chambers is $60,077,000.

Once the new 54-inch diameter pipeline is constructed from Richland-Chambers Reservoir to the Ennis booster pump station, additional pipeline and pumping capacity will be needed to deliver the water to the Kennedale balancing reservoirs. The pipeline from Ennis to Kennedale would be sized to convey 88 MGD supply from Richland-Chambers combined with 108 MGD from the Cedar Creek portion of the Trinity Reuse Project that is in excess of the existing 72-inch pipeline capacity (Table 5-8). The total additional delivery capacity needed is

Table 5-10
Integrated Water Supply Plan 2 Component Sizes and Estimated Costs

Component (date needed)	Capacity[1] and Size	Estimated Cost[2]
Richland-Chambers Pipeline High Capacity Operation (2006)		
Add pumping units at lake pump station	98 MGD	$4,350,000
Booster pump station at Ennis	98 MGD	$12,000,000
Trinity River Reuse Project – Richland-Chambers Reservoir		
Wetland Treatment System (2006)		$24,087,000
a. river intake and pump station[3]	107 MGD	
b. raw water pipeline[3,4]	107 MGD	
c. wetlands and sedimentation ponds[4]		
d. treated water pump station[3]	122 MGD	
e. treated water pipeline[3,4]	122 MGD	
R/C Raw Water Pipeline No. 2 from R/C to Ennis Booster Pump Station (2014)		
a. lake pump station expansion	88 MGD	$13,346,000
b. raw water pipeline	54" dia., 29.8 miles	$70,175,000
Additional Delivery Capacity – Ennis Booster to Lake Benbrook		
Raw Water Pipeline, Ennis to Kennedale (2014)	196 MGD	
a. raw water pipeline (includes 108 MGD capacity for reuse project at Cedar Creek)	84"	$168,731,000
b. booster pump stations	2	$33,710,000
Kennedale Balancing Reservoir Improvements (2022)		
c. additional balancing reservoir	1 or 2	$6,600,000
d. pump station to increase delivery capacity to Lake Benbrook	90 dia., 17.7 miles	$9,771,000
Trinity River Reuse Project – Cedar Creek Reservoir		
Wetland Treatment System (2022)		$28,600,000
a. river intake and pump station[2]	96 MGD	
b. raw water pipeline[2,3]	96 MGD	
c. wetlands and sedimentation ponds[3]		
d. treated water pump station[2]	99 MGD	
e. treated water pipeline[2,3]	99 MGD	
Cedar Creek Raw Water Pipeline No. 2 from Cedar Creek to Ennis Booster Pump Station (2022)		
a. lake pump station expansion	108 MGD	$14,445,000
b. raw water pipeline	60" dia., 25.6 miles	$45,281,000
Marvin Nichols I Reservoir (2034)		
a. dam and reservoir	560,151 acft/yr	Costs dependent on terminus and cost share arrangements
b. water intake and pump station	Note (5)	
c. raw water pipeline	160 miles	
d. booster pump stations	Note (5)	
e. terminus at ______________	4 pump stations	

1 Pumping capacities include a max summer month delivery factor of 12 percent of annual volume.
2 Estimated costs are in 1998 dollars.
3 Pumping capacities obtained from "Yield Analysis of Trinity River Project," R. J. Brandes Company, June 1998, Table 3-1.
4 Facility sizes and estimated costs obtained from "Wetland Treatment System Conceptual Plan," Alan Plummer Associates, Inc., January 1997, Appendix B, Table III-9, and Section IV.
5 Pipeline capacity and diameter is dependent on several factors, including potential shared facilities with other water supply entities, and potential phasing of the project.

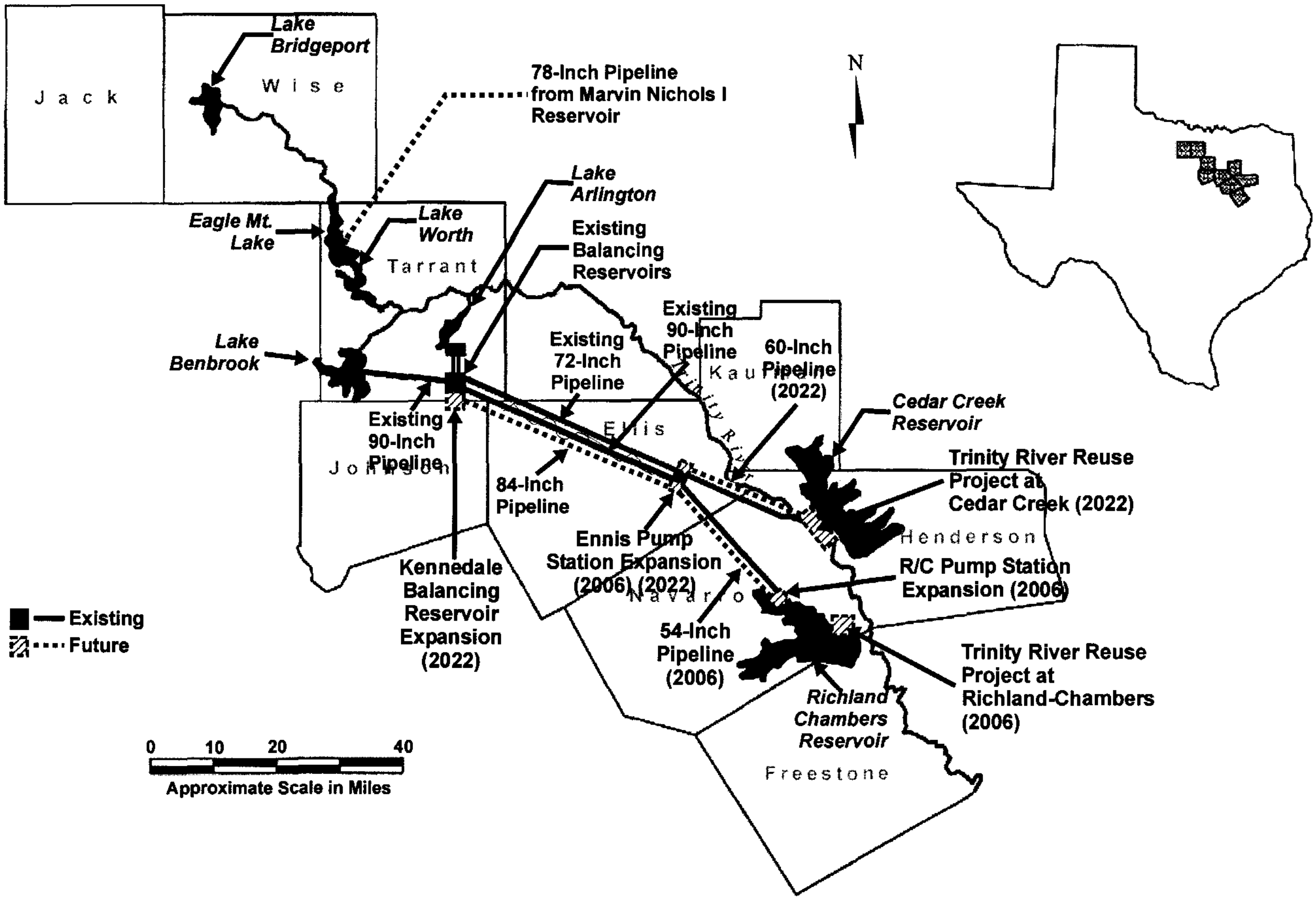

Figure 5-5. Integrated Water Supply Plan 2 — Delivery System Improvements

196 MGD. This would require a 84-inch diameter pipeline (for 9 fps and 5 percent downtime). The cost for the 84-inch diameter pipeline, booster pump station and storage at Ennis and Waxahachie, and terminus structure at Kennedale is estimated to be $202,441,000.

At Kennedale, an additional balancing reservoir would be needed as well as a booster pump station to increase delivery capacity through the existing 90-inch diameter pipelines (from 120 MGD to 280 MGD) to Lake Benbrook. The estimated cost of the improvements at Kennedale and pipeline to Lake Benbrook is $16,371,000.

The Trinity River Reuse Project at Cedar Creek Reservoir should be implemented by 2022. This project would consist of a 96 MGD river intake, pump station, and pipeline, the treatment system ponds, treated water pump station and pipeline. The cost for the Cedar Creek portion of the reuse project is estimated to be $28,600,000. In order to deliver the increased water supply resulting from the reuse project to the Ennis booster pump station, a new 60-inch diameter pipeline would be needed as described earlier in Section 5.4.1.2 and Table 5-8. The estimated cost for the 60-inch diameter pipeline and pump station at Cedar Creek Reservoir is $59,726,000.

The final component of integrated water supply Plan 2 would be construction of Marvin Nichols I Reservoir by 2034. Pipeline capacities, delivery points, and project costs are dependent on several factors, including the quantity of the District's share of the project, phasing of the project elements, and potential shared facilities with other project sponsors.

Appendix A

Reservoir Sedimentation Rate

Prepared by

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Appendix A

A.1 Introduction

Of particular importance to this project is the accumulation of sediment in the reservoirs utilized by the Tarrant Regional Water District (TRWD or District). Sediment affects the storage volume of a reservoir and affects its future water yields. For this project, two approaches are utilized to predict loss of reservoir capacity due to sediment deposition. The first approach is based upon the evaluation of available sedimentation survey results for reservoirs in the upper Trinity River Basin. The second approach is based upon the application of the Soil and Water Analysis Tool (SWAT) watershed model by the District to evaluate in more detail the sediment loading patterns for the reservoirs. The SWAT model, which was developed by the Natural Resources Conservation Service (previously the Soil Conservation Service), utilizes meteorological and hydrological information to calculate the amount of sediment delivered to a reservoir. The purpose of this section is to summarize the results of available sediment surveys and to review the additional perspectives gained through the applications of the SWAT model.

A.2 Capacity Loss Rates Due To Sediment Accumulation

Sedimentation survey information for nine reservoirs in the upper Trinity River Basin was reviewed for this study. Sedimentation surveys for District reservoirs included Bridgeport, Cedar Creek, Eagle Mountain, and Richland-Chambers. Sedimentation surveys undertaken by the United States Army Corps of Engineers (USACE) for other nearby reservoirs included Bardwell, Grapevine, Lavon, Lewisville, and Navarro Mills. The most convenient method for making comparisons of capacity losses due to sediment accumulation is to express the results in terms of capacity loss per square mile of drainage area per year. The drainage area utilized for this calculation generally only includes the "sediment contributing area," which is the drainage area downstream of any major upstream reservoirs.

For the nine reservoirs listed above, the capacity loss rate ranged from 0.53 to 4.15 acre-feet per square mile per year. The capacity loss values, as well as supplemental information, are shown in Table A-1.

Capacity loss rates are strongly affected by the types of soils and land use in the drainage area. The reservoirs with drainage areas primarily in the Blackland Prairie Land Resource Area

Table A-1
Reservoir Capacity Losses

Reservoir Name	*Drainage Area (sq. mi.)*	*Sediment Contributing Area (sq. mi.)*	*Survey Period (years)*	*Capacity Loss*		*Land Resource Area*
				(acft/yr)	*(acft/sq. mi./yr)*	
Bridgeport	**1,111**	**1,111**	**1968 – 1988**	**590**	**0.53**	**Primarily Cross Timbers and Prairies**
Eagle Mountain	**1,970**	**859**	**1968 – 1988**	**617**	**0.72**	**Primarily Cross Timbers and Prairies**
Cedar Creek	**1,007**	**1,007**	**1966 – 1995**	**1,453**	**1.44**	**Blackland Prairie and Post Oak Savannah**
Richland-Chambers	**1,957**	**1,459**	**1987 – 1994**	**4,976**	**3.41** **2.65(1)**	**Primarily Blackland Prairie**
Grapevine	**695**	**675**	**1952 – 1961** **1961 – 1966** **1952 – 1966**	**556** **511** **541**	**0.82** **0.76** **0.80**	**Primarily Cross Timbers and Prairies**
Lewisville	**1,660**	**1,599**	**1954 – 1960** **1960 – 1965** **1954 – 1965**	**2,328** **1,580** **1,983**	**1.46** **0.99** **1.24**	**Primarily Cross Timbers and Prairies with Some Blackland Prairie**
Lavon	**770**	**738**	**1953 – 1959** **1959 – 1965** **1953 – 1965**	**1,415** **1,578** **1,496**	**1.92** **2.14** **2.03**	**Primarily Blackland Prairie**
Navarro Mills	**320**	**302**	**1963 – 1972**	**634**	**2.10**	**Primarily Blackland Prairie**
Bardwell	**178**	**169**	**1965 – 1972** **1972 – 1981** **1965 – 1981**	**336** **699** **537**	**1.99** **4.15** **3.19**	**Primarily Blackland Prairie**

(1) The volumetric measurement of Richland-Chambers Reservoir sedimentation rate may be influenced by the accuracy of the pre-construction reservoir volume survey. Consequently, the long-term Blackland Prairie sedimentation rate exhibited at Cedar Creek Reservoir, Richland-Chambers Reservoir, Lake Lavon, Navarro Mills Reservoir, and Bardwell Reservoir of 2.65 acft per square mile per year will be used for estimating Richland-Chambers Reservoir future yield (2.65 acft/mi^2/yr x 1,459 mi^2 = 3,867 acft/yr).

exhibit high capacity loss rates in the range of 2 to 4 acre-feet per square mile per year, with an average value of approximately 2.65 acre-feet per square mile per year. These reservoirs include Lavon, Navarro Mills, Bardwell, and Richland-Chambers. Blackland Prairie soils are very susceptible to erosion where they are not protected adequately. Thus, the capacity loss rates for reservoirs in these areas are sometimes higher than may have been anticipated in the original reservoir design. Reservoirs with drainage areas primarily in the Cross Timbers and Prairies Land Resource Area exhibit lower capacity loss rates in the range of 0.5 to 1.5 acre-feet per square mile per year. These reservoirs include Lewisville, Grapevine, Bridgeport, and Eagle Mountain.

A.3 Sediment Deposition

When evaluating the amount of sediment which is washed off the land surface and is deposited in a reservoir, the sediment in the reservoir is commonly expressed on a weight basis (e.g., tons per square mile per year) rather than a volume basis (e.g., acre-feet per square mile per year). The soils deposited in reservoirs are less compacted than the soils in their watersheds. In-situ, dry Texas soils generally range in weight from 70 pounds per cubic foot for clays up to 110 pounds per cubic foot for sands. In contrast, reservoir sediments tend to be less dense because they are less compact. The sediments in the reservoirs studied for this report have dry weights which range from approximately 20 pounds per cubic foot to 80 pounds per cubic foot. The dry weight of the reservoir sediments depends upon the soil types, the gradation, and the degree of compaction. Samples taken from main channels in the downstream reaches of the reservoirs tend to be of finer gradation and have less compaction than samples taken in the upstream reaches and the overbank areas.

Table A-2 provides a summary of sediment deposition rates for the USACE reservoirs and District reservoirs in the Upper Trinity basin. As shown on the table, the USACE sediment surveys applied average sediment dry weights between approximately 35 pounds per cubic foot and 53 pounds per cubic foot for Grapevine, Lewisville, Lavon, Navarro Mills, and Bardwell. The Natural Resources Conservation Service (NRCS) generally applies a value of 50 pounds per cubic foot when evaluating reservoir deposits. The densities of the soils deposited in the TRWD reservoirs were not measured during recent sedimentation surveys. Thus, for the purposes of this project, dry weights of 36 and 50 pounds per cubic foot were applied in calculations for the

Table A-2
Sediment Deposition Summary

Reservoir Name	*Drainage Area (sq. mi.)*	*Sediment Contributing Area (sq. mi.)*	*Survey Period (years)*	*Capacity Loss*		*Dry Weight (lbs./cu. ft)*	*Sediment Deposition*	
				(acft/yr)	*(acft/sq. mi./yr)*		*(tons per yr)*	*(tons/sq. mi./yr)*
Bridgeport	1,111	1,111	1968 – 1988	590	0.53	(50.0)	(643,000)	(578)
						(36.0)	(462,000)	(416)
Eagle Mountain	1,970	859	1968 – 1988	617	0.72	(50.0)	(672,000)	(782)
						(36.0)	(484,000)	(563)
Cedar Creek	1,007	1,007	1966 – 1995	1,453	1.44	(50.0)	(1,582,000)	(1,571)
						(36.0)	(1,140,000)	(1,131)
Richland-Chambers	1,957	1,459	1987 – 1994	4,976	3.41	(50.0)	(5,419,000)	(3,714)
					2.65(1)	(36.0)	(3,902,000)	(2,674)
Grapevine	695	675	1952 – 1961	556	0.82	35.8	434,000	639
			1961 – 1966	511	0.76	35.3	381,000	565
			1952 – 1966	541	0.80	35.3	415,000	615
Lewisville	1,660	1,599	1954 – 1960	2,328	1.46	50.6	2,573,000	1,609
			1960 – 1965	1,580	0.99	50.6	1,741,000	1,089
			1954 – 1965	1,983	1.24	50.6	2,186,000	1,367
Lavon	770	738	1953 – 1959	1,415	1.92	53.1	1,639,000	2,221
			1959 – 1965	1,578	2.14	53.1	1,825,000	2,472
			1953 – 1965	1,496	2.03	53.1	1,733,000	2,348
Navarro Mills	320	302	1963 – 1972	634	2.10	36.1	499,000	1,651
Bardwell	178	169	1965 – 1972	336	1.99	37.7	275,000	1,633
			1972 – 1981	699	4.15	37.7	574,000	3,406
			1965 – 1981	537	3.19	37.7	441,000	2,618

Note: Data shown in parentheses are estimates.

(1) The volumetric measurement of Richland-Chambers Reservoir sedimentation rate may be influenced by the accuracy of the pre-construction reservoir volume survey. Consequently, the long-term Blackland Prairie sedimentation rate exhibited at Cedar Creek Reservoir, Richland-Chambers Reservoir, Lake Lavon, Navarro Mills Reservoir, and Bardwell Reservoir of 2.65 acft per square mile per year will be used for estimating Richland-Chambers Reservoir future yield (2.65 acft/mi^2/yr x 1,459 mi^2 = 3,867 acft/yr).

District reservoirs to demonstrate the potential range of the weights of sediment deposits. For the nine reservoirs shown in Table A-2, the average sediment deposition rates ranged from approximately 400 to 3,700 tons per square mile per year.

A.4 Application Of The SWAT Model

The SWAT model is a product of a long-term program of nonpoint source pollution modeling conducted by the United States Department of Agriculture's Agricultural Research Service (USDA-ARS). The SWAT model was formed by combining two previous models called ROTO (Routing Output to Outlet) and SWRRB (Simulation for Water Resources in Rural Basins). The objective in model development was to predict the impact of management on water, sediment, and agricultural chemical yields in large basins. When applying the SWAT model, these basins are divided into many subwatersheds. Point and nonpoint information is input into the model and SWAT routes the runoff, sediment and chemicals through the watershed. The SWAT model can simulate many years of activity and utilizes a daily time step. Subwatershed components of SWAT are included in eight major divisions--hydrology, weather, sediment, soil temperature, crop growth, nutrients, pesticides, and agricultural management. A geographic information system (GIS) interface has been developed for the model to allow for the input of soil, land use, weather, management and topographic data from available databases for the region being studied.

The great advantage provided by SWAT is that it can estimate sediment loadings to a reservoir in a more detailed time frame than is provided by the sediment surveys discussed in the previous sections of this report. For the purpose of this study, the SWAT model was run for each of the four District reservoirs by NRCS and TRWD and sediment loadings were estimated on a monthly basis for the periods covered by the sediment surveys. The results of these simulations are discussed for these four reservoirs in the following sections of this report.

A.5 SWAT Sediment Analysis For Cedar Creek Reservoir

The Cedar Creek Reservoir watershed was divided into 71 subwatersheds and the SWAT model was applied to estimate sediment loadings and inflows to the reservoir for the 29-year period covered by the 1995 sediment survey. Rain gage records for the watershed and for nearby watersheds were utilized by the model for precipitation estimates. The model results are summarized by year in Table A-3. The total sediment estimate shows excellent agreement with the results of the sediment survey. The estimated annual average rainfall for the period was approximately 39.97 inches, which is 3 percent higher than the long-term annual average of 38.9 inches for Kaufman County. Annual rainfall depths utilized by the model ranged from approximately 26.94 inches to 53.83 inches. Sediment loading rates were estimated by the model to range from approximately 414,000 tons per year in 1978 to 3,958,000 tons per year in 1990. As would be expected, the wetter years tended to produce more sediment than the dryer years. This relationship is further illustrated in Table A-4, where the annual results for sediment are ranked from the highest rate to the lowest.

Further insight was gained by reviewing the model sediment results for each month. It is important to note that the model indicates that much of the sediment enters the reservoir during a few months. For example, the model indicated that approximately 25 percent of the sediment entered the reservoir in 2.3 percent of the months; 50 percent of the sediment entered the reservoir in 7 percent of the months; and 75 percent of the sediment entered the reservoir in 18 percent of the months. These results support the concept that much of the sediment is carried to the reservoir during relatively few, high runoff events.

A.6 SWAT Sediment Analysis for Richland-Chambers Reservoir

The Richland-Chambers Reservoir watershed was divided into 20 subwatersheds and the SWAT model was applied to estimate sediment loadings and inflows to the reservoirs for the seven year period covered by the 1994 sediment survey. The model results are summarized by year on Table A-5. The total sediment estimate shows very good agreement with the results of the sediment survey. The estimated annual average precipitation for the period was approximately 42.58 inches, which is 12 percent higher than the long-term annual average of 37.9 inches for Navarro County. Annual rainfall depths utilized by the model ranged from approximately 33.57 inches in 1988 to 48.25 inches in 1991.

Sediment loading rates were estimated by the model to range from approximately 1,883,000 tons per year in 1988 to 8,602,000 tons per year in 1992. The annual results for sediment are ranked from highest rate to lowest in Table A-6. A more detailed review of the monthly results for the model indicate that approximately 25 percent of the sediment entered the

Table A-3
Cedar Creek Sediment and Flow Data

Year	Sediment (tons/year)	Inflow (cubic ft/sec)	Annual Precipitation (inches)
1966	2,236,073	591.44	46.43
1967	1,184,224	370.76	44.41
1968	1,716,045	633.81	39.75
1969	2,409,507	707.26	48.18
1970	1,417,700	529.65	39.53
1971	1,493,816	437.14	44.17
1972	569,990	296.25	26.94
1973	3,117,697	904.99	53.67
1974	1,132,703	413.83	40.54
1975	768,485	324.50	29.67
1976	1,317,756	396.53	40.34
1977	775,833	298.37	29.28
1978	413,908	162.43	34.23
1979	1,430,958	438.90	42.98
1980	521,050	193.85	28.13
1981	2,317,226	577.32	47.37
1982	743,956	305.78	36.28
1983	1,200,437	415.25	28.97
1984	469,495	190.32	36.46
1985	2,680,443	692.78	41.14
1986	2,427,213	836.85	50.70
1987	1,043,077	369.34	30.26
1988	444,968	189.26	29.43
1989	2,900,075	693.14	37.20
1990	3,957,751	1018.34	53.83
1991	1,877,011	676.89	50.61
1992	1,851,861	667.71	41.13
1993	1,824,924	596.39	40.16
1994	1,843,650	727.74	47.47
Total	46,087,833		
Average	1,589,236	523.46	39.97

Table A-4
Cedar Creek Sediment and Flow Data
(Ranked by Annual Sediment Load)

Year	Rank	Sediment (tons/year)	Cumulative (tons/year)	Percent Total	Inflow (cubic ft/sec)	Annual Precipitation (inches)
1990	1	3,957,751	3,957,751	9%	1018.34	53.83
1973	2	3,117,697	7,075,448	15%	904.99	53.67
1989	3	2,900,075	9,975,523	22%	693.14	37.20
1985	4	2,680,443	12,655,966	27%	692.78	41.14
1986	5	2,427,213	15,083,179	33%	836.85	50.70
1969	6	2,409,507	17,492,686	38%	707.26	48.18
1981	7	2,317,226	19,809,912	43%	577.32	47.37
1966	8	2,236,073	22,045,985	48%	591.44	46.43
1991	9	1,877,011	23,922,996	52%	676.89	50.61
1992	10	1,851,861	25,774,857	56%	667.71	41.13
1994	11	1,843,650	27,618,507	60%	727.74	47.47
1993	12	1,824,924	29,443,431	64%	596.39	40.16
1968	13	1,716,045	31,159,476	68%	633.81	39.75
1971	14	1,493,816	32,653,291	71%	437.14	44.17
1979	15	1,430,958	34,084,250	74%	438.90	42.98
1970	16	1,417,700	35,501,950	77%	529.65	39.53
1976	17	1,317,756	36,819,706	80%	396.53	40.34
1983	18	1,200,437	38,020,142	82%	415.25	28.97
1967	19	1,184,224	39,204,367	85%	370.76	44.41
1974	20	1,132,703	40,337,070	88%	413.83	40.54
1987	21	1,043,077	41,380,147	90%	369.34	30.26
1977	22	775,833	42,155,980	91%	298.37	29.28
1975	23	768,485	42,924,465	93%	324.50	29.67
1982	24	743,956	43,668,422	95%	305.78	36.28
1972	25	569,990	44,238,412	96%	296.25	26.94
1980	26	521,050	44,759,462	97%	193.85	28.13
1984	27	469,495	45,228,957	98%	190.32	36.46
1988	28	444,968	45,673,925	99%	189.26	29.43
1978	29	413,908	46,087,833	100%	162.43	34.23
Total		46,087,833				
Average		1,589,236			523.46	39.97

Table A-5
Richland-Chambers Sediment and Flow Data

Year	*Sediment (tons/year)*	*Inflow (cubic ft/sec)*	*Annual Precipitation (inches)*
1988	**1,882,761**	**451.61**	**33.57**
1989	**8,100,317**	**1542.34**	**39.30**
1990	**5,429,928**	**1302.94**	**45.87**
1991	**5,177,200**	**1207.25**	**48.25**
1992	**8,602,064**	**1962.88**	**45.96**
1993	**4,433,132**	**1076.60**	**40.30**
1994	**5,110,530**	**1277.52**	**44.80**
Total	**38,735,932**		
Average	**5,533,705**	**1260.16**	**42.58**

Table A-6
Richland-Chambers Sediment and Flow Data
(Ranked by Annual Sediment Load)

Year	*Rank*	*Sediment (tons/year)*	*Cumulative (tons/year)*	*Percent Total*	*Inflow (cubic ft/sec)*	*Annual Precipitation (inches)*
1992	**1**	**8,602,064**	**8,602,064**	**22%**	**1962.88**	**45.96**
1989	**2**	**8,100,317**	**16,702,381**	**43%**	**1542.34**	**39.30**
1990	**3**	**5,429,928**	**22,132,309**	**57%**	**1302.94**	**45.87**
1991	**4**	**5,177,200**	**27,309,509**	**71%**	**1207.25**	**48.25**
1994	**5**	**5,110,530**	**32,420,039**	**84%**	**1277.51**	**44.80**
1993	**6**	**4,433,132**	**36,853,171**	**95%**	**1076.60**	**40.30**
1988	**7**	**1,882,761**	**38,735,932**	**100%**	**451.61**	**33.57**
Total		**38,735,932**				
Average		**5,533,705**			**1260.16**	**42.48**

reservoir in 5 percent of the months; 50 percent of the sediment entered the reservoir in 13 percent of the months; and 75 percent of the sediment entered the reservoir in 26 percent of the months. As with the previous discussion of Cedar Creek Reservoir, these results support the concept that much of the sediment is carried to the reservoir during relatively few, high runoff events.

Some care should be taken in applying the Richland-Chambers sedimentation results. The seven years covered by the sedimentation survey is a relatively short time for determining average sedimentation rates and the rainfall for the period was somewhat above the average value for the region. Additional insight into long-term sediment deposition rates for Richland-Chambers could be gained through the application of the SWAT model to a longer hydrologic record for the watershed.

A.7 SWAT Sediment Analysis For Lake Bridgeport and Eagle Mountain Lake

The combined watershed for Lake Bridgeport and Eagle Mountain Lake was divided into 142 subwatersheds and the SWAT model was applied to estimate sediment loadings and inflows to the reservoirs for the 20-year period covered by the 1988 sediment survey. The model results are summarized by year for Lake Bridgeport on Table A-7 and for Eagle Mountain Lake on Table A-8. The sediment loadings estimated by the model were higher than the values measured by the sediment surveys. The model inputs are currently being revised by the NRCS.

For the Lake Bridgeport analysis, the estimated annual average rainfall for the period was approximately 32.37 inches, which is 5 percent higher than the long-term annual average of 30.7 inches for Jack County. For the Eagle Mountain Lake analysis, the estimated annual average rainfall for the period was approximately 34.78 inches, which is 7 percent higher than the long-term annual average of 32.6 inches for Wise County.

A.8 Summary of Sediment Losses Due to Sediment Deposition

Losses in reservoir capacity caused by sediment disposition vary extensively among the District reservoirs. Available sediment surveys indicate that the rates of capacity loss range from approximately 590 acre-feet per year for Lake Bridgeport to 4,976 acre-feet per year for Richland-Chambers Reservoir. The rate of capacity loss depends upon the size of the drainage area, the types of soils, the land uses, the rainfall patterns and other watershed characteristics. Reservoirs located in the Blackland Prairie Land Resource area exhibit higher capacity loss rates due to sediment deposition than reservoirs located outside this area. For this reason, reservoirs located in the Blackland Prairie area sometimes exhibit more rapid capacity losses than were originally anticipated when the reservoirs were designed.

Table A-7
Bridgeport Sediment and Flow Data

Year	*Sediment (tons/year)*	*Inflow (cubic ft/sec)*	*Annual Precipitation (inches)*
1969	525,637	137.36	35.86
1970	269,841	88.28	29.53
1971	119,753	42.73	29.22
1972	2,293,325	252.11	22.98
1973	331,709	101.34	34.97
1974	527,518	158.19	34.68
1975	589,952	190.67	41.92
1976	381,749	91.45	31.70
1977	621,950	98.87	19.77
1978	204,688	61.09	23.38
1979	227,449	104.52	34.14
1980	648,860	148.30	24.95
1981	4,256,133	693.49	60.14
1982	1,627,245	325.91	36.61
1983	69,333	28.25	21.34
1984	552,513	126.06	28.02
1985	813,839	217.16	32.73
1986	561,902	198.09	41.83
1987	551,300	173.73	38.35
1988	333,955	70.97	25.21
Total	15,508,650		
Average	775,433	174.14	32.37

The drainage area for Richland-Chambers Reservoir is located primarily in the Blackland Prairie Land Resource Area and the drainage area for Cedar Creek Reservoir is partially located in this area. Watershed models, such as SWAT, can provide valuable insight into changes in deposition rates on a short-term or long-term basis as the result of factors such as rainfall patterns, soil types and management practices. For estimates of long-term reservoir yields, models such as SWAT are valuable for determining the sensitivity of the yield calculations to sediment deposition rates. Field surveys of reservoir volumes should be performed on a periodic

Table A-8
Eagle Mountain Sediment and Flow Data

Year	Sediment (tons/year)	Inflow (cubic ft/sec)	Annual Precipitation (inches)
1969	235,104	88.63	35.15
1970	191,603	86.86	35.53
1971	76,509	51.91	37.30
1972	1,063,626	143.36	37.77
1973	158,298	88.98	40.80
1974	935,872	207.62	45.66
1975	724,752	204.80	36.43
1976	51,490	33.19	38.82
1977	795,741	137.00	31.63
1978	32,969	22.95	23.99
1979	401,600	111.93	38.07
1980	155,000	54.73	21.88
1981	9,769,824	1061.77	46.57
1982	2,476,852	413.83	37.71
1983	27,183	21.89	27.56
1984	39,857	33.90	30.70
1985	891,271	243.64	33.52
1986	1,068,548	249.29	40.90
1987	1,151,986	265.53	29.66
1988	146,438	55.79	25.88
Total	20,394,522		
Average	1,019,726	178.87	34.78

basis, perhaps every 5 years, until the sedimentation rate for each water supply reservoir is established within reasonable confidence limits.

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3. Texas State Soil and Water Conservation Board, A Comprehensive Study of Texas Watersheds and Their Impacts on Water Quality and Water Quantity, January 1991.

4. Texas Water Development Board, Volumetric Survey of Richland-Chambers Reservoir, prepared for the Tarrant County Water Control and Improvement District Number One, March 31, 1995.

5. Texas Water Development Board, Volumetric Survey of Cedar Creek Reservoir, prepared for the Tarrant County Water Control and Improvement District Number One, July 31, 1995.

6. Army Corps of Engineers, Report on Sedimentation, Grapevine Lake: Denton Creek, Trinity River Basin, Texas, Resurveys of November 1961 and November 1966, November 1971.

7. Army Corps of Engineers, Report on Sedimentation, Lake Lavon: East Fork of Trinity River, Trinity River Basin, Texas, Resurvey of October 1965, June 1975.

8. Army Corps of Engineers, Report on Sedimentation, Lewisville Lake: Elm Fork of Trinity River, Trinity River Basin, Texas, Resurvey of September 1965, July 1975.

9. Army Corps of Engineers, Report on Sedimentation, Navarro Mills Lake: Richland Creek, Trinity River Basin, Texas, Resurvey of September 1972, April 1976.

10. Army Corps of Engineers, Report on Sedimentation, Bardwell Lake: Waxahachie Creek, Texas, Trinity River Basin, Texas, Resurvey of August 1981, September 1987.

Appendix B

Hydrologic Analyses

Appendix B

Detailed analyses of the inflows to both Richland-Chambers and Cedar Creek Reservoirs were performed by R.J. Brandes Company as part of another study.[1] The computed reservoir inflows derived as part of this study were used in the simulation of the reservoir yields for the East Texas Reservoirs modeled for the District's Water Management Plan. Excerpts from the aforementioned study, detailing the computation of inflows to the East Texas Reservoirs, are included in this Appendix.

[1] R.J. Brandes Company, "Yield Analysis of Trinity River Project," prepared for Tarrant Regional Water District, June 1998.

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1.3 SIMYLD-II Model Structure

Two separate SIMYLD-II models have been developed for evaluating Project yields. One for the Richland-Chambers Reservoir system and one for the Cedar Creek Reservoir system. Because of the necessity to determine "available" inflows for each of the reservoirs, i. e., inflows remaining after all upstream senior water rights have been satisfied, each of the SIMYLD-II models includes demand and storage nodes that reflect all currently existing upstream senior water rights. This includes all upstream reservoirs and direct diversions for senior water rights, as well as, any junior water rights for which either the Richland-Chambers Reservoir or Cedar Creek Reservoir water rights have been subordinated by special agreement. In accordance with effective Certificates of Adjudication, the recognized priority dates for Richland-Chambers Reservoir and Cedar Creek Reservoir have been established as October 18, 1954 and May 28, 1956, respectively.

The SIMYLD-II model structure for the Richland-Chambers Reservoir system is illustrated by the network diagram in Figure 1-1. Triangles are used to distinguish storage reservoirs and demand points, and circles identify nodes where demands (open arrows) and/or inflows (solid arrows) are defined. Richland-Chambers Reservoir is designated as Node 3, and the total demand specified for Richland-Chambers Reservoir, which includes the proposed Project incremental yield, is identified with the open arrow labeled "TRWD Project Demand". The name and authorized annual diversion amount of individual senior water rights (demands), or junior water rights with subordination agreements with respect to Richland-Chambers Reservoir, also are indicated. Solid lines with arrows, which are referred to as links, connect the reservoirs and nodes, and indicate the direction of flow. As shown on the diagram, Navarro Mills Reservoir (Node 5) on Richland Creek, Halbert Reservoir (Node 2) on Elm Creek, Clark Reservoir (Node 1) on Little Mustang Creek, Bardwell Reservoir on Waxahachie Creek, and Alvarado Reservoir (Node 7) on Turkey Creek are included in the SIMYLD-II model upstream of Richland-Chambers Reservoir (Node 3). A separate reservoir node also is included in the model to represent the wetlands water quality treatment system associated with the Project (Node 6). Diversions from the Trinity River are made into the wetlands node to maintain a constant prescribed storage volume of 3,000 acre-feet, i. e., 1.5 feet of average depth over 2,000 acres. Evaporation losses from the wetlands then are

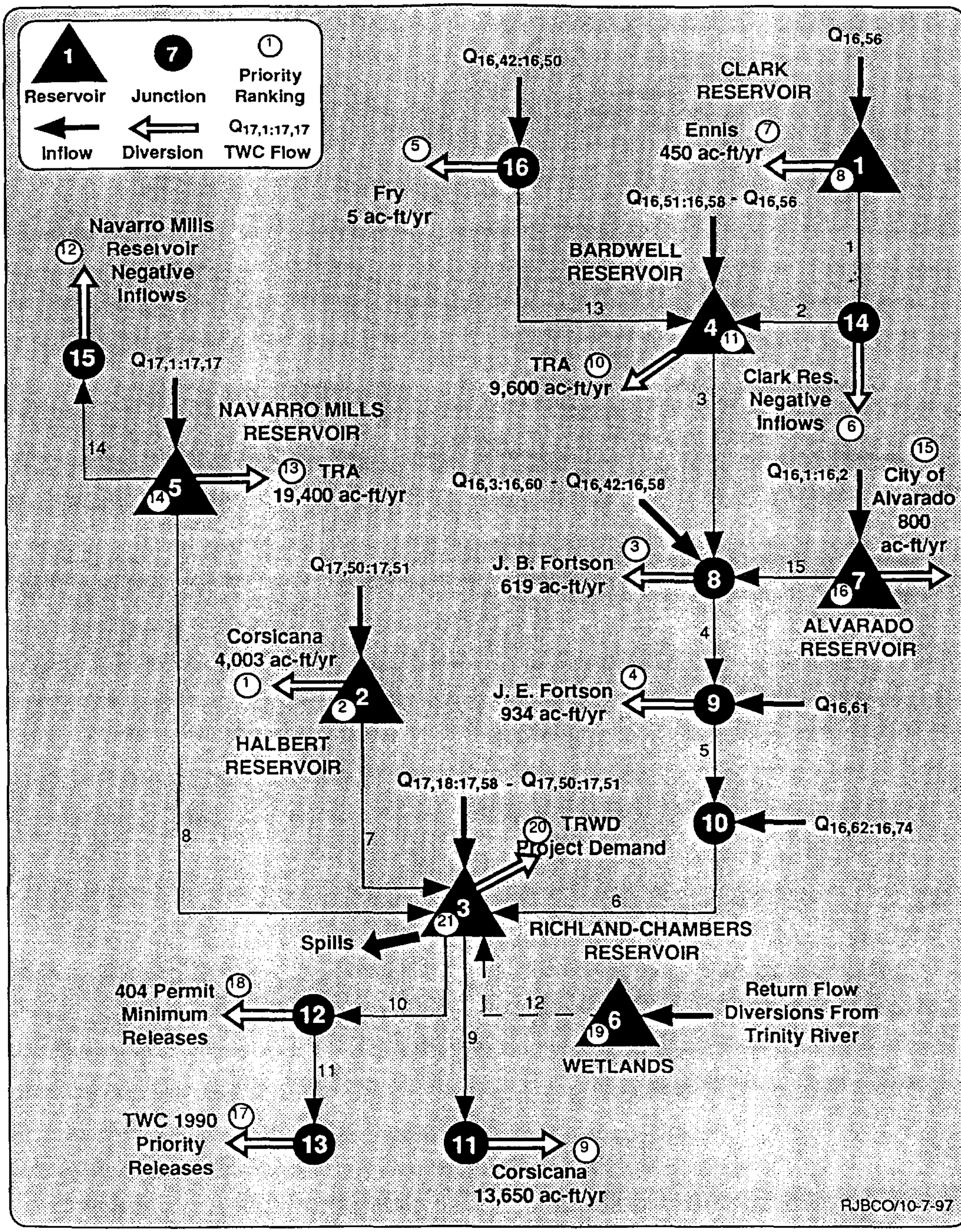

FIGURE 1-1
SIMYLD MODEL NETWORK FOR RICHLAND-CHAMBERS RESERVOIR WITH UPSTREAM SENIOR WATER RIGHTS AND TRINITY RIVER DIVERSION

simulated, and diversions into Richland-Chambers Reservoir are made in accordance with the specified reservoir stage-related operating rules to produce the additional Project yield. Additional demands on Richland-Chambers Reservoir for its required 404 Permit minimum release of 5.0 cfs (Node 12) and for satisfying downstream senior water rights (Node 13) are specified at downstream nodes. The quantities of inflow passed through the reservoir to satisfy downstream senior water rights are specified in the SIMYLD model based on results from the Texas Water Commission's (TWC) Water Availability Model of the Trinity River Basin (October, 1990) as provided by the Texas Natural Resource Conservation Commission (TNRCC).

Priorities assigned in the SIMYLD-II model to individual demands and storage reservoirs are indicated by the numbers in small open circles. These priorities are used in the SIMYLD-II model to rank demand and storage operations each time step (month) during a simulation in accordance with water rights priority dates and/or subordination agreements and other operating criteria. The lowest assigned priority value (in this case, a value of "one" for the Corsicana diversion at Node 2) corresponds to the highest priority ranking in the model for performing a particular operation.

Finally, it should be noted that each of the inflows to nodes identified on the diagram by solid arrows has the source of the inflows specified as subscripted Q's. These subscripted Q's refer to the individual subwatersheds in the 1990 TWC Water Availability Model of the Trinity River Basin from which the naturalized flows for the indicated inflow points were obtained. The development of these inflows is discussed in more detail in Section 2.0.

For the Cedar Creek Reservoir system, the SIMYLD-II model network diagram as applied in this study is illustrated in Figure 1-2. The same symbols and terminology described above for the Richland-Chambers Reservoir system also have been used in developing this model structure. Node 5 represents Cedar Creek Reservoir. Additional reservoir storage nodes are included for upstream senior water rights reservoirs at Terrell City Lake (Node 2) on Muddy Cedar Creek, Hunt Oil Reservoir (Node 3) on Williams Creek tributary, and McHenry Wallace Reservoir (Node 1) on North Twin Creek. Forest Grove Reservoir (Node 6) on Caney Creek also is included in the model with its permitted operating rules and TRWD contract stipulations incorporated into the SIMYLD-II code. The diversion of an average of approximately 3,000 acre-feet per year of water

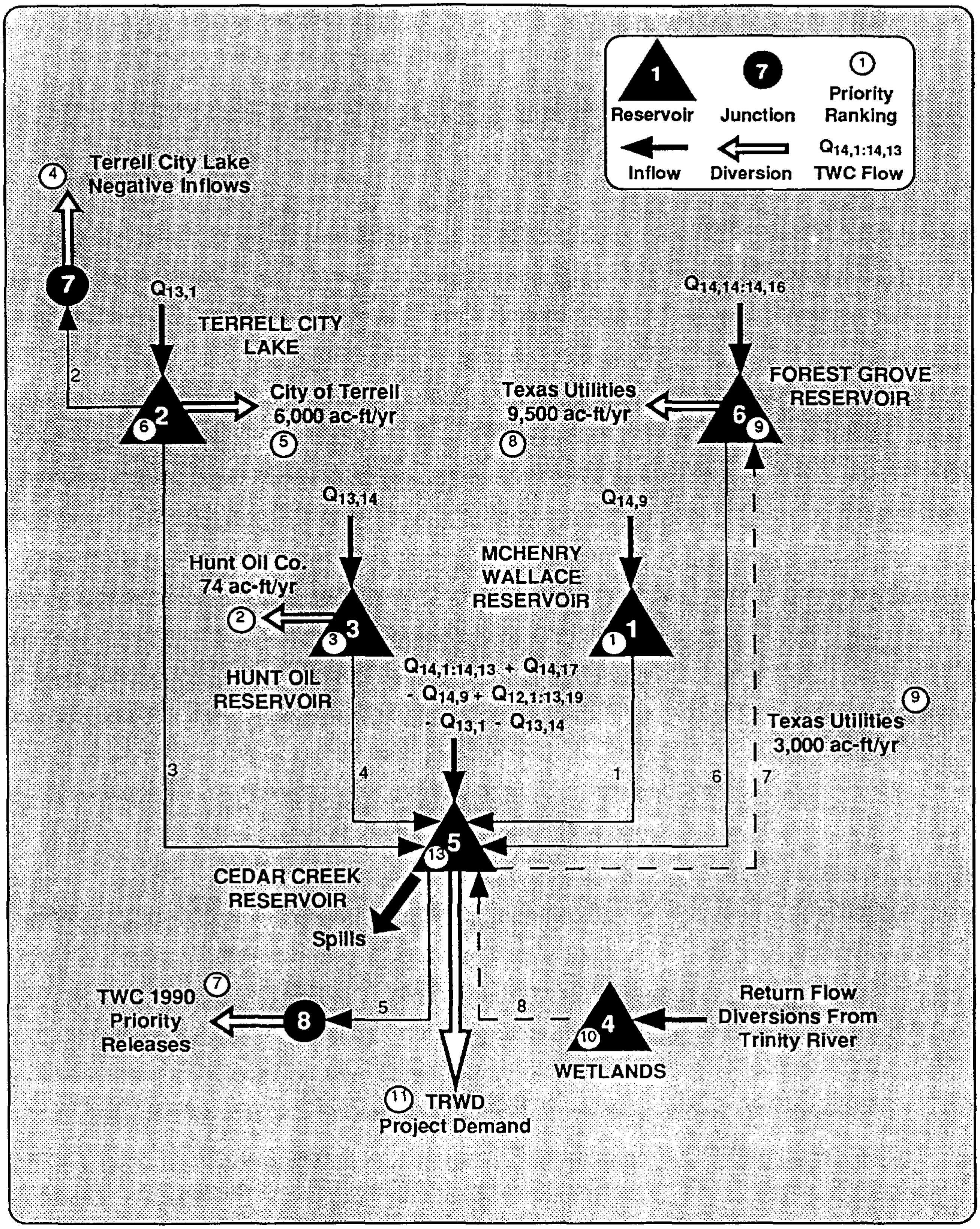

FIGURE 1-2
SIMYLD MODEL NETWORK FOR CEDAR CREEK RESERVOIR
WITH UPSTREAM SENIOR WATER RIGHTS AND TRINITY RIVER DIVERSION

from Cedar Creek Reservoir back to Forest Grove Reservoir is included in the model in accordance with the contract agreement between the TRWD and Texas Utilities, Inc.

Again, a separate reservoir node also is included in the model to represent the wetlands water quality treatment system associated with the Project (Node 4). Diversions from the Trinity River are made into the wetlands node to maintain a constant prescribed storage volume (18 inches of average depth over 1,800 acres), from which evaporation losses then are simulated and diversions into Cedar Creek Reservoir are made in accordance with specified reservoir stage-related operating rules to produce the additional Project yield. Additional demands on Cedar Creek Reservoir for satisfying downstream senior water rights also are specified at a downstream node (Node 8). The monthly amounts of inflows passed through the reservoir to satisfy downstream senior water rights are specified based on results from the TWC Water Availability Model of the Trinity River Basin (1990) as provided by the TNRCC. Again, priorities are assigned in the SIMYLD-II model to individual demands and storage reservoirs, as indicated by the numbers in small open circles, to rank these operations in accordance with water rights priority dates and/or subordination agreements and other operating criteria.

2.0 BASIC INPUT DATA

2.1 Streamflows

Inflows to each of the nodes in the SIMYLD-II models for Richland-Chambers Reservoir and Cedar Creek Reservoir have been developed from monthly naturalized flow data obtained from the Texas Water Commission (TWC) Water Availability Model for the Trinity River Basin (October, 1990). These naturalized flow data are referred to as "Total Runoff" in the TWC model, and they were requested from the Texas Natural Resource Conservation Commission for specific subwatersheds included in the TWC Trinity River Basin model. The period of record for which these naturalized flows are available from the 1990 TWC model is 1940-1981.

In developing the inflows required for the SIMYLD-II models, the 1990 TWC naturalized flows for specific subwatersheds were aggregated at points where upstream water rights senior to Richland-Chambers and Cedar Creek Reservoirs are located. In the Richland-Chambers watershed, Navarro Mills and Bardwell Reservoirs have been considered to be senior to Richland-Chambers Reservoir because of subordination agreements with the TRWD. Lake Alvarado, although junior, has been included as a senior water right following discussions with TRWD staff. In the Cedar Creek watershed, the Forest Grove Reservoir has been included in the SIMYLD-II model as per the contractual agreement between TRWD and Texas Utilities, Inc.

One point to note is that the 1990 TWC naturalized flows in the Chambers Creek watershed have been adjusted to account for an apparent minor error in the TWC flow development methodology. This error resulted in a disproportionate percentage of the total flow being allocated to the drainage area upstream of Bardwell Reservoir. Also, some of the inflows from the 1990 TWC model for certain subwatersheds are negative because of the manner in which they were derived during the naturalization process. For example, when the TWC was adjusting the gaged flows for the effects of historical reservoir storage and evaporation losses and for the effects of historical diversions and return flows, the resulting naturalized flows sometimes were determined to be negative, and these negative values were used by TWC in its modeling to reflect natural channel losses. For operating the SIMYLD-II models developed in this study, these negative naturalized flows have been preserved. In some cases, separate demand nodes have been established in the model networks to account for the inherent water losses. These demand nodes are identified on the network diagrams in Figures 1-1 and 1-2.

Summaries of the monthly inflows to Richland-Chambers Reservoir and to Cedar Creek Reservoir as simulated with the SIMYLD-II models are presented in Tables 2-1 and 2-2, respectively, for the entire simulation period, 1940-1981. These flows are expressed in acre-feet, and they reflect operation of the SIMYLD-II models taking into account all upstream senior water rights diversions and reservoirs.

2.2 Reservoir Area-Capacity Data

Area-capacity data for Richland-Chambers and Cedar Creek Reservoirs have been obtained from current TRWD water supply planning studies being conducted by HDR Engineering, Inc.[1], and these data have been incorporated into the SIMYLD-II models. For current reservoir sedimentation and storage conditions, the area-capacity data used in the models correspond to the most recent volumetric survey information developed by the Texas Water Development Board (TWDB) in 1995 for Richland-Chambers[2] and Cedar Creek[3] Reservoirs. For future reservoir sedimentation and storage conditions, the same projected year-2050 area-capacity relationships used by HDR have been applied in the models. The use of year-2050 reservoir sedimentation conditions for evaluating future Project yield in this investigation is appropriate since the TRWD presently is examining its water supply options for meeting the anticipated demands of its customers through the year 2050.

The projected year-2050 area-capacity relationships for Richland-Chambers and Cedar Creek Reservoirs are based on extrapolations of current relationships using observed historical sediment accumulation rates for various reservoirs in the region, including Richland-Chambers Reservoir,

[1] HDR Engineering, Inc.; "Water Conservation and Emergency Demand Management Plan, Tarrant Regional Water District"; September, 1997; Austin, Texas.
[2] Texas Water Development Board; "Volumetric Survey of Richland-Chambers Reservoir"; 1995; Austin, Texas.
[3] Texas Water Development Board; "Volumetric Survey of Cedar Creek Reservoir"; 1995; Austin, Texas.

TABLE 2-1 MONTHLY INFLOWS TO RICHLAND-CHAMBERS RESERVOIR AS SIMULATED WITH SIMYLD-II MODEL

(Acre-Feet)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	14	5,317	702	121,084	38,949	65,299	122,173	818	1	5	337,248	195,498	887,108
1941	65,108	277,213	160,771	91,913	170,471	225,906	168,935	11,631	727	20,708	5,037	13,338	1,211,758
1942	4,578	10,098	12,954	678,250	130,248	82,891	3,615	17,740	159,405	72,739	50,054	72,351	1,294,923
1943	18,590	5,565	55,192	61,067	255,991	66,526	1,882	45	59,224	50,070	450	6,510	581,112
1944	81,748	198,582	71,497	32,040	608,492	56,437	4,736	53	50	452	8,607	72,647	1,135,341
1945	144,413	239,328	557,842	301,001	14,323	192,092	133,170	8,336	3,275	76,022	18,048	33,833	1,721,683
1946	67,676	175,628	69,734	30,083	329,100	69,986	2,094	9,658	1,432	774	60,482	31,821	848,468
1947	198,358	18,831	124,678	120,102	24,656	69,532	467	3,558	8,370	401	2,761	31,082	602,796
1948	23,688	34,535	61,159	20,572	295,418	6,881	15,146	9	0	0	85	145	457,638
1949	13,856	51,588	37,180	31,331	44,316	16,112	4,878	762	0	6,413	130	71	206,637
1950	6,189	157,261	8,355	89,045	75,052	5,488	4,731	49	726	0	0	0	346,896
1951	715	6,257	356	554	6,854	57,413	70	0	8,729	2	0	0	80,950
1952	0	4,590	7,475	121,488	94,097	2,069	239	0	0	0	13,480	51,102	294,540
1953	14,285	2,609	96,021	25,516	342,468	733	1,396	7	2,965	6,521	1,542	19,021	513,084
1954	11,328	405	74	1,048	31,067	39	0	11	0	1,606	3,361	29	48,968
1955	911	12,660	14,929	8,986	13,125	13,962	515	5,710	8,105	520	0	0	79,423
1956	2,136	19,289	25	397	68,294	7,093	17	98	19	127	20,493	1,486	119,474
1957	1,638	20,723	21,690	711,429	404,787	77,308	513	112	359	58,850	202,938	12,049	1,512,396
1958	33,908	13,768	46,098	128,160	487,673	2,570	8,980	14,106	104,125	10,626	2,597	5,421	858,032
1959	2,184	48,118	7,540	81,685	196,661	284,171	12,920	1,189	1,004	146,746	10,624	133,512	926,354
1960	221,336	40,586	19,675	8,977	18,185	18,402	984	7,285	161	10,897	4,957	291,600	643,045
1961	381,898	248,242	131,802	18,415	7,721	148,594	60,946	2,031	3,970	5,704	89,480	64,340	1,163,143
1962	10,465	23,695	9,634	52,044	14,677	56,749	5,843	786	10,670	54,629	7,075	7,510	253,777
1963	3,585	1,707	3,347	24,524	22,039	2,051	861	1,075	717	1,017	458	205	61,586
1964	558	882	3,484	5,062	2,350	1,034	1,792	1,337	221	1,219	9,035	786	27,760
1965	6,511	54,186	26,822	12,601	381,924	12,640	1,790	1,884	1,485	629	4,445	877	505,794
1966	1,332	20,173	5,517	543,105	251,711	3,222	1,856	6,005	5,572	2,900	1,033	916	843,342
1967	667	650	1,460	9,311	4,719	38,785	7,466	1,306	63,712	222,747	166,309	122,499	639,631
1968	176,989	99,219	181,848	199,484	556,420	134,310	9,652	2,170	1,265	2,922	5,494	19,947	1,389,720
1969	2,663	56,432	171,414	98,204	509,877	20,308	2,480	1,717	144	4,443	4,649	40,412	912,743
1970	10,327	92,878	266,751	76,513	15,216	15,141	2,451	1,448	8,597	74,350	8,821	1,918	574,411
1971	1,926	5,109	3,511	11,914	5,029	1,430	3,056	3,153	1,126	70,436	25,066	271,424	403,180
1972	132,125	12,833	4,276	2,173	4,344	2,377	3,010	1,493	1,753	22,268	12,510	8,234	207,396
1973	53,942	57,960	164,221	362,391	92,616	297,347	23,588	5,808	27,068	146,986	33,396	25,209	1,290,532
1974	50,272	19,092	11,254	4,555	34,231	3,643	2,024	4,512	73,570	85,909	399,810	70,832	759,704
1975	50,587	203,517	50,805	176,757	393,283	102,413	15,015	3,272	2,864	1,839	1,982	1,453	1,003,787
1976	2,658	3,594	21,015	145,037	173,571	89,576	84,896	3,331	54,748	47,580	11,257	73,792	711,055
1977	17,062	163,555	155,209	273,596	33,914	5,277	2,565	2,386	2,197	1,069	1,134	1,774	659,738
1978	1,075	15,193	51,518	2,223	8,567	2,333	2,294	3,033	3,218	1,823	2,583	778	94,638
1979	20,815	17,781	87,358	69,735	262,007	140,844	9,366	10,808	6,366	2,310	2,130	32,245	661,765
1980	107,828	55,081	11,837	127,973	210,833	5,759	2,651	2,424	1,565	1,635	863	2,809	531,258
1981	1,026	955	8,715	6,182	28,997	292,548	28,006	2,074	1,656	81,506	8,792	4,255	464,712

TABLE 2-2 MONTHLY INFLOWS TO CEDAR CREEK RESERVOIR AS SIMULATED WITH SIMYLD-II MODEL

(Acre-Feet)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL
1940	102	4,043	1,725	64,312	76,972	15,169	27,559	1,721	165	1	137,567	108,460	437,796
1941	12,226	56,335	66,679	18,996	89,884	268,642	23,901	15,265	305	14,767	9,916	17,765	594,681
1942	6,213	16,763	11,262	415,918	121,010	107,116	408	5,384	24,091	9,299	21,844	57,300	796,608
1943	17,159	9,039	51,030	35,292	65,856	165,383	780	17	1,869	16,316	82	11,296	374,119
1944	45,262	69,336	46,181	14,823	267,804	19,338	870	9	209	67	23,194	87,354	574,447
1945	58,090	122,832	339,434	127,368	3,503	127,565	126,443	1,161	1,759	20,924	13,069	12,354	954,502
1946	75,059	130,175	24,710	7,818	131,195	119,015	137	7,688	3,219	1,549	193,083	28,653	722,301
1947	52,222	3,236	28,283	205,016	6,974	46,081	269	9,964	7,613	159	21,777	141,392	522,986
1948	45,707	58,316	74,628	6,628	106,443	753	1,950	573	146	0	2,058	2,116	299,318
1949	45,355	87,634	22,706	21,829	25,943	8,032	1,492	5	0	8,838	621	434	222,889
1950	40,333	209,808	3,678	45,101	111,402	2,727	16,376	2,939	1,092	0	2,007	49	435,512
1951	12,270	43,571	1,052	1,189	12,400	64,207	2,866	0	529	2,508	403	0	140,995
1952	1,468	1,187	8,372	138,652	102,371	7,500	273	0	0	0	12,419	60,890	333,132
1953	14,085	985	26,210	44,460	258,255	155	320	1,208	6,209	111	153	17,538	369,689
1954	42,694	5,565	200	10,351	40,624	1,400	-81	-81	-66	30,687	21,964	1,199	154,456
1955	3,395	22,468	26,996	45,411	4,552	3,424	177	410	896	92	-16	-19	107,786
1956	135	23,916	174	298	31,866	377	279	260	226	89	19,414	1,109	78,143
1957	11,228	23,381	43,815	524,195	211,907	37,399	184	573	8,186	103,440	145,438	16,363	1,126,109
1958	42,478	2,251	34,734	230,569	234,365	1,989	23,552	8	8,803	3,448	2,275	1,221	585,693
1959.	886	51,982	16,148	81,151	60,756	21,011	2,243	171	70	36,459	7,703	96,196	374,776
1960	153,845	47,413	19,037	1,356	2,919	4,505	2,663	2,839	1,333	760	6,782	192,933	436,385
1961	113,120	69,876	67,592	10,300	3,366	96,408	12,486	732	1,591	300	17,365	37,554	430,690
1962	7,325	19,069	9,878	54,408	28,752	11,019	55,487	4,816	20,917	12,051	29,471	11,823	265,016
1963	5,052	735	1,208	71,671	31,277	250	113	145	68	176	2	-11	110,686
1964	27	574	4,441	34,640	6,296	318	188	74	5,544	310	5,823	264	58,499
1965	4,690	92,537	6,360	1,845	152,577	3,076	261	155	8,533	84	7,910	107	278,135
1966	7,194	43,151	4,484	399,023	147,354	2,553	1,098	2,967	5,902	5,737	133	343	619,939
1967	431	262	2,164	13,592	20,452	26,490	11,257	177	13,820	255,267	56,863	96,088	496,863
1968	96,869	49,867	142,386	61,096	134,164	20,952	2,887	272	439	279	5,648	17,909	532,768
1969	5,467	60,132	122,218	26,126	344,198	3,186	513	515	281	13,693	4,159	59,233	639,721
1970	14,949	102,774	193,743	68,902	14,454	15,958	620	620	31,107	66,683	2,898	867	513,575
1971	723	6,875	3,070	1,302	3,284	681	71,279	10,930	1,393	182,210	10,119	271,548	563,414
1972	75,509	2,872	1,689	1,267	1,423	6,238	1,007	862	561	8,845	15,625	15,098	130,996
1973	61,777	50,323	89,281	194,789	14,583	211,342	5,796	1,291	15,150	98,692	73,521	69,047	885,592
1974	154,301	9,198	4,687	19,661	83,900	92,206	559	-2,278	14,946	37,226	272,200	67,111	753,717
1975	19,201	183,102	43,916	99,776	31,859	13,820	2,091	398	406	586	172	127	395,454
1976	389	586	2,502	359,754	89,017	26,263	19,241	979	11,553	25,834	2,129	35,134	573,381
1977	20,178	157,478	140,558	81,270	1,917	30,928	1,702	1,810	1,237	1,015	16,542	2,042	456,677
1978	1,995	51,330	50,575	4,372	6,411	1,225	3,440	2,830	6,155	1,278	4,660	5,132	139,403
1979	78,501	45,878	77,287	26,223	223,103	13,717	112	10,273	4,703	1,280	1,347	42,601	525,025
1980	109,953	26,514	9,940	35,109	88,420	4,613	1,927	1,846	5,991	4;538	1,406	11,960	302,217
1981	685	565	4,239	1,263	26,628	265,861	47,450	1,954	4,967	40,204	11,214	4,497	409,527

Appendix C

Recreation Analysis

Appendix C

C.1 Introduction

Water-oriented recreation, which includes boating, fishing, water skiing, swimming, picnicking, and open space activities, are quite popular in the District's service area. In its 1990 Outdoor Recreation Plan, the Texas Parks and Wildlife Department projected that 30 to 32 percent of the 4.2 million people of the North Central Texas area in which the District's water supply lakes are located would participate in boating, fishing, and swimming.1 An objective of this study is to estimate the recreation value of the District's water supply lakes for normal pools and for lower pool levels that might occur as the lakes are operated for water supply purposes. However, since recreation use data are not available for the District's lakes, studies of similar lakes were obtained and reviewed, in an effort to obtain information that might be useful in evaluating potential effects of lake levels upon recreation use of the District's lakes. In addition, annual park usage data were obtained from the Texas Parks and Wildlife Department and daily park usage data (two parks) were obtained from the Trinity River Authority for neighboring Lake Joe Pool. Information on marinas and boat slips at District lakes was also obtained. Summary information obtained from these studies and lake use data are presented below.

C.2 Lake Texoma Recreation Study

In 1988, the United States Army Corps of Engineers (USACE) Tulsa District performed a recreation study of Lake Texoma.[2] This USACE study is probably the most useful of the information collected to assess recreation impacts of varying elevations of lakes as it includes a visitor survey on the effects of pool level fluctuations on visitation at Lake Texoma, and the magnitude of such effects. The visitor survey was conducted during June and July of 1988, in a two-week time span that included weekdays, weekends, and the Fourth of July weekend. Given the large size of the lake and the number of recreation sites (50, including 26 marinas), two representative sites were selected for the survey. During the two-week survey period, 350

[1] 1990 TORP—Assessment and Policy Plan, Texas Parks and Wildlife Department, Austin, Texas, 1992, pages 4–5.
[2] Lake Texoma Recreation Study, U.S. Army Corps of Engineers, Tulsa District, Tulsa, Oklahoma, 1988.

visitors were interviewed, from which 316 usable questionnaires were obtained. The interview addressed the following issues:

- Visitors' recreation profile;
- Recreation-related costs and spending;
- Willingness to pay for recreation; and
- Visitors' lake level preference.

The above issues included information such as distance traveled, number of annual visits, type of recreation participation (e.g., camping, fishing, water skiing,), visitor income, travel cost of visit to lake, reported recreation spending ($/person/day), willingness to pay for recreation ($/respondent/day), willingness to pay for stable lake level ($/person/day), and visitors' lake level preference. Respondents' reports on high lake level limits at which visitation would be terminated and respondents' reports on low lake level limits at which visitation would be terminated are shown in Tables C-1 and C-2, respectively. As can be seen, high lake levels of 12 feet above the top of the conservation pool elevation could affect visitation decisions by about 59 percent of the respondents, while low lake levels of 18 feet below the top of the conservation pool could affect visitation decisions by about 61 percent of the respondents. The following were the most bothersome adverse factors associated with changing lake levels in the order ranked by respondent replies.

- Effect on appearance of shore and beaches;
- Inability to launch boat;
- Possibility of boat damage;
- Effect of size of swimming beach;
- Effect on fishing conditions; and
- Other (e.g., odors emanating from the lake at low level conditions, and deteriorating safety at high levels).

This study also presents equations for estimating economic loss associated with low pool and high pool levels and includes an example of applying economic models to estimate recreation benefits loss as a function of lake elevation for high lake elevation events. However, the report cautions that "the estimated recreation demand equations and the derived visitation loss coefficients and recreation day values were based on the assumption that the cost of recreation, as defined, and lake level conditions are the prime factors affecting recreation

Table C-1.
Respondents' Reported High Lake Level Limits at Lake Texoma at which Visitation would be Terminated by Respondents' Origin Zone
(number responding)

Origin Zone (Miles)	Lake Level*					No Limit
	620'msl	622'msl	624'msl	627'msl	629'msl	
Less than 10	4	7	13	15	21	50
11–20	0	2	6	10	17	14
21–50	2	0	5	0	2	11
51–75	0	0	3	4	0	7
76–100	2	2	9	1	4	10
100–125	1	1	8	0	3	7
126–150	3	1	5	0	5	8
151–200	4	2	6	1	7	17
Over 200	0	0	4	2	3	7
Total Responding	16	15	59	33	62	131
Percent	5.06%	4.75%	18.67%	10.44%	19.62%	41.46%
Cumulative	5.06%	9.81%	28.48%	38.92%	58.54%	100.00%

* Top of conservation pool is at elevation 617 ft-msl, and spillway crest is at elevation 640 ft-msl.

Source: Recreation Survey and estimates.

Table C-2.
Respondents' Reported Low Lake Level Limits at Lake Texoma at which Visitation would be Terminated by Respondents' Origin Zone
(number responding)

Origin Zone (Miles)	Lake Level*					No Limit
	613'msl	610'msl	605'msl	600'msl	599'msl	
Less than 10	2	4	17	19	20	48
11–20	3	5	7	10	10	14
21–50	2	4	2	1	0	11
51–75	3	2	0	1	1	5
76–100	3	3	2	0	10	10
100–125	2	5	4	1	1	7
126–150	3	5	5	0	4	5
151–200	2	6	2	2	10	17
Over 200	0	1	1	1	7	6
Total Responding	20	35	40	35	63	123
Percent	6.33%	11.08%	12.66%	11.08%	19.94%	38.92%
Cumulative	6.33%	17.41%	30.07%	41.15%	61.09%	100.00%

* Top of conservation pool is at elevation 617 ft-msl, and spillway crest is at elevation 640 ft-msl.

Source: Recreation Survey and estimates.

demand. These are reasonable and well tested assumptions. It is obvious, however, that there are other factors affecting the demand for recreation, one of which is especially significant. For example, hydrologic events are in many instances accompanied by weather conditions, or conversely, weather conditions prompt hydrologic events. In either case, it is entirely possible that, during such events, prevailing weather conditions, rather than lake levels, are the prime cause for declining visitations."

The draft USACE study also considered the effects of lake level fluctuations on public and private facilities. Though no estimates were made concerning economic impact of lake level on these facilities, two of six marina owner respondents indicated that a low lake elevation of 610 feet, which in this case is 7 feet below the top of the conservation pool, causes a reduction in income of 50 percent or more.

C.3 The Economic Significance of Boating Visitation to the Highland Lakes

In July 1994, the USACE published a study for the Lower Colorado River Authority with particular emphasis on the economic significance of water-related recreation as a function of lake levels in Lakes Buchanan and Travis, located in Llano, Burnet, and Travis Counties. These are the only lakes of the five Highland Lakes group with variable lake levels.[3] This study was based on generalized data from the Texas Parks and Wildlife Department and more detailed studies by the USACE under the Section 22 (Planning Assistance to States) program.

A first phase of the study involved collection of available data on recreation visitation and expenditures at the Highland Lakes and the effects of periodic drawdowns of Lakes Buchanan and Travis on recreation availability at those lakes. A second phase included a visitor survey, economic impact assessment based on the findings of the survey, and a user-ready database system for mailing list maintenance.

Significant conclusions of this study include the following:

- The five Highland Lakes receive about 608,000 boating-party trips per year under baseline conditions. This is equivalent to about 2 million persons per year. These visitors spend about $103 million per year under baseline conditions.

[3] The Economic Significance of Boating Visitation to the Highland Lakes, U.S. Army Corps of Engineers, Fort Worth District, Fort Worth, Texas, July 1994.

- Low-water conditions at Lake Travis or Buchanan would lead to a one-third reduction in the number of annual boating-party trips at either lake, with visitor recreation dropping by about $22 million at Lake Travis and about $5 million at Lake Buchanan.
- The $103 million in annual recreation visitor spending supports over 1,900 jobs in the local regional economy. The total economic effects, including multiplier effects, result in $133 million per year in output and sales in the local regional economy, $77 million per year in regional income, and almost 3,200 jobs. Low-water conditions at Lake Buchanan would result in an annual regional loss of $7 million in output and sales, $4 million in income, and 165 jobs. Low-water conditions at Lake Travis would result in an annual regional loss of $30 million in output and sales, $18 million in income, and 726 jobs.
- The above findings consider only a part of the total economic effects of water-related recreation at the Highland Lakes -- the part resulting from boating visitors originating within the 16 counties responsible for 80 percent of the boating activity at the lakes. These findings could be increased by 97 percent to account for visitors from all Texas counties and non-boating visitors.

C.4 Social and Economic Study of the Lake Fork Reservoir Recreational Fishery

This study was published by the Texas A&M University Department of Wildlife and Fisheries Sciences on July 15, 1996 for the Texas Parks and Wildlife Department and the Sabine River Authority for Lake Fork Reservoir, located in Wood and Rains Counties, approximately 70 miles east of Dallas.[4] This study involved surveys of anglers to determine market segments using the reservoir, angler profiles from each segment, fishing trip profiles, money sent by each segment on fishing trips to the lake, economic impacts of expenditures to the local region, present economic value of the reservoir, and angler attitudes toward fishery management regulations. The survey showed annual number of fishing trips to Lake Fork Reservoir for the June 1994 through May 1995 period at 204,740, with total number of days fishing of 348,000. Expenditures ranged from $35 per day by local anglers to $128 per day by out-of-state anglers. The estimated total economic value of the Lake Fork recreational fishery is $38 million per year.[5] Some of the information in this study could be useful to the District in planning similar surveys for its lakes or in extrapolating the results of limited surveys of fisherman-days at District lakes. At the present time, surveys of fishing activity are not available for the District's lakes.

[4] A Social and Economic Study of the Lake Fork Reservoir Recreational Fishery, Hunt, Kenan, and Robert Ditton, Department of Wildlife and Fisheries Sciences, Texas A&M University, College Station, Texas, 1996.

C.5 Information Obtained from the Trinity River Authority on Recreation at Lake Joe Pool

A representative of the Trinity River Authority provided the following observations about recreation usage at Lake Joe Pool:

- The core group of lake users consists primarily of fishermen. This group seems to be sensitive to lake levels. If the lake drops significantly, visitation by this group will drop.
- The second major group of users includes boaters who are not necessarily fishermen. This group is also sensitive to lake levels.
- People who are visiting the lake to camp also engage in fishing, boating, swimming, etc.
- Other factors such as rain, temperature, and wind probably have as much impact on lake usage as lake level. For example, even though people like to be at the lake during warm weather, they seem to stop coming as the temperature gets over 90 degrees. Also, higher-than-normal wind seems to deter lake usage.

Trinity River Authority provided information on usage of its two parks at Joe Pool Lake during the December 1993 through October 1996 time period.[6] This information is summarized in Figures C-1 and C-2. The information on park visitation is compared with information on lake elevation in Table C-3; however, no clear relation between lake elevation and recreation usage was apparent during this time period.

C.6 Recreational Uses of the District's Lakes

C.6.1 Lake Bridgeport

Recreational use of Lake Bridgeport is primarily fishing and water skiing (see Table C-4 for number of boat slips). However, in recent years, there has been a significant increase in residential development around Lake Bridgeport as the populations of Tarrant and Denton Counties have increased. An example of economic loss associated with extremely low lake levels at Lake Bridgeport was developed from the information in the aforementioned Lake Texoma Study, and an estimated peak boating use of 500 boats per day at Lake Bridgeport. The Lake Texoma Study visitor survey indicated an average spending for recreation of $16.15 per

[5] Ibid.

[6] Meeting of October 16, 1996; Arlington, Texas.

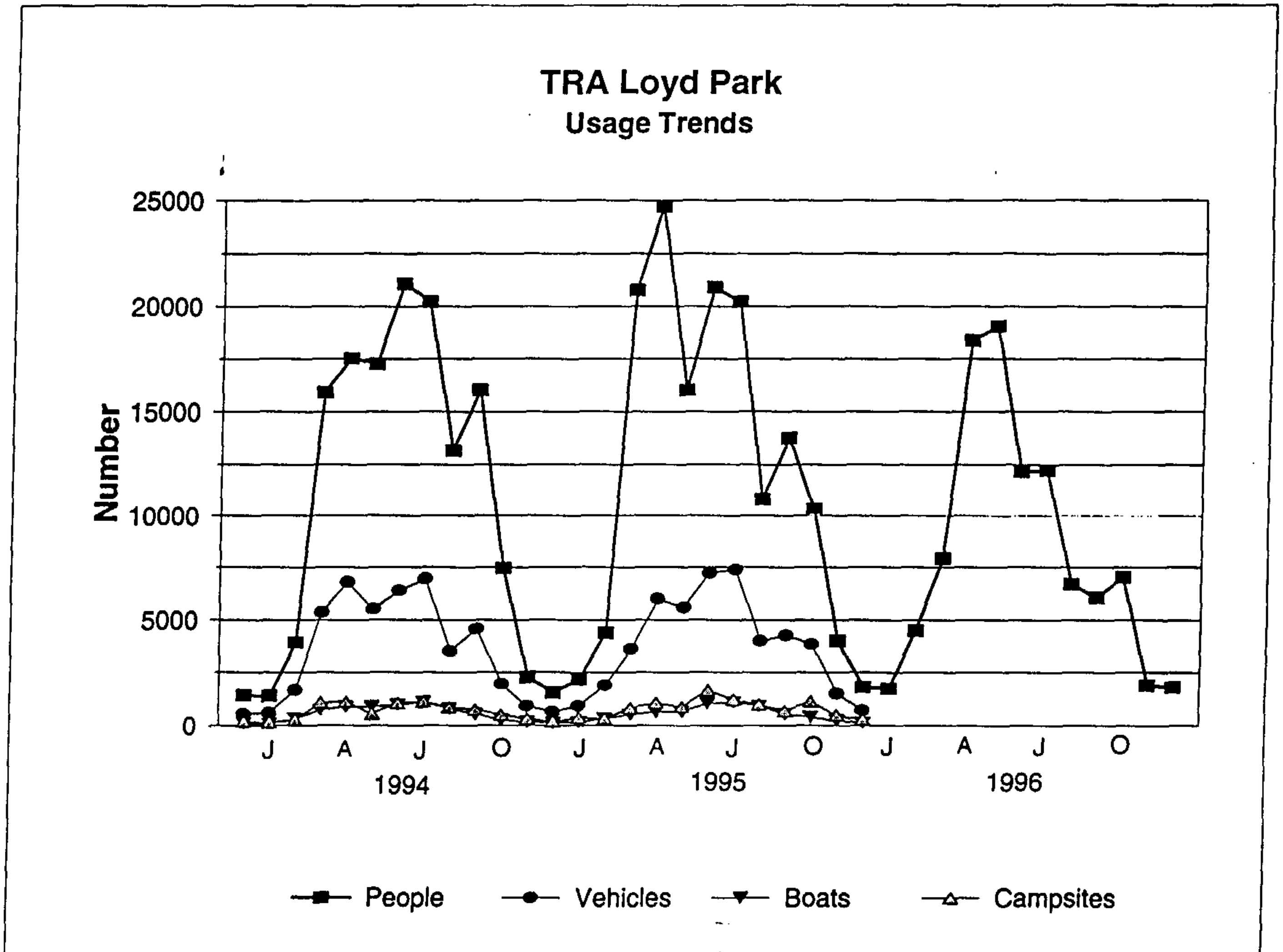

Figure C-1. TRA Loyd Park Usage Trends

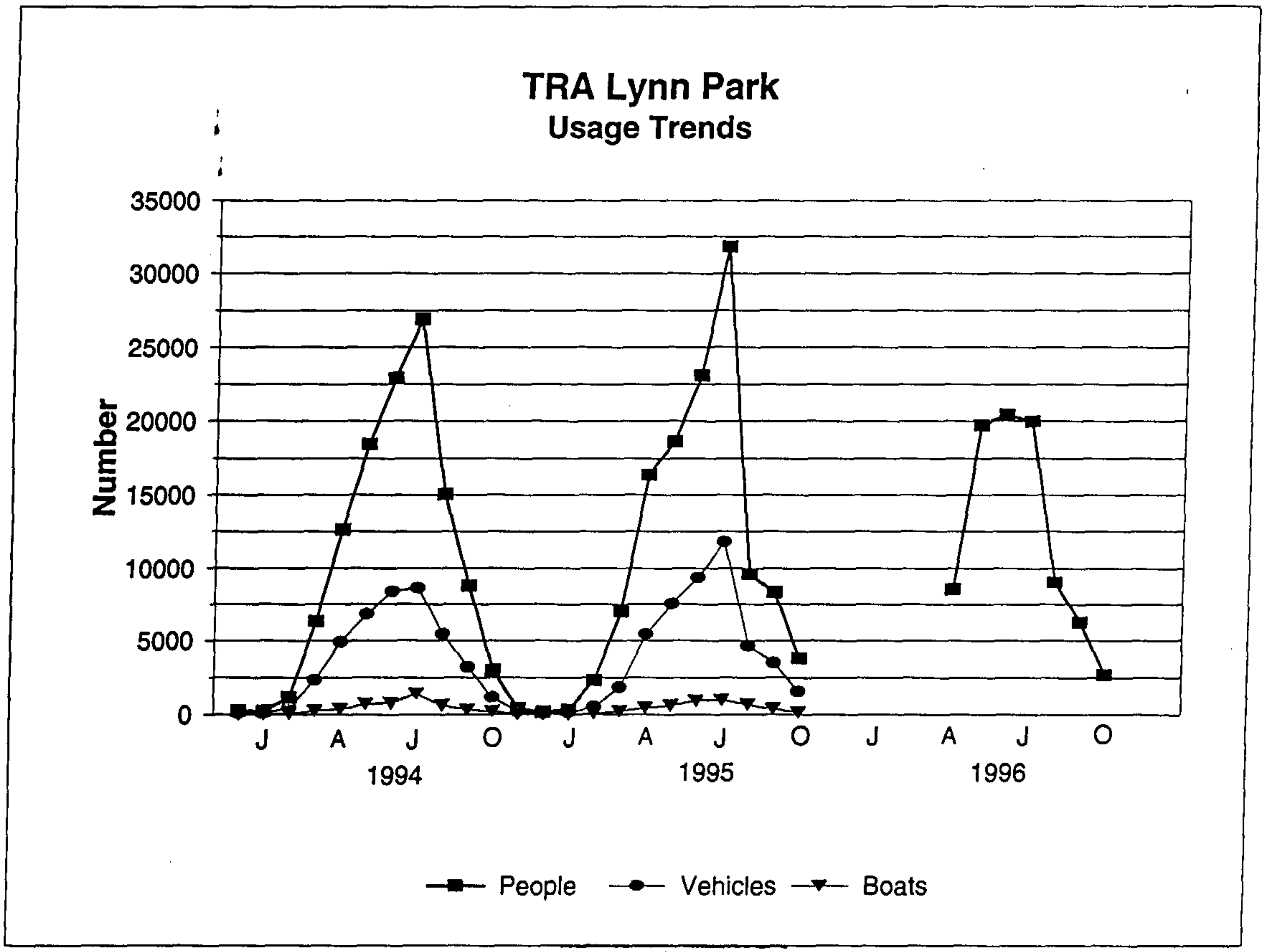

Figure C-2. TRA Lynn Park Usage Trends

Table C-3.
Lake Levels, 1994 – 1996
Joe Pool Lake Near Duncan, USGS Station 08049800

Year	Month	Average of Daily Mean Value
1994	1	521.15
1994	2	521.66
1994	3	522.16
1994	4	522.02
1994	5	522.02
1994	6	519.89
1994	7	519.38
1994	8	518.68
1994	9	518.31
1994	10	533.46
1994	11	519.81
1994	12	521.01
1995	1	521.55
1995	2	521.94
1995	3	526.68
1995	4	522.74
1995	5	523.40
1995	6	522.44
1995	7	521.73
1995	8	521.48
1995	9	521.11
1995	10	520.80
1995	11	520.38
1995	12	520.00
1996	1	519.68
1996	2	519.39
1996	3	519.04
1996	4	518.97
1996	5	518.61
1996	6	518.13
1996	7	517.67
1996	8	517.11
1996	9	517.37
1996	10	517.17
1996	11	518.78
1996	12	520.72

Table C-4.
Number of Boat Slips at Tarrant Regional Water District Lakes

Lake	Number of Slips
Lake Bridgeport	
D&D Marina	14
Runaway Bay Marina	106
Wood Marina	14
Scout Camp Marina (Private)	6
Twin Hills Marina	40
Wizard Bay (Private)	18
Private Docks (±)	325
Subtotal	523
Eagle Mountain Lake	
Fort Worth Boat Club	218
Harbor One Marina	350
Lake Country Marina	400
Lakeview Marina	100
Bal Harbor (Private)	24
The Landing (Private)	38
Pelican Bay Marina	24
Twin Points Marina	42
West Bay Marina	186
Tarrant County Marina (Proposed)	337
Private Docks (±)	2,000
Subtotal	3,719
Cedar Creek Lake	
Causeway Marina	20
Cedar Creek Landing	20
Clear Creek Landing	14
Don's Port Marina	110
Fisherman's Wharf Marina	28
Harbor Light Marina	96
Lakeland Marina (Private)	12
Royal 121 (Private)	16
Sandy Shores Marina	80
Star Harbor Marina	64
Destiny Marina	30
Treasure Isle Marina	30
Twin Creeks Marina	2
Private Docks (±)	5,000
Subtotal	5,522
Richland-Chambers*	
Oak Grove Marina (to be in place in 1997)	10
Private Docks (±)	200
Subtotal	210
Total	9,974

* Four other marinas exist on Richland-Chambers, but provide only gas, bait, tackle, and boat launching.

person per day (travel cost not included). Assuming three people per boat and three 3-day holiday weekends per boating season, results in $218,025 in recreation spending. If extremely low lake levels reduced usage by 61 percent, as inferred by the Lake Texoma Study, a loss in recreation spending of $133,000 per year would result.

C.6.2 Eagle Mountain Lake

Eagle Mountain Lake is heavily used for boating, water skiing, and sailing, with fishing being a secondary recreation activity at this lake. A large marina development is planned on the west side of the lake by the developer that is constructing a similar project at Lake Joe Pool (see Table C-4 for number of boat slips). Using the Lake Bridgeport example of economic loss associated with extremely low lake levels, and an estimated peak boating use of 3,700 boats per day, results in an estimated loss of $984,000 annually in recreation spending associated with Eagle Mountain Lake for the time period considered.

C.6.3 Cedar Creek Lake

Cedar Creek Lake is popular for both boating and fishing. Crappie fishing is particularly popular with a "Crappiethon" event being held at the lake last year (see Table C-4 for number of boat slips). Based upon the Lake Texoma study, for an estimated boating use of 5,500 boats per day, annual recreation business losses from low lake levels would be $1.47 million.

C.6.4 Richland-Chambers

Richland-Chambers is a new lake with recreation development not yet well-organized. For example, there is not yet a marina on the lake, and recreation is mostly fishing. In 1996 there was a bass tour/boat show at Richland-Chambers (see Table C-4 for number of boat slips). However, there are no data available with which to make estimates of boating and associated economics responses to changes in lake levels.

C.6.5 Visitation to Weekend Homes

At several District lakes, particularly at Cedar Creek and Eagle Mountain, weekend homes provide the basis for much of the lake visitation. Low lake levels discourage the use of these weekend homes and consequently result in reduced spending in the stores and recreation facilities surrounding the lakes. However, there are no data available with which to estimate the business losses resulting from low lake levels.

C.7 Conclusions and Recommendations

Based on information available to the District, significant changes in lake levels have a significant effect on Eagle Mountain Lake and Cedar Creek Lake recreation values and; for the near future, a lesser effect on Lake Bridgeport and Richland-Chambers Reservoir recreation values. Estimates presented in this study of recreational spending loss of about $2.59 million annually that is associated with low lake levels at District lakes can only be considered as "order of magnitude" estimates. As previously indicated, additional data are needed to develop reliable estimates of the recreation value of the four District lakes and changes in recreation value associated with changing lake levels. In order to gain a better understanding of the recreation value of the District's lakes, it will be necessary to collect data from a sample of lake users, including (a) dollars spent per person per outing; (b) number of outings per year; (c) number of people per outing; and (d) number of outings per year at normal, medium, and low lake levels.

Appendix D

Risk and Reliability Assessment

Appendix D

D.1 Risk Assessment Summary

The District has taken an aggressive role in assessing the reliability of its water delivery system facilities. To assess the system facilities, the District performed an inventory of its major components to record maintenance logs and past failures. Expected equipment life, estimated reliability, and cost of failures are estimated and included in the inventory. The gathered data were used to develop a relational database model in Microsoft Access that assigned each component a Risk Index. An electronic copy of the database model is included with this appendix. After calculating the Risk Indices, the District's As-Is condition was determined. The inventory was also used to analyze the number of failures reported and amount of downtimes associated with each failure.

The Risk Index is a relative comparison tool that relates the probability of a component failing with the consequences of its failure. The risk assessment focused on the District's East Texas raw water delivery components including both the Cedar Creek and Richland-Chambers reservoir facilities. Seventy-one components were inventoried and ranked from highest Risk Index (worst) to lowest Risk Index (best). The highest Risk Index (5.20) was shared by the electrical components at four of the five pumping facilities in the inventory. Their high ranking is the result of momentary power failures that occur on an annual basis and the consequence of electrical outages on the delivery system. The only electrical component not included in the group is the Medium Voltage Electrical System at the Cedar Creek Ennis Booster Station (CC2). Because CC2 is currently off-line and used only as needed, its probability of failure is lower than the other electrical systems which are on-line. The ranking also identified the pumping units at the Richland-Chambers Lake Intake Station (RC1) as critical components. Although not indicated directly by the component rankings, the two large diameter pipelines are also considered vital to the East Texas system.

Because complete elimination of all component failures is impractical if not impossible, the key to maintaining reliability is to decrease the system's vulnerability. A number of measures can be taken to minimize vulnerability. The most critical is having an adequate back-up network with a defined emergency operations manual. Even though the characteristics of each failure scenario are different, a well-defined and coordinated response plan will provide the District staff with the necessary information to react in a timely and appropriate manner. The District is currently updating and creating a comprehensive emergency response plan.

The next step to reduce vulnerability is routine maintenance and preventive measures that reduce the frequency of component failure. The District routinely inspects its key components, and a preventive maintenance program is in place for all its active pumping units. The District should continue its preventive maintenance program, and make sure that the emergency response plan accounts for operations with any single unit or entire facility out of service. In addition, focus should be made to ensure the reliability of all units not used under primary operations such as the Cedar Creek Ennis Booster Station (CC2).

Preventive measures play a significant role in maintaining the reliability of the two East Texas pipelines. The pipelines have experienced a number of failures due to weakening caused by corrosion. Failures of the weakened pipeline have been triggered by waterhammer induced by power outages and thrust restraint movement. The District has an aggressive program to stop the progression of corrosion damage, and has installed cathodic protection on 4 of the 10 pipeline segments. The District has plans to complete 4 more segments by the year 2000. The cathodic protection program has rescued the Cedar Creek line from obsolescence and increased the expected useful life of both pipelines dramatically. The District also performs visual and internal inspections of the two pipelines periodically. The District should continue its preventive measures and increase its efforts to inspect the entire pipeline system. Identifying and replacing damaged pipe will increase system reliability and reduce potential hazards created by a ruptured pipe.

Although preventive maintenance is key, redundancy is still the primary means of ensuring system reliability. This is especially true for the District's electrical systems. Ideally, the pumping stations should have two separate power sources, either two primary transmission lines from separate sources or a single transmission line with an on-site generation unit. Since all the District's pumping facilities are tied to external power sources, they are vulnerable to a power failure on the electric utility's grid. Power failures could be caused by lightning, damage to the transmission line (e.g., tornado), or problems within the distribution grid. Single transmission lines serve both CC1 and RC1. The step-down electric transformers at the transmission line are key components and failure of these cause significant, if not total, loss of pumping capability. CC1 has two transformers feeding the station while RC1 has only one with the ability to tie to another transformer if needed. Two transmission lines serve both Waxahachie stations (CC3 and RC3) and the Ennis station (CC2) with two transformers dedicated to each station. Dual feeds to the motor control switchgear from separate transformers also increase reliability. The most vulnerable configuration is at RC1 where only one feed serves a single breaker. This makes the station vulnerable to the condition of the primary feed cable, the breaker, and the transformer. Having a spare breaker at this site and the other pump stations is a measure that the District should pursue. Supplying a second transmission line to the two intake plants would also decrease the District's vulnerability to electrical failures.

Another critical item in maintaining reliability is proper training for operators and maintenance staff. Staff should be well versed in emergency response and have the proper safety training for equipment operation. The staff should be cross-trained at multiple duties in order to reduce the system's dependence on any single individual's skills and decision-making ability.

Overall, the assessment revealed that the District operates a fairly reliable system. On a scale from 1 to 10, the average Risk Index is 1.48. This low score is primarily due to the interconnected configuration of the East Texas facilities. The two East Texas pipelines are interconnected to the intermediate booster stations and delivery points allowing each pipeline to serve as a backup for the other (albeit at a reduced pumping capacity) in the event of a pipeline failure. In addition, the new Lake Benbrook Connection facilities will provide backup water supply to respond to facility downtimes in the East Texas facilities. However, the additional facilities and the build-out of existing facilities are also associated with increasing water demands from District customers. Increasing system demands will minimize the ability of the Cedar Creek pipelines to serve as the Richland-Chambers pipeline back-up and vice versa. One noticeable result of the reliability analysis is the increasing trend of failure frequency reported with downtimes for both Cedar Creek and Richland-Chambers components. Tracking this trend and monitoring the impact of preventive measures over time will be an essential task for the District.

This assessment represents only a "snapshot" of the system. The real value of the assessment and the model will be to continually maintain the failure data and use this study as a benchmark of comparison. The model's database structure should facilitate data management and provide the features necessary to tailor the model as needed over time.

D.2 Introduction

D.2.1 General Background

Ensuring that customer demands are met with reliable water supplies under the most cost-effective operations is the prime goal to any water supply utility. Achieving this reliability is a dynamic process. It requires the ability to operate efficiently under normal conditions as well as the flexibility to react to such emergencies as component failures, operator errors, natural disasters, or other catastrophic events. Establishing the system's reliability under normal operations is essentially a straightforward procedure dependent on mostly known factors including system capacity, power charges, permitted diversions, and customer demands. Determining the system's reliability under unforeseen events is a more abstract process, and often a study of system vulnerability. By identifying and addressing the utility's most vulnerable components, the District will be able to implement a strategy to sustain its reliability to its customers.

Currently, there is no standard approach to assess a water utility's vulnerability and corresponding reliability. The American Water Works Association (AWWA) provides an outline for assessing system vulnerability in their M19 manual.[1] The AWWA recommends analyzing a number of hypothetical failure scenarios, and evaluating their impact on each component in the system. After a number of failure scenarios are analyzed, the system's critical components are identified and the appropriate measures are prescribed to strengthen the system's reliability. The work herein follows some of the general methods outlined in M19, but takes a more systematic approach to evaluating each component. The approach taken here is similar to the risk management methods applied in the petroleum industry.[2]

In basic terms, the objective is to inventory each of the water delivery system's major components, and calculate the amount of vulnerability or risk associated with each component.

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[1] American Water Works Association. "Emergency Planning for Water Utility Management: AWWA M19-Second Edition.," 1984.

[2] Muhlbauer, Kent W., *Pipeline Risk Management Manual, Second Edition.* Gulf Publishing Company, Houston, 1992.

The system inventory reduces the ambiguity and subjectiveness of forecasting future events by incorporating maintenance records, operating experience, expected equipment lifetime, expected failure incidences, and failure logs to assess system reliability. Using the inventory, the likelihood of possible failure mechanisms and their consequences are considered and weighted based on their importance. From the possible failures and their consequences, a risk index is calculated for each component. This provides the platform to rank and assess the system's components on the same scale. After ranking the components, the most critical system components can be identified and addressed. As the system inventory is updated and additional operating experience is obtained, this assessment tool will serve as a benchmark of comparison for future assessments.

D.2.2 Method

A standardized data gathering format was developed in order to bring together the information needed to assess system reliability. Much of the information was developed by District staff through a survey form on each of its major facilities. Past failures and maintenance records were gathered as well as information on design life and the likelihood of future failures. The District's staff also rated the consequences of each component failing. Once the information was collected, a Microsoft Access Version 2.0 database was created to manage and analyze the data. The database was programmed to calculate an index for each component based on the collected survey data. The analysis established the As-Is condition of the District's facilities, and serves as the reference point for recommended future actions and the preparation of an emergency response plan.

D.3 Model Description

D.3.1 Risk Index

To evaluate the reliability of the District's system and its components, a Risk Index was formulated to relate the probability of a component failing with the consequences of its failure. The Risk Index method assigns a single risk measurement value to each system component regardless of the failure mechanism. The Risk Index is a relative measurement tool in that a Risk Index of a single component by itself is of little value until put in relation to another component's index. The strength of this method is that it provides the structure to compare components with dissimilar functions (i.e., Pumping Units at RC1 versus the Electrical Systems at CC3) as well as components with similar functions (i.e., Pumping Units at RC1 versus Pumping Units at CC1) on the same scale.

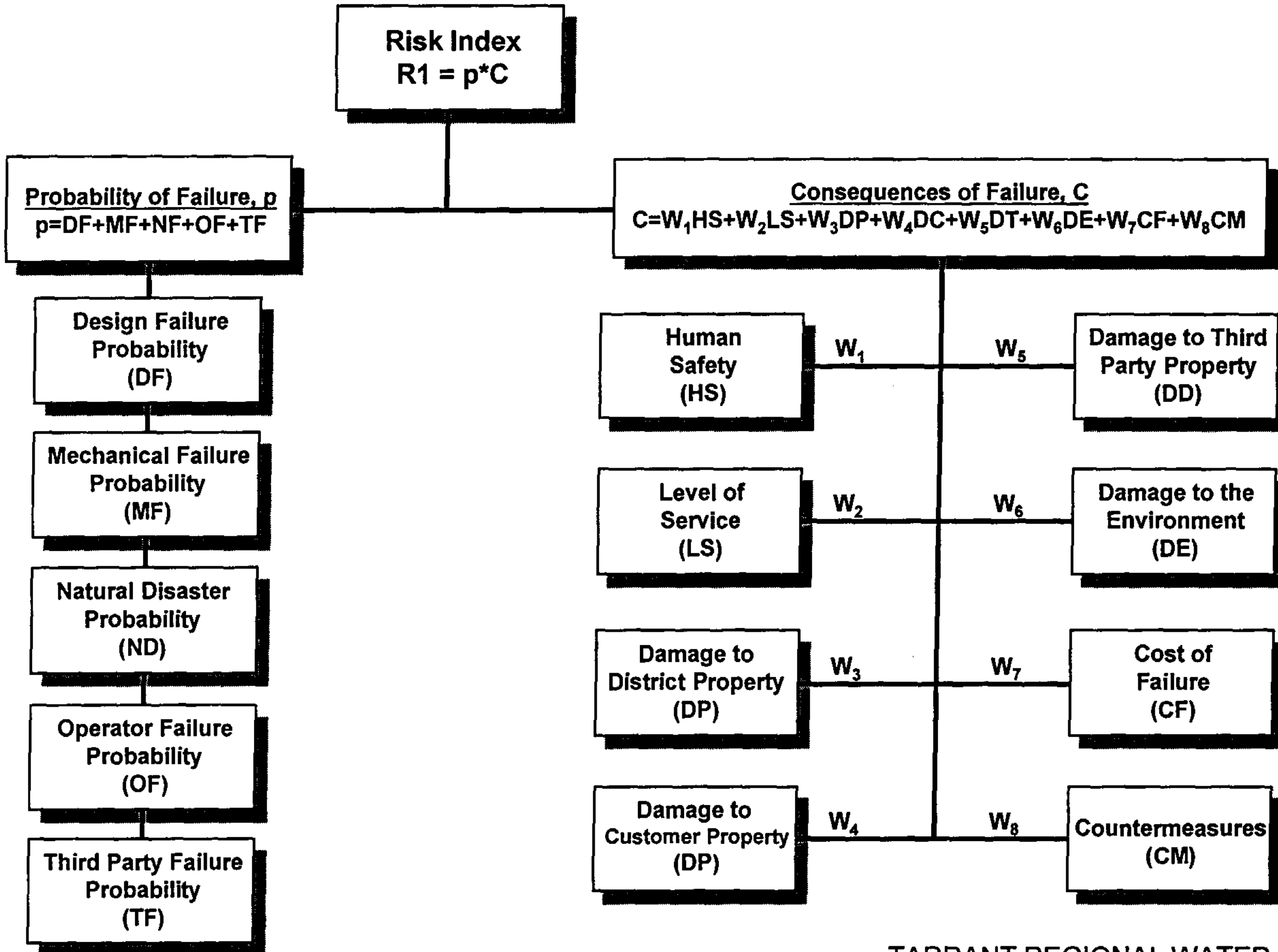
The Risk Index is the product of two components: the Probability of Failure (p) and the Consequences of Failure (C). The Probability of Failure is the aggregate probability of all the defined failure mechanisms. Estimation of the probability of each failure mechanism is based on the results of the system inventory conducted by the District and engineering experience. The Consequences of Failure term quantifies the implications of a component failure by scoring and weighting each possible consequence. The following paragraphs describe the variables and criteria associated with the Risk Index. Figure D-1 displays the relationships involved in calculating the Risk Index.

D.3.2 Probability of Failure

The probability of failure is the likelihood that a component will fail. It is the summation of the probabilities associated with each failure mode detailed below:

- **Design Failure**: Component failure due to the inadequacy (if any) of the component design. A pipeline break due to lack of reinforcing wire to resist operating pressures is an example of design failure.
- **Mechanical Failure**: Accounts for the system component failing due to a mechanical failure such as a valve malfunction. Equipment fatigue and lack of maintenance leads to mechanical failures.
- **Natural Disasters**: The probability that the system component will fail due to extreme meteorologic, hydrologic, or geologic conditions. This factor should use the probability of the most likely natural event that would cause the component to fail.
- **Operator Failure**: Encompasses failures caused by plant personnel such as improper system operation, defective repair, or improper maintenance. This factor accounts for the human side of operations.
- **Third Party Failure**: Accounts for failures caused by people outside the control of the District. Acts of vandalism and accidents caused by the public are considered third party failures.

The probability of failure can be thought of as a return period or frequency of a component failing. For example, a probability of 0.5 would correspond with a 2-year return frequency of



Possible consequences (i.e., HS, LS, DD, ...) are given a score of 1 to 10, see text for methods.

W_1, W_2, W_3 are weighting factors dependent on the importance of the consequence.

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RISK INDEX
MODEL RELATIONSHIPS

FIGURE D-1

failure (i.e., on average, a failure can be expected about every 2 years). The model provides a number of ways to arrive at the probability of each failure mode. It can be based on historic failure data, the estimated life of the component, the estimated shortest return period for the failure mode, or the longest estimated return period for the failure mode. Information on failure modes and probabilities was gathered for each major system component during development of the system inventory.

The general procedure followed to calculate failure mode probabilities was to use historic data if available, and use the District's estimate of the shortest return period between failures for components lacking sufficient failure mode data. When historic data are available, failure probabilities are equal to the number of failures for the period of consideration divided by the number of years in the period. The period of consideration either starts from the time the facility went on-line, or the year of the latest component replacements or major repair. This accounts for any decrease in expected failures that should follow maintenance or replacement. When estimated failure return periods are used, the probability of failure equals the inverse of the return period.

D.3.3 Consequence of Failure

The Consequence of Failure, C, measures the impact and importance a component failure has on the system. In order to determine the value of C, District staff assigned each component a score for each of the possible consequences defined below.

Each consequence is scored on a scale from 1 to 10 based on the criteria outlined in Table D-1. Once scored, each consequence is weighted and tallied to determine C. The weighting factors emphasize the consequences that have greater importance to the overall consequences of failure. For example, human safety is assigned the greatest weight while property damage is given the least weighting. To keep C on a scale from 1 to 10, the sum of all the weighting factors is equal to one. Table D-2 shows the weights given to each consequence.

- **Human Safety**: The consequence of a failure endangering human life ranges from no potential hazard (1) to potentially life-threatening (10).
- **Level of Service**: A measure of the percentage of system capacity lost due to a component failure ranges from 0 (1) to 100 (10 percent.

Table D-1
Consequences of Failure Scoring Criteria

Consequences	0	1	2	3	4	5	6	7	8	9	10
Human Safety	No potential for hazard		Slight potential for hazard			Hazard to human safety			Substantial hazard to human safety		Life-threatening hazard
Level of Service	0% lost		20% lost			50% lost			80% lost		100% lost
Damage to District Property	No potential damage		Slight potential for damage			Damage to property			Substantial damage to property		Total destruction of property
Damage to Customer Property	No potential damage		Slight potential for damage			Damage to property			Substantial damage to property		Total destruction of property
Damage to Third Party Property	No potential damage		Slight potential for damage			Damage to property			Substantial damage to property		Total destruction of property
Damage to the Environment	No potential damage		Slight potential for damage			Damage to property			Substantial damage to property		Total destruction of property
Cost of Failure	$0		$20,000			$50,000			$80,000		$100,000 and up
Countermeasures	All possible measures taken		80% of possible measures taken			50% of possible measures taken			20% of possible measures taken		No measures taken

Table D-2
Consequence of Failure Weighting Factors

Consequence	Weighting Factor	Value
Human Safety	W_1	0.35
Level of Service	W_2	0.20
Damage to District Property	W_3	0.05
Damage to Customer Property	W_4	0.05
Damage to Third Party Property	W_5	0.05
Damage to the Environment	W_6	0.10
Cost of Failure	W_7	0.10
Countermeasures	W_8	0.10
		Total = 1.00

- **Damage to District Property**: The consequence of a failure damaging any of the District's property ranges from no damage (1) to total loss of property (10).
- **Damage to Customer Property**: The consequence of a failure causing damage to any **customer's** property ranges from no damage (1) to total loss of property (10).
- **Damage to Third Party Property: The consequence of a failure damaging any property owned** by a third party, either public or private, ranges from no damage (1) to total loss of property (10).
- **Damage to the Environment**: An estimate of the potential harm a failure could have on the terrestrial or aquatic environment ranges from no damage (1) to total loss of habitat (10).
- **Cost of Failure**: The amount of money required to repair the failure ranges from minor cost (1) to major cost (10) (i.e., in excess of $100,000).
- **Countermeasures**: Accounts for the degree to which available measures have been taken to mitigate the potential impacts of a component failure. An example would be if a back-up transformer is available to quickly replace the in-service transformer in the event of a failure. Ranges from all possible measures taken (0) to no measures taken (10).

D.4 Risk Assessment

D.4.1 District's System Inventory

The District identified and inventoried 71 of its major components. The inventory focused on the East Texas water delivery facilities. In the assessment, the East Texas facilities are broken down into four major sub-systems: Cedar Creek facilities (CC), Richland-Chambers facilities (RC), the Arlington Outlet Works, and East Texas Common Components.

Cedar Creek Facilities

The Cedar Creek facilities are composed of an intake pumping station at Cedar Creek Reservoir (CC1), and two booster stations at Ennis (CC2) and Waxahachie (CC3). The pumping facilities are connected by 68 miles of 72-inch diameter prestressed concrete cylinder pipe (PCCP), and 6 miles of 84-inch diameter PCCP terminating at the Rolling Hills Water Treatment Plant.

Richland-Chambers Facilities

The Richland-Chambers facilities consist of 72 miles of 90-inch diameter PCCP stretching between an intake pumping station at Richland-Chambers Reservoir (RC1) and a booster station at Waxahachie (RC3), and terminates at Rolling Hills Water Treatment Plant.

Arlington Outlet Works

The Arlington Outlet Works is the facility used to supply water to Lake Arlington.

East Texas Common Components

The East Texas Component category accounts for any components that function in more than one of the other three major systems such as communications equipment, pipeline junctions, and the Balancing Reservoirs. The components are further categorized by facility type. Table D-3 shows all the facility categories and the number of components inventoried in each sub-system.

Table D-3
Inventoried Facilities and Components Matrix

Facility Type	Cedar Creek Facilities	Richland-Chambers Facilities	Arlington Outlet Works	East Texas Common Components
Building/Structure	2	2	1	—
Chemical Systems	3	2	—	—
Communications Equipment	—	—	—	1
Control System	3	2	1	—
Dam Structure	—	—	—	1
Discharge/Suction Piping or Structure	2	1	1	—
Electrical Transmission	4	2	—	—
Mechanical Systems	2	2	—	—
Pipeline	5	5	—	1
Pipeline Valves	2	2	—	—
Pumping Equipment	17	5	—	—
Storage Tanks	2	—	—	—

The District reported 157 component failures dating back to 1981. Table D-4 shows the total number of failures reported for each system and the average component downtime due to failure. Also shown are the first year of a reported failure and the year in which the system went on-line. As expected, more failures have occurred in older facilities, in this case, the Cedar Creek facilities. The Cedar Creek facilities have been in operation since 1972 and were the only source of water from East Texas until Richland-Chambers facilities came on-line in 1988. An important value in Table D-4 is the average number of hours a component is in the failed state before returning to normal operation. Both Richland-Chambers and Cedar Creek average around 1,000 hours of component downtime per failure. This can be attributed to the long lead times needed to replace or retrofit components in the pumping facilities. Average downtime for pipeline facilities is much shorter. The pumping equipment failures by themselves average around 2,000 hours of downtime, whereas the average downtimes for the pipeline are around 60 hours. One reason for the pipeline facilities' relatively short downtimes is the fact that pipe joints are readily accessible from Gifford-Hill American, a PCCP manufacturer in the Dallas-Ft. Worth area.

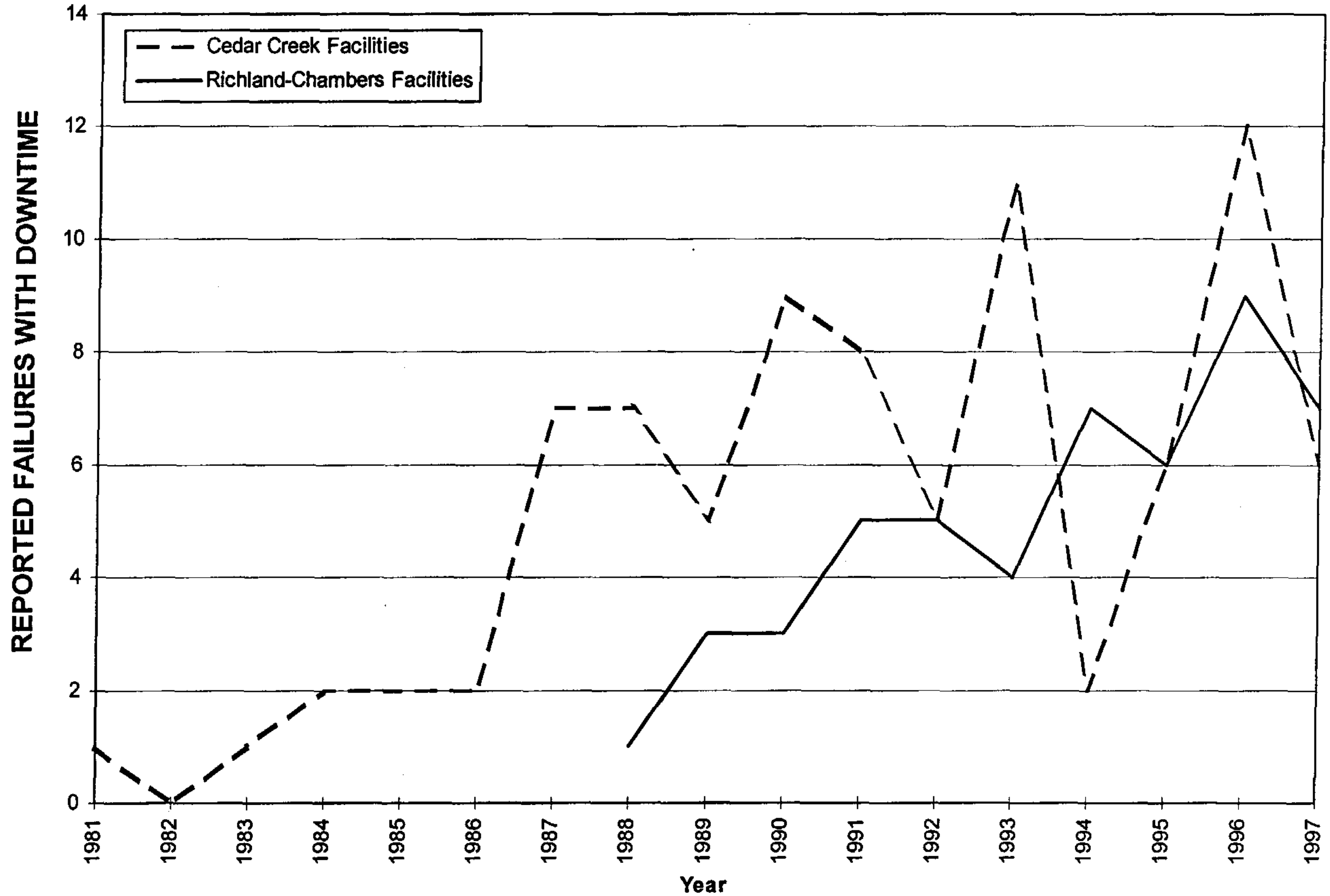
Table D-4
Reported Failures for the East Texas Systems

System	Total No. of Failures	Average Downtime (hours)	Year of First Reported Failure	Year On-Line
Cedar Creek Facilities	135	921	1981	1972
Richland-Chamber Facilities	81	1,051	1988	1988
Arlington Outlet Works	6	365	1992	1972
East Texas Common Components	17	10	1980	1972

Figure D-2 plots the number of failures reported with downtimes per year for the Cedar Creek and Richland-Chambers facilities. From the first reported failures, Richland-Chambers and Cedar Creek have averaged approximately five failures with downtime per year. The plots show an increasing trend for both East Texas systems.

D.4.2 Risk Index Assessment

Rankings based on the calculated Risk Index have been made for each component. The 10 components with the highest risk indices are shown in Table D-5. A complete ranking of all inventoried components is provided at the end of this appendix. The average and median Risk Indices for the inventory are 1.48 and 0.95, respectively. The highest Risk Index is shared by the medium voltage electrical system components at four of the District's five pumping facilities in the inventory. Since momentary power outages occur on an annual basis, and the importance of these electrical systems to the delivery system are considered equal, all four components share the same probability of failure and consequence scores. The only electrical component not included in the top 10 is the medium voltage electrical system at CC2. Because CC2 is currently off-line and used only as needed, its probability of failure is lower than the other electrical systems which are on-line. The next group of components in the ranking are the pumping units at RC1. This reflects the importance of RC1's pumping facilities to the District's system and the past problems encountered with the motors in each of the three pumping units at RC1. Since the District has performed substantial maintenance on the three units over the past 3 years, the probability of failure for each unit was calculated based on the estimated return frequency of



Failure incidences are for intakes, pumping equipment, electrical, controls, and piplines.

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WATER MANAGEMENT PLAN

FAILURE HISTORY FOR THE EAST TEXAS FACILITIES

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FIGURE D-2

failure instead of historic data. This is reflected by the equal probabilities of failure for the three units. The similarity of the units resulted in equal consequence scores. The last component listed is the RC1 Chlorine Feed System. Its high ranking is primarily the result of its high consequence score. A catastrophic failure of the chlorine feed could result in possible life and significant damage to the environment and property. Three other chemical feed components are ranked 11th, 12th, and 13th for these same reasons. This magnifies the importance of having proper containment systems as well as prepared staff to deal with any chemical system failures. The importance of the Richland-Chambers facilities is evident in that 7 of the top 10 components are from the Richland-Chambers portion of the water delivery system. The assessment clearly indicates that the District's on-line electrical systems and Richland-Chambers pumping equipment are the most critical facilities in maintaining the District's reliability.

Table D-5
Components with the Highest Risk Indices

Rank	Component	System	p	C	Risk Index
1	Waxahachie (RC3) Medium Voltage Electrical System	Richland-Chambers	1.00	5.20	5.20
2	Intake (RC1) Medium Voltage Electrical System	Richland-Chambers	1.00	5.20	5.20
3	Waxahachie (CC3) Medium Voltage Electrical System	Cedar Creek	1.00	5.20	5.20
4	Intake (CC1) Medium Voltage Electrical System	Cedar Creek	1.00	5.20	5.20
5	Intake (RC1) Pumping Unit No. 1	Richland-Chambers	0.70	5.40	3.78
6	Intake (RC1) Pumping Unit No. 2	Richland-Chambers	0.70	5.40	3.78
7	Intake (RC1) Pumping Unit No. 3	Richland-Chambers	0.70	5.40	3.78
8	Intake (CC1) Low Voltage Electrical System	Cedar Creek	1.00	3.70	3.70
9	Intake (RC3) Pumping Unit No. 11	Richland-Chambers	0.60	5.40	3.60
10	Intake (RC1) Chlorine Feed	Richland-Chambers	0.51	7.00	3.58

The Risk Index of the pipeline components are summarized in Table D-6 and range from 0.17 to 2.72. Although the pipeline segments are key components and are perhaps more vulnerable to failure than other components (i.e., pumps or electrical equipment), there are three

Table D-6
East Texas Pipeline Risk Indices

Pipeline Segment	Probability of Failure	Consequence of Failure	Risk Index
Cedar Creek			
I	0.55	4.95	2.72
II	0.25	3.80	0.95
III	0.29	3.50	1.02
IV	0.09	3.20	0.29
V	0.09	4.15	0.37
Richland-Chambers			
I	0.22	5.45	1.21
II	0.05	3.45	0.17
III	0.05	3.45	0.17
IV	0.56	3.90	2.17
V	0.22	5.95	0.60

mitigating factors that cause the Consequence of Failure factor (C) to be lower than other items. Consequently, the Risk Index for the pipeline components is lower than for the other facilities listed in Table D-5. The mitigating items that cause the consequence factor (C) to be lower for the pipeline segments are:

- The outage times for pipeline failures are relatively short compared to pumping equipment or electrical components;
- With two sources of supply and parallel pipelines, each pipeline serves as a backup for the other, thereby lessening the possibility of complete cessation of water deliveries; and
- Terminal storage at the balancing reservoirs, Lake Arlington and Lake Benbrook ensures that water deliveries can continue during outages of expected duration.

Section I of Cedar Creek (CC-I) and Section IV of Richland-Chambers (RC-IV) have the two highest risk scores. Two notable reasons for CC-I's ranking is its possibility of impacting public safety and its likelihood of failure. Portions of CC-I's right-of-way (ROW) run through parking lots near Mansfield, Texas. As population growth increases in the Dallas-Ft. Worth metroplex, more ROW will be exposed to public development, and the potential for a hazardous situation will only increase in this area. The increased probability of failure for CC-I is due to its potential for hydrogen embrittlement failures (i.e., corrosion-induced failure). Impressed current cathodic protection on concrete cylinder pipe and stray currents in low resistivity soils can cause embrittlement of the pipe's prestressing wires. One hydrogen embrittlement failure occurred in October of 1996, and the foreseeable return period to another failure is estimated at 2 years for CC-I. RC-IV's high index score is the result of failures that have occurred due to the impaired thrust restraint at changes in pipeline alignment. The District has replaced 5 joints on each side of 6 alignment changes, and has identified 339 damaged sections and recorded movement at 37 joints in the segment.

Other pipeline segments have also experienced failures. Two joints in CC-III will be replaced in the winter of 1997, and seven segments have been found with damage. Segment RC-I runs through a rapidly expanding commercial area and has been plagued by two recent failures. Several damaged segments have been found in the CC-II segment, and the District foresees that a number of other joints have sustained damage. The pipe segment with the highest consequence of failure, RC-V has not experienced any substantial problems to date.

D.4.3 As-Is Condition

Based on the results of the risk assessment, the District has a very reliable response system in place to react to problems. On a scale from 1 to 10, the system average Risk Index is 1.48. The predominance of Richland-Chambers' components in the top 10 risk indices, reflects the District's current operations of using the Richland-Chambers water as the primary source from East Texas. As previously mentioned, the most critical facilities identified by the Risk Index ranking are the electrical systems at the primary pumping facilities and the pumping equipment at RC1. However, both the Richland-Chambers and Cedar Creek pipelines traverse over 70 miles of right-of-way making them vital components to the District's water delivery system. Due to the proximity of the two East Texas sources, the Cedar Creek and Richland-Chambers pipelines run in parallel and are linked at major points along the alignment. In the event of a failure on one system, the probability is that the other system can be relied on to continue delivery at its normal rate. As future demands increase and the capacity of the system is used more fully, the redundancy of the delivery system will remain important, but water delivery through only one pipeline will meet a lower percentage of the demand. The addition of the Benbrook pipeline will provide the District with terminal storage to sustain water deliveries under emergency situations.

The East Texas facilities are essential components to the District's operations. Maximizing their reliability must continue to be a paramount goal of the District. A notable result of the assessment is the upward trend of component failures with downtime in both the Cedar Creek and Richland-Chambers facilities. With increasing system demands and age, this trend will only increase unless the District continues to takes an aggressive role in addressing its vulnerabilities. Since this assessment is only a "snapshot" of the system, the District should continue to monitor this failure trend and monitor the impacts of its preventive measures.

Eliminating failures and creating a fail-safe water delivery system is inordinately expensive, if not impossible. The primary way to ensure reliability is redundancy. Having an available back-up ready at all times reduces the system's vulnerability and eases the stress an individual failure can place on the equipment and staff. Since a completely redundant system is not feasible, the realization that component failures are a part of operations and that increasing system demands increases the system's exposure to failure, are essential starting points of maintaining a reliable system. Identifying the most vital components is the next step, and taking a proactive role in planning and implementing countermeasures that strengthen the system's ability to respond under stress is the final element of maintaining system reliability. The District has taken strides in each of these areas; however, as with all utilities, there are opportunities to improve. The more preventive measures taken to avoid or prepare for emergencies, the more likely the staff and equipment will be able to manage an emergency situation. The District's focus should be directed to the three most critical components: the electrical systems, the pumping equipment, and the two large diameter pipelines.

For the electrical systems, the primary measure to decrease vulnerability and thereby increase reliability is redundancy. Dual transmission lines from separate sources provide a strong safety net for dealing with power outage or damage to transmission lines. Ideally, pumping stations with a single transmission line power supply should have an on-site generation unit. Since all the District's pumping facilities are tied to external power sources without on-site generation, they are vulnerable to a power failure on the electric utility's grid. If the entire grid failed, the pumping units would be inoperable. Momentary power outages have occurred often enough at the pumping stations that their probability of occurring is set at 100 percent. Single transmission lines serve both CC1 and RC1. CC1 has two transformers feeding the station while RC1 has only one with a back-up available if needed. Two transmission lines serve CC3, CC2, and RC3 with two transformers dedicated to each station. Supplying a second transmission line from a different location in the grid to the two intake plants would decrease the District's vulnerability to electrical failures. Providing alternate paths to power at the motor control switchgear is another means of combating the impact of electrical component failures. The District completed a major overhaul of the switchgear at CC1. The most vulnerable configuration is at RC1 where only one feed serves a single main breaker. This makes the station vulnerable to the condition of the feeder cable and the breaker. CC1 recently experienced a transformer failure on the low voltage system that disabled the entire station for 24 hours. A similar failure at RC1 would create a larger problem due to the single feed and lack of an on-line backup. The District should have a spare breaker at this site, and spare breakers at each of the other pump stations. The District does have staff to respond to electrical problems. One master electrician and three other electricians can be reached at any time and are within an hour of the pumping sites.

The pumping units at RC1 were identified as the most critical pumping components. Under high capacity operations, the Cedar Creek and Richland-Chambers pumping units each supply approximately 50 percent of the needed capacity. Making each RC1 units provide 16.66 percent of the entire capacity. Under low capacity operations, the split is roughly 33 percent to 66 percent between Cedar Creek and Richland-Chambers, respectively. The most substantial problem reported at the RC1 station is the wearing of the motor thrust bearings. They are wearing out as often as once a year without any indications of cause. The motor bearings are routinely inspected and replaced as needed by the District. Equipment at RC1 as well as at the District's other pumping units are routinely maintained and replaced. Beside the catastrophic cone valve failure at CC1 in 1996, most pumping equipment downtimes have been the result of preventive maintenance. The cone valve failure resulted in all six CC1 units being fitted with new ball valves. The three primary units at the CC2 have also been fitted with new ball valves due to inadequate material properties of the old cone valves. Variable frequency drives have been added to RC3 to provide more flexibility and better system balance. The only preventive measure lacking is a comprehensive emergency response plan. The plan should account for appropriate safety measures to be taken in the event of a failure as well as optimize system operations when a unit goes down.

The District has done a superior job in addressing the vulnerability of the East Texas pipelines. Corrosion is the most recognized problem with the pipeline facilities. Corrosion can originate from physical damage to the pipe including impaired thrust restraint, waterhammer, and improper installation. These mechanisms can damage the mortar coating protecting the pipe reinforcing wire. Once exposed to moisture, the reinforcing wire is susceptible to attack by chlorides, groundwater, and stray currents. In order to prevent failures caused by corrosion, the District has installed zinc anode beds for cathodic protection. This has reduced corrosion of the Cedar Creek pipeline, and the on-going cathodic protection installations will extend the life of East Texas pipelines significantly. Of the 10 segments, 4 already have cathodic protection and 4 more segments will be protected by the year 2000. The visual inspection and pipe-to-soil potential measurements need to be continued. These routine measures will allow the District to identify damaged pipe and make scheduled replacements before a catastrophic failure can occur. Although the cathodic protection will reduce corrosion failures, it will not totally eliminate the problem. Waterhammer and lack of thrust restraint will continue to damage the pipe's mortar coating, which will create the pathway for corrosion. Therefore, cathodic protection should not reduce the amount of effort allotted for inspecting and maintaining the pipelines. Increased development around the pipeline right-of-way will necessitate a proper emergency response plan to be in place and coordinated with all the District's staff. The plan should also be communicated with the Department of Public Safety and any local emergency response agencies.

One portion of the District's system that has not been addressed in this assessment but will remain an essential part of the operations is the District's staff. Currently, the District has trained staff to respond to failures for almost all of the inventoried components. The building and structural components at each pumping station were the only components without repair staff. As the District's system expands, the appropriate human resources must be available to respond to the additional operation demands. Staff should be well versed in emergency response, and have the proper safety training for equipment operation. Cross-training is essential as it reduces the system's dependence on an individual's skills and availability during emergencies. The proper staffing needs are a part in larger issues that will need attention from the District. With the current addition of the Benbrook facilities and the future Richland-Chambers' booster station at Ennis, the additional number of pumping units in use and the increasing hours of operation will create the need for more well-trained staff and a well-coordinated maintenance schedule. Strategic planning and budgeting will require a greater effort as the District grows.

Assessing the system's vulnerabilities and reliability is a dynamic process. In performing this reliability assessment, it is noted that the delivery facilities are never at 100 percent operational level, as some component at any given time is either out of service for maintenance or repair. Consequently, this assessment shows that the District is consistently in a reactionary state to current conditions. The District recognizes this fact and is taking the necessary steps to alleviate the stresses created by untimely events before the burden of a larger system becomes a reality.

D.5 Model Formulation

This section is an overview of the Risk Index Model's formulation in Microsoft Access Version 2.0 (Access) and a guide for its operation. Access is a powerful relational database for the Microsoft Windows operating system. It was chosen as the model's platform due to the District's familiarity with the program and the program's ability to store and manipulate data efficiently in a Windows-type screen setting. The model was created on an IBM compatible 486-33 MHz personal computer with 8 MB of RAM running Windows 95. The model's size is approximately 1.4 MB. It is assumed that the operator has a basic understanding of Microsoft Access Version 2.0. For a complete guide to Access functions and workings, Access program documentation should be consulted.

D.5.1 Database Structure

The main objective of using the database platform was to efficiently enter and manage the information gathered during the system inventory. The advantage of using a relational database is that each piece of information need only be identified and entered once. From these identification tags and data sets, any number of relationships can be created for running the model or analyzing the data. Access uses four basic objects to work with data: tables, forms, queries, and reports. Access stores data in tables with individual field identifiers much like a spreadsheet. These tables are the backbone of the database; however, they are not very user friendly for entering data. In order to make data entry easier, forms can be created from tables in Access that prompt the user to enter data in the correct field. Forms also serve a number of other purposes in Access. They can be programmed to perform calculations or graph data. Forms can also display the results of a query, or be defined to act as a tool bar with buttons that execute predefined macros. Access allows forms to be embedded in other forms as subforms. This feature makes viewing related data easier. A query is a searching tool that examines and displays data from any number of tables based on a set of criteria. Reports provide a customized layout for printing database information. The Risk Index Model uses each one the objects defined above. Table D-7 shows the names and descriptions of the key objects in the model.

D.5.2 Opening the Model

Once Access is open, the Risk Index Model can be opened under the **File** menu and the ***Open Database*** function. A dialogue box will request the file name and its directory path. The model's filename is R&R.mdb. After entering the filename and location, the model will open to the model's directory screen shown in Figure D-3. Each of the buttons on the directory form will open the specified form or report. The first four buttons going down the screen are for entering data and running the model, and the last two buttons are for viewing the model's results. Access' database directory has been minimized and is hidden behind the directory form. It is not necessary to maximize this window for operating the model, but it provides a complete guide to all the tables, forms, queries, reports, and macros defined in the database.

Table D-7
Key Objects in the Risk Index Model

Tables	Forms	Queries	Reports
Consequences	Consequences (s[1])	Downtimes by Component Type	Downtime by Facility
Countermeasures	Countermeasures (s)	Downtimes by System	Downtime by System
Facility Types	Facility Types	Facility Search	Downtime by Year
Failures Information	Failures Info (s)	Failures	Failures
Foreseeable Failures	Foreseeable (s)	Risk Inventory	
Major Replacement & Maintenance	Repair (s)	System Search	
System Inventory	Risk Index		
Weighting Factors	System Failure Inventory		
	Weighting Factors		

[1](s) indicates that the form is embedded in another form as a subform.

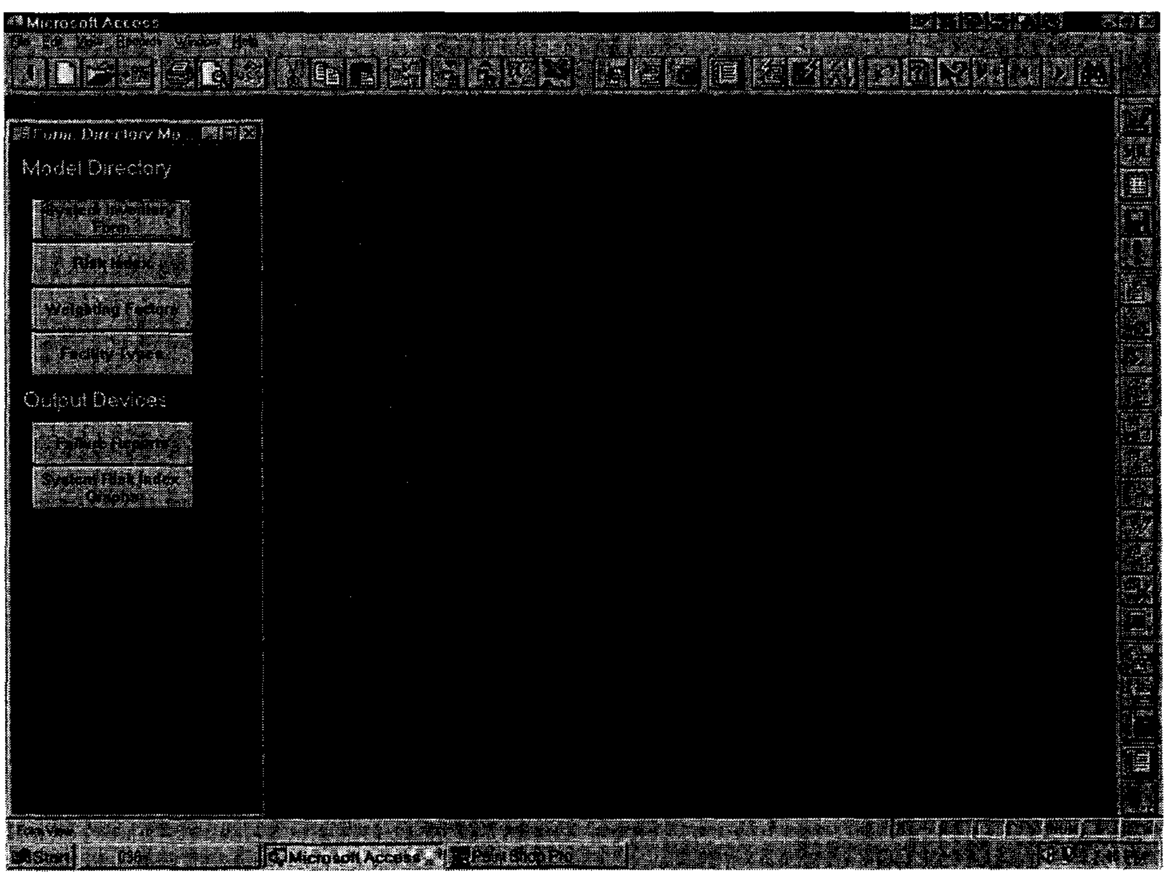
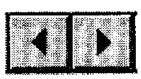


Figure D-3. Risk Index Model Directory

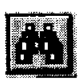
D.5.3 System Inventory Information

Clicking the **System Inventory** button with the mouse will bring up the ***System Inventory Form*** as shown in Figure D-4. All the information gathered in the District's inventory can be found using this form. It is mostly made of subforms that can be viewed or edited. The subform and data field entries are defined in Table D-8. The entire contents of the form can be viewed by using the scroll bars on the right-hand side of the form. Figure D-5 displays the bottom portion of the ***System Inventory Form***.

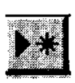
The following toolbar buttons are useful for moving around in the multiple form records. If these buttons are not available, the toolbars can be customized through the **View** menu under the ***Toolbars*** function.



These buttons will take the user to either the previous or next form in the database.



This button will open a dialogue box to find specified information. It allows the user to search the fields for the specified text or numeric information.



This button will create a new record in the database. It clears the form's fields for data entry.

D.5.4 Risk Index

Clicking the **Risk Inventory** button in the model directory brings up the ***Risk Inventory Form*** as shown in Figure D-6. This is where the Risk Index is calculated. As shown in Figure D-6, all the variables related to the Risk Index are displayed. Three buttons are available for editing each variable: **Update Consequences, Update Probabilities,** and **View System Inventory**. The two updating buttons bring up windows for editing the consequence scores and the probability calculations. The **System Inventory** button displays the system inventory information entered for the component under consideration.

Table D-8
System Inventory Data Fields and Subforms

Form/Field	Description
System Inventory	*Main Form*[1]
Name	Component Name.
ID	Identification tag for component.
Component Type	Pull down menu of available components (Pipeline, Electrical Systems, etc.).
System	Pull down menu of available systems (Cedar Creek, Richland Chambers, etc.).
Estimated Annual Operation Time (hrs.)	Number of hours that component operates per year.
Estimated Design Life (yrs.)	Estimated design life of component.
Starting Year in Historic Probability Calculation	Starting year of range for calculating probabilities of failure from historic data.
Notes	Items of interest for component.
Failure Information	*Subform*
ID	Identification tag for failure. Id is not global for all records.
Description	Description of failure
Mode	Mode of Failure. Should be entered as DF, MF, NF, OF, or TF as described in Section 3.
Year	Year that failure occurred.
Time	Date and time of failure.
Downtime (hrs.)	Number of hours that component is in failed state.
Cost of Repair	Number of dollars required to repair component.
Notes	Items of interest for failure.
Foreseeable Failures	*Subform*
No.	Number tag for failure.
Description	Description of foreseeable failure.
Mode	Mode of failure. Should be entered as DF, MF, NF, OF, or TF as described in Section 3.
Return Period (yrs.)	Estimated return period for foreseeable failure.
Impact of Failures	*Subform*
Consequences List	List of possible consequences with fields for scores (1-10).
Countermeasures	Subform
Countermeasures	Possible countermeasures and radio buttons to record if measure is In-Place and if it is Possible.
Others	Fields for other possible countermeasures for a particular facility.
Replacement/Major Repair	*Subform*
Description	Description of component replacement or repair.
Date	Date of replacement or repair.

[1] In order to create a new record, one of the fields in the System Inventory Form must be the active cell. To make a cell active, highlight it by left-clicking it with the mouse.

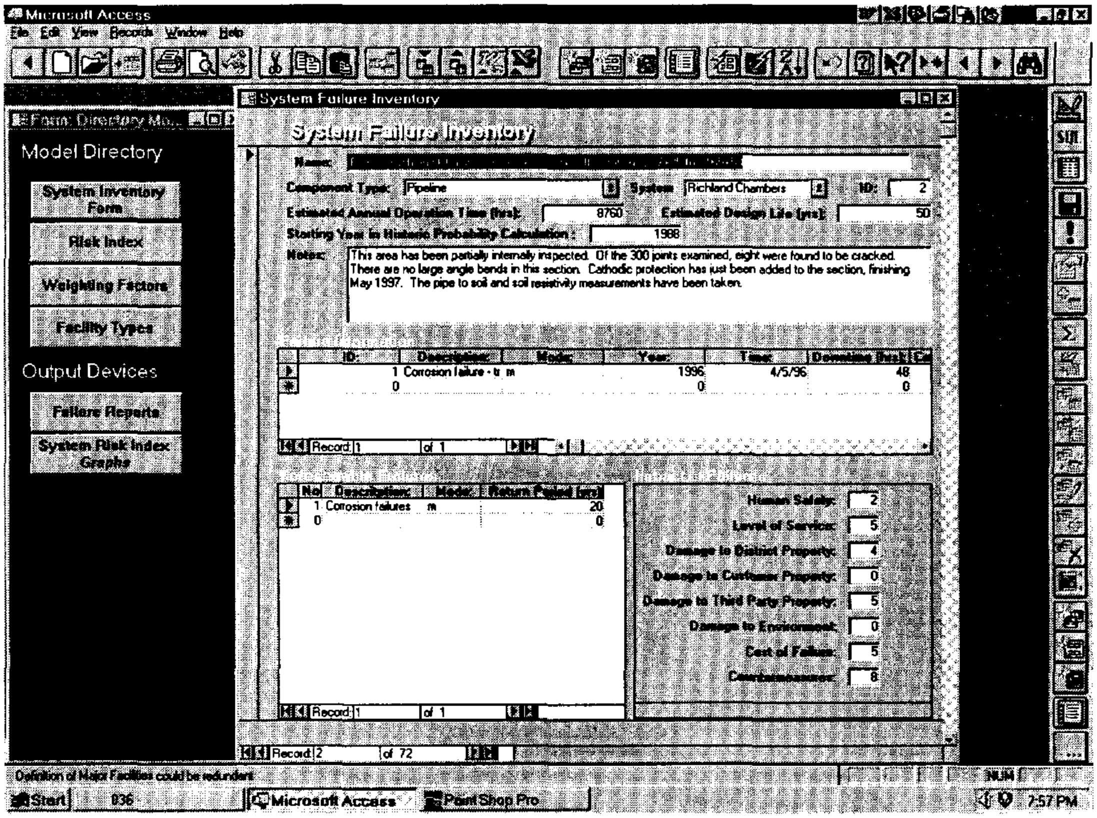


Figure D-4. System Inventory Form — Upper Portion

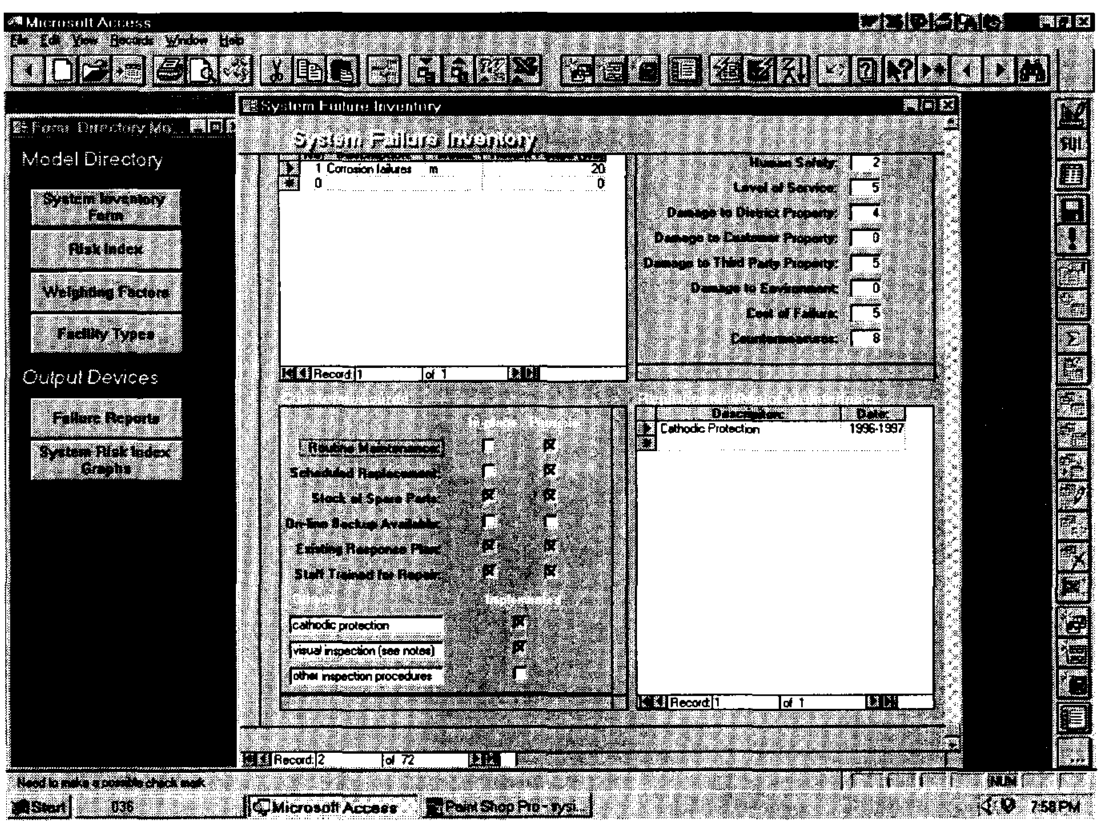


Figure D-5. System Inventory Form — Lower Portion

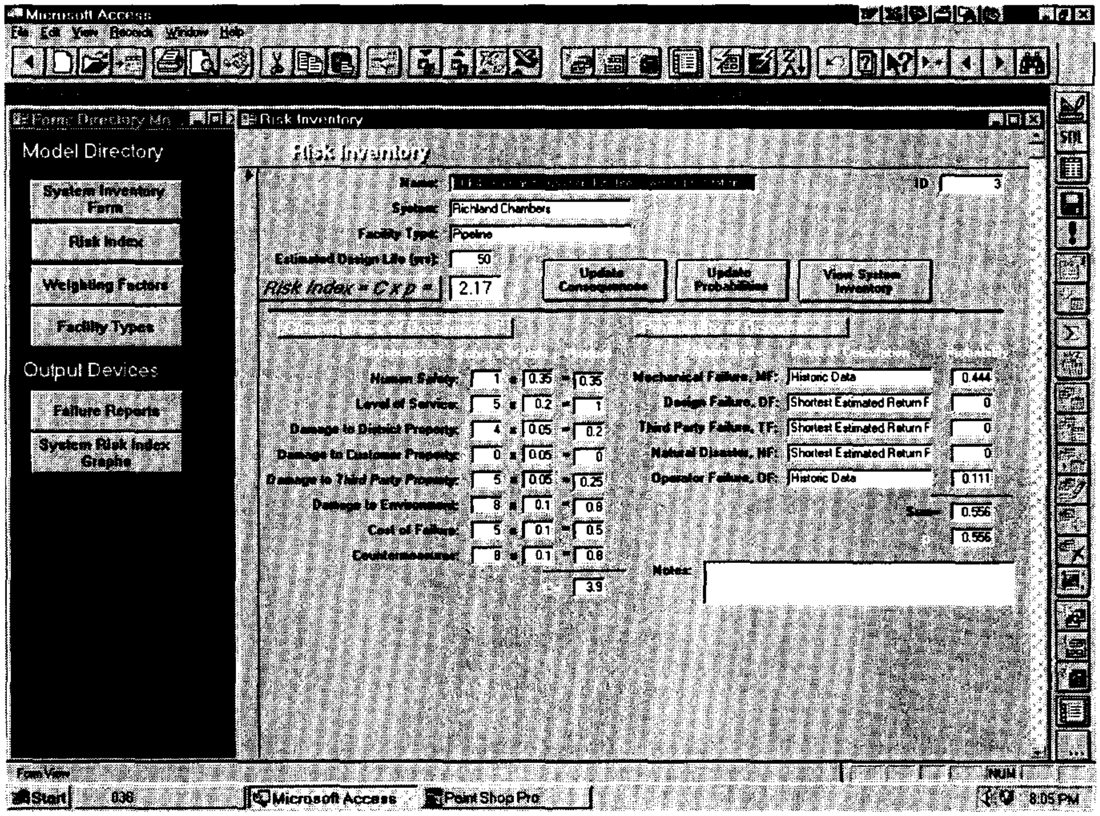


Figure D-6. Risk Inventory Form

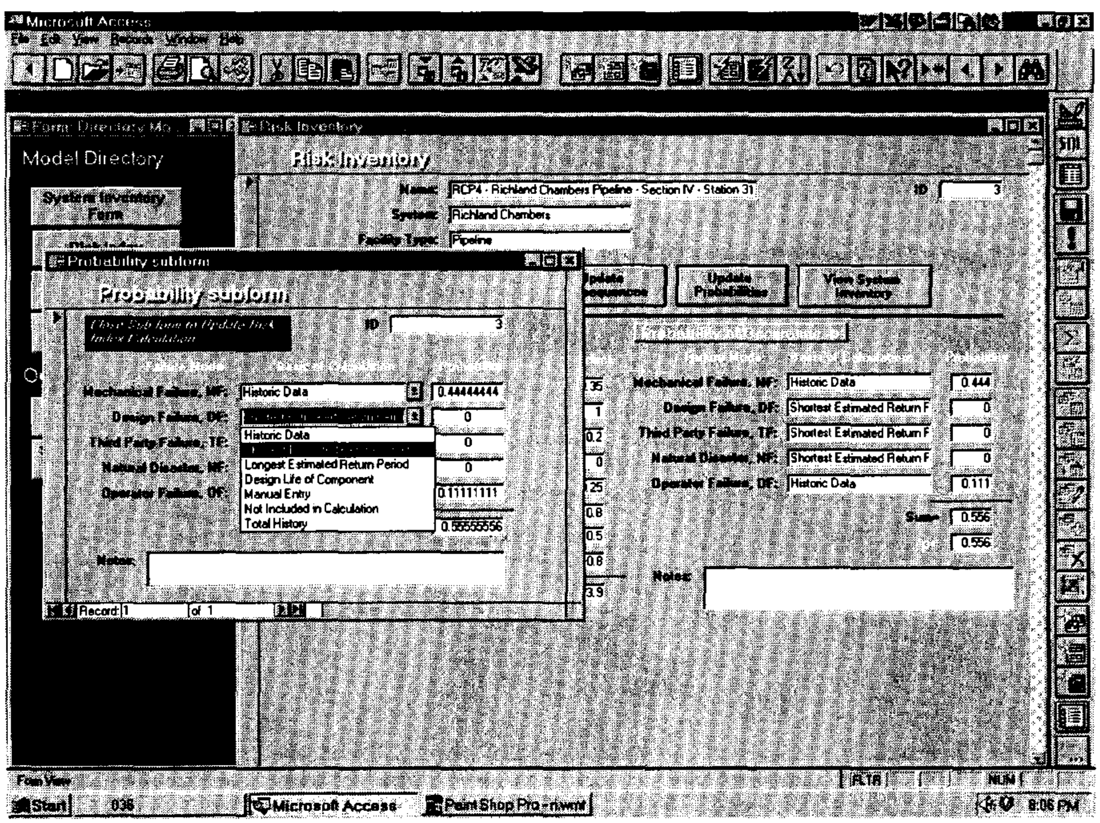


Figure D-7. Risk Inventory Form with Probability Subform Open

The consequence scores displayed are those entered during the system inventory. They can be edited from the updating window or the ***System Inventory Form***. Figure D-7 displays the window for calculating the probabilities of failure. For each failure mode, a pull down menu displays all the options defined in Section 3. Highlighting the option and right-clicking the mouse will initiate the calculation. If any values are changed, the editing window must be closed for the updates to take affect on the Risk Index calculation and any other related forms, tables, or reports.

D.5.5 Output Devices

The bottom portion of the Model Directory is dedicated to viewing results of the model. Clicking the output device buttons will bring up subdirectories as shown on Figure D-8. The model can display bar graphs of risk indices or print predefined reports. Clicking the buttons in the subdirectory will open the corresponding output screen. The graphs and reports available are shown in Figure D-8. Figure D-9 displays a bar graph generated in Access to display the Risk Indices for similar facilities in the database. The reports available are generated from the inventory information and the model's calculations. The user can output Risk Indices for each component by facility, system, or rank by clicking the appropriate button. Component downtimes from the system inventory data can be reported by year, facility, or system, and failure records can also be viewed using the **Failure Records** button. Figure D-10 shows an example of the Risk Index Rankings report displayed on the computer screen. All the output devices have been programmed into the model. The user can edit the format of these forms, or create output devices tailored for the intended use. The Access user's manual should be consulted before editing or creating graphics and reports.

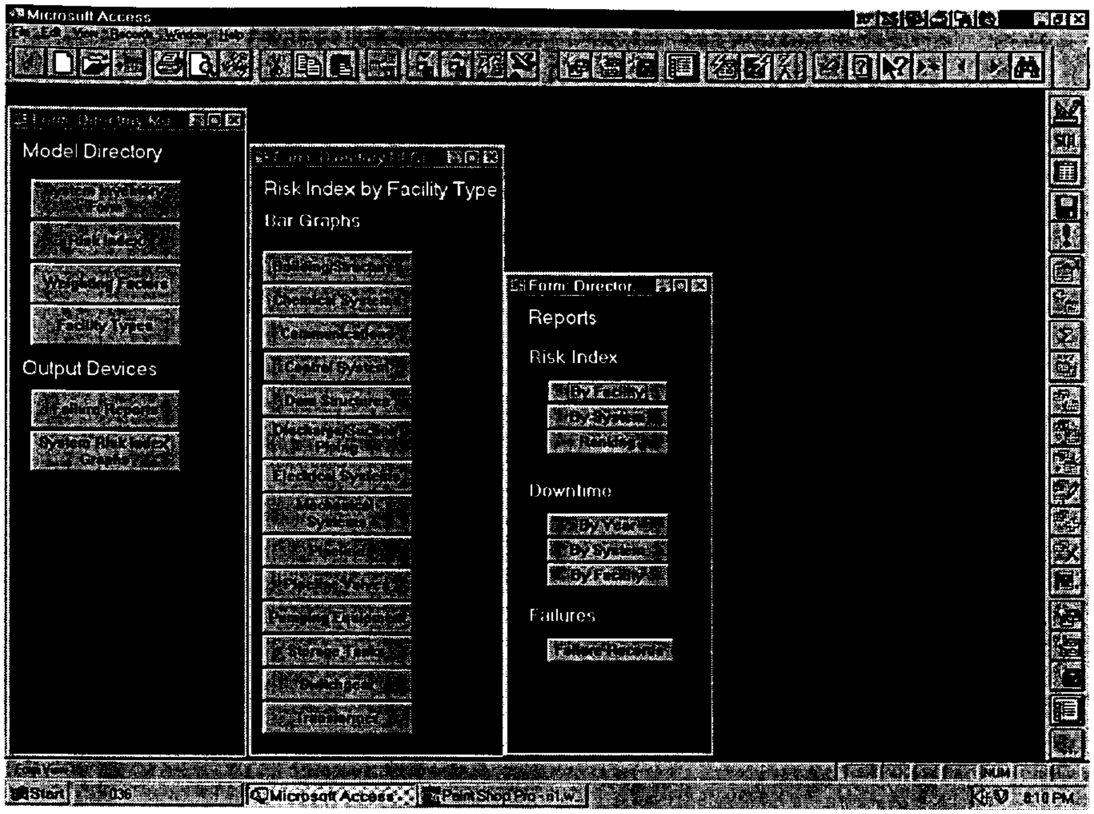


Figure D-8. Output Devices

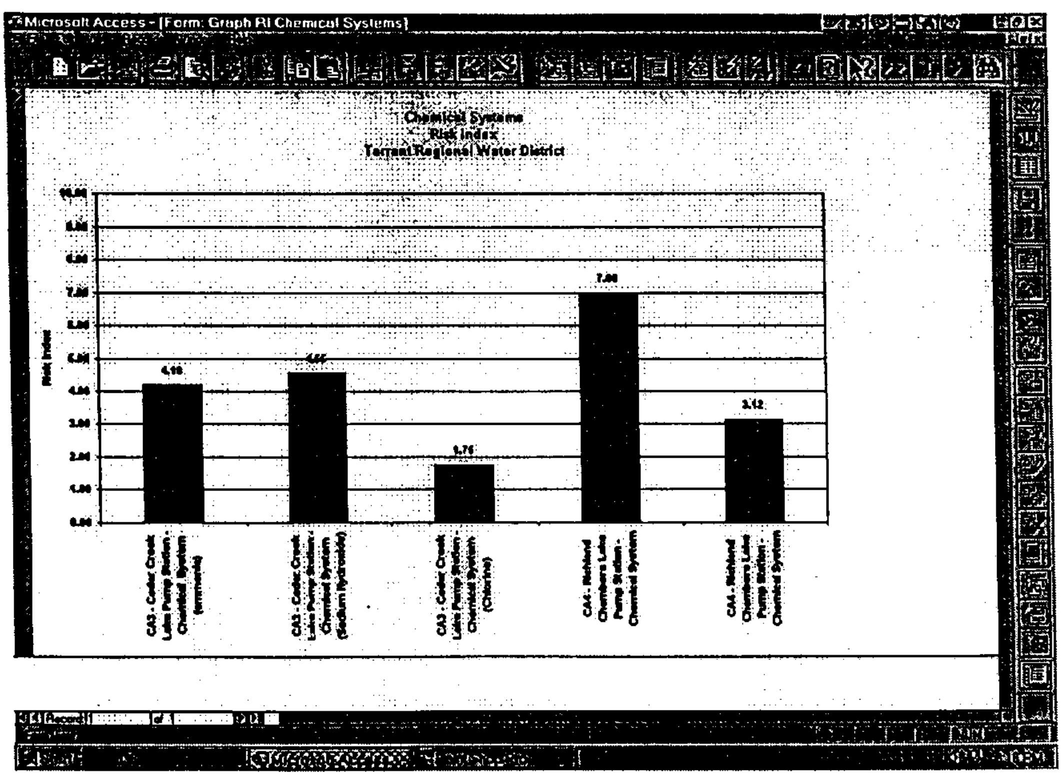
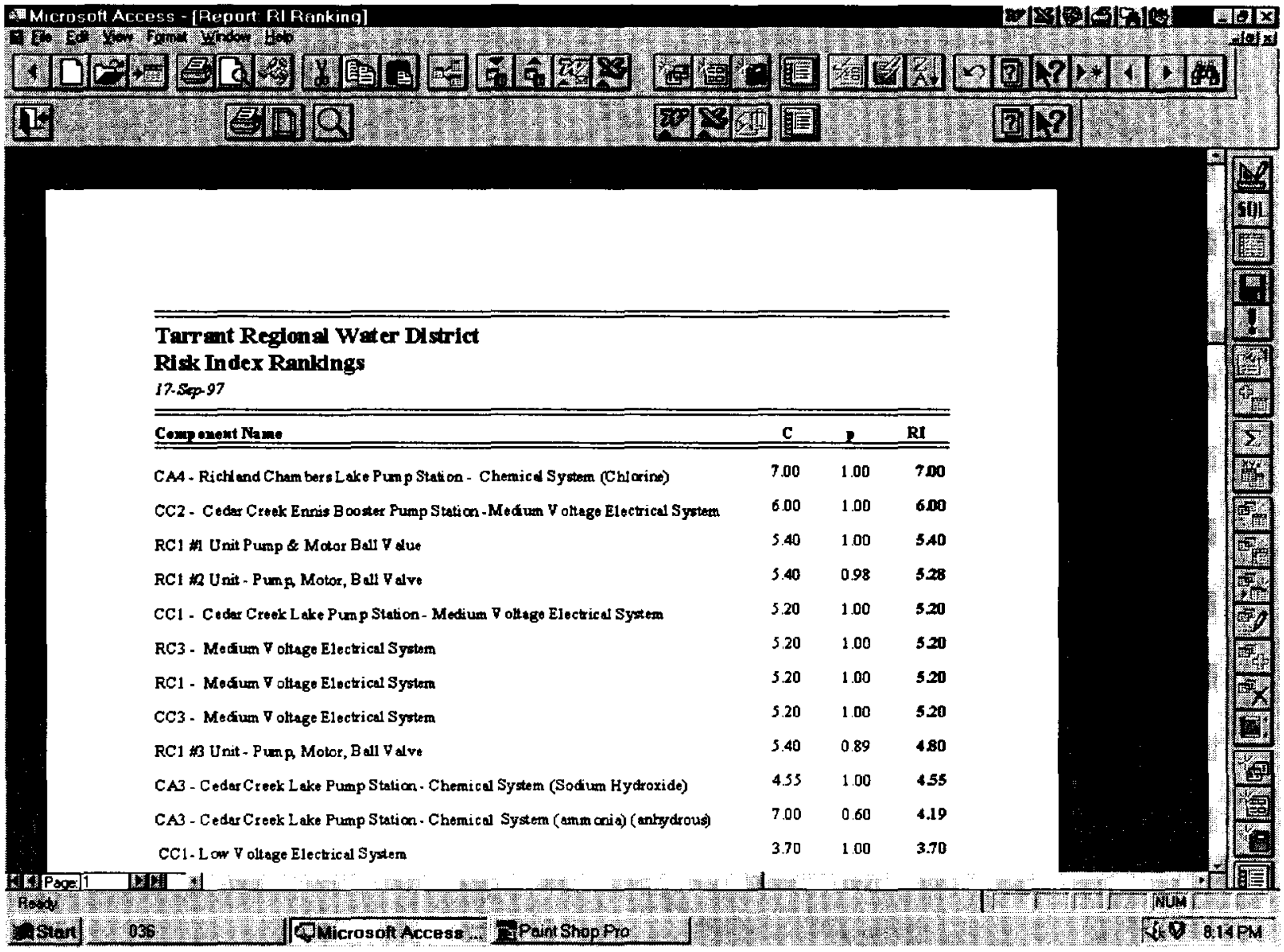


Figure D-9. Risk Indices Bar Graph



Tarrant Regional Water District
Risk Index Rankings
17-Sep-97

Component Name	C	P	RI
CA4 - Richland Chambers Lake Pump Station - Chemical System (Chlorine)	7.00	1.00	7.00
CC2 - Cedar Creek Ennis Booster Pump Station - Medium Voltage Electrical System	6.00	1.00	6.00
RC1 #1 Unit Pump & Motor Ball Value	5.40	1.00	5.40
RC1 #2 Unit - Pump, Motor, Ball Valve	5.40	0.98	5.28
CC1 - Cedar Creek Lake Pump Station - Medium Voltage Electrical System	5.20	1.00	5.20
RC3 - Medium Voltage Electrical System	5.20	1.00	5.20
RC1 - Medium Voltage Electrical System	5.20	1.00	5.20
CC3 - Medium Voltage Electrical System	5.20	1.00	5.20
RC1 #3 Unit - Pump, Motor, Ball Valve	5.40	0.89	4.80
CA3 - Cedar Creek Lake Pump Station - Chemical System (Sodium Hydroxide)	4.55	1.00	4.55
CA3 - Cedar Creek Lake Pump Station - Chemical System (ammonia) (anhydrous)	7.00	0.60	4.19
CC1 - Low Voltage Electrical System	3.70	1.00	3.70

Figure D-10. Risk Index Ranking Report

Risk and Reliability Assessment

Attachment No. 1
Inventoried Components

Tarrant Regional Water District
Inventoried Components

System

Facility Type **Name**

<u>Arlington Outlet Works</u>

Building/Structure

AO1 - Outlet Structure - Arlington

Control System

AO1 - Instrumentation & Control

Discharge/Suction Piping or Structures

AO1 - Discharge/Suction Piping

<u>Cedar Creek</u>

Building/Structure

CC1 - Cedar Creek Lake Pump Station - Pump Station Structure

CC3 - Waxahachie Booster Pump Station - Pump Station Structure

Chemical Systems

CA3 - Cedar Creek Lake Pump Station - Chemical System (anhydrous ammonia)

CA3 - Cedar Creek Lake Pump Station - Chemical System (Sodium Hydroxide)

CA3 - Cedar Creek Lake Pump Station -Chemical System (Chlorine)

Control System

CC1 - Cedar Creek Lake Pump Station - Instrumentation & Control

CC3 - Waxahachie Booster Pump Station - Instrumentation & Control

CC2 - Ennis Booster Pump Station - Instrumentation & Control

Discharge/Suction Piping or Structures

CC1 - Cedar Creek Lake Pump Station - Suction/Discharge Piping

CC3 - Suction/Discharge Piping

System	
Facility Type	Name

Electrical Transmission

CC1 - Cedar Creek Lake Pump Station - Medium Voltage Electrical System

CC3 - Medium Voltage Electrical System

CC1- Low Voltage Electrical System

CC2 - Cedar Creek Ennis Booster Pump Station -Medium Voltage Electrical System

Mechanical Systems

CC1 - HVAC - Exhaust Fans & Air Handling Units

CC3 - HVAC- Exhaust Fans & Air Handling Units

Pipeline

CCP1 - Cedar Creek - Section I, Station 310+00 to 1200+00

CCP3 - Cedar Creek Pipeline - Section III, Station 2100+00 to 3002+00

CCP2 - Cedar Creek Pipeline - Section II, Station 1200+00 to 2100+00

CCP5 - Cedar Creek Pipeline - Section V, Station -0+50 to 310+00

CCP4 - Cedar Creek Pipeline - Section IV, Station 3002+00 to 3896+00

Pipeline Valve

CCPV - Cedar Creek Pipeline - blow-off and air valves (numerous)

CCPMV - Cedar Creek Pipeline - mainline valves (11)

Pumping Equipment

CC3 - Hydraulic Accumulator System

CC3 #2 Unit - Pump, Motor, Cone/Ball Valve (Waxahachie Booster Station #2)

CC3 #3 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)

CC1 #4 Unit - Pump, Motor, Ball/Cone Valve

CC1 - Hydraulic Accumulator System

System	
Facility Type	Name

CC1 #3 Unit - Pump, Motor, Ball/Cone Valve

CC1 #2 Unit - Pump, Motor, Ball/Cone Valve

CC1 #6 Unit - Pump, Motor, Ball/Cone Valve

CC3 #1 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)

CC1 #5 Unit - Pump, Motor, Ball/Cone Valve

CC3 #4 Unit - Pump Motor Cone Value

CC1 #1 Unit - Pump, Motor, Ball/Cone Valve

CC3 #5 Unit - Pump Motor, Cone Valve

CC3 #7 Unit Pump, Motor, Cone Valve

CC3 #6 Unit Pump, Motor, Cone Valve

CC3 #8 Unit - Pump, Motor, Cone Valve

CC3 #9 Unit Pump, Motor, Cone Valve

Storage Tanks

CC2 - Ground Storage Tanks

CC3 - Ground Storage Tanks

East Texas

Communications Equipment

SCADA

Dam Structure

BR1 - Balancing Reservoir Embankment & Structures

Pipeline

Cedar Creek/Richland Chambers PL Xovers @ Ennis, Waxahachie, Rolling Hills, Balancing Reser

Richland Chambers

System

Facility Type **Name**

Building/Structure

RC1 - Richland Chambers Pump Station - Building

RC3 - Waxahachie Booster Pump Station - Building

Chemical Systems

CA4 - Richland Chambers Lake Pump Station - Chemical System (Chlorine)

CA4 - Richland Chambers Lake Pump Station - Chemical System (aqua Ammonia)

Control System

RC1 - Richland Chambers Lake Pump Station - Instrumentation & Control

RC3 - Waxahachie Booster Pump Station- Instrumentation & Control

Discharge/Suction Piping or Structures

RC1- Suction/Discharge Piping

Electrical Transmission

RC1 - Medium Voltage Electrical System

RC3 - Medium Voltage Electrical System

Mechanical Systems

RC1 - HVAC- Exhaust Fans & Air Handling Units

RC3 - HVAC - Echaust Fans & Air Handling Units

Pipeline

RCP4 - Richland Chambers Pipeline - Section IV - Station 3165+50 to 4124+00

RCP1 - Richland Chambers Pipeline, Section I - Station 301+00 to 1249+00

RCP5 - Richland Chambers Pipeline - Section V - Station 301+00 to 1249+10

RCP2 - Richland Chambers Pipeline - Section II Station 1249+00 to 2207+25

RCP3 - Richland Chambers Pipeline - Section III - Station 2207+25 to 3165+50

Pipeline Valve

System	
Facility Type	Name

RCPMV - Richland Chambers Pipeline - Mainline Valves

RCPV - Richland Chambers Pipeline - blow-off and air valves (numerous)

Pumping Equipment

RC1 #2 Unit - Pump, Motor, Ball Valve

RC1 #3 Unit - Pump, Motor, Ball Valve

RC1 #1 Unit Pump & Motor Ball Value

RC3 #11 Unit - Pump, Motor, Ball Valve

RC3 #12 Unit - Pump, Motor, Ball Valve

RC3 #13 Unit - Pump, Motor, Ball Valve

Risk and Reliability Assessment

Attachment No. 2
Risk Index Rankings

Tarrant Regional Water District
Risk Index Rankings
09-Nov-97

Component Name	C	p	RI
CC1 - Cedar Creek Lake Pump Station - Medium Voltage Electrical System	5.20	1.00	**5.20**
RC3 - Medium Voltage Electrical System	5.20	1.00	**5.20**
CC3 - Medium Voltage Electrical System	5.20	1.00	**5.20**
RC1 - Medium Voltage Electrical System	5.20	1.00	**5.20**
RC1 #2 Unit - Pump, Motor, Ball Valve	5.40	0.70	**3.78**
RC1 #1 Unit Pump & Motor Ball Value	5.40	0.70	**3.78**
RC1 #3 Unit - Pump, Motor, Ball Valve	5.40	0.70	**3.78**
CC1- Low Voltage Electrical System	3.70	1.00	**3.70**
RC3 #11 Unit - Pump, Motor, Ball Valve	5.40	0.67	**3.60**
CA4 - Richland Chambers Lake Pump Station - Chemical System (Chlorine)	7.00	0.51	**3.58**
CA3 - Cedar Creek Lake Pump Station - Chemical System (anhydrous ammonia)	7.00	0.49	**3.40**
CA3 - Cedar Creek Lake Pump Station - Chemical System (Sodium Hydroxide)	4.55	0.72	**3.28**
CA4 - Richland Chambers Lake Pump Station - Chemical System (aqua Ammonia)	3.60	0.87	**3.12**
RC1- Suction/Discharge Piping	6.80	0.43	**2.95**
RC1 - HVAC- Exhaust Fans & Air Handling Units	2.85	1.00	**2.85**
CCP1 - Cedar Creek - Section I, Station 310+00 to 1200+00	4.95	0.55	**2.72**
RC3 #12 Unit - Pump, Motor, Ball Valve	5.40	0.44	**2.40**
RC3 #13 Unit - Pump, Motor, Ball Valve	5.40	0.44	**2.40**
RCP4 - Richland Chambers Pipeline - Section IV - Station 3165+50 to 4124+00	3.90	0.56	**2.17**
CC1 - Cedar Creek Lake Pump Station - Suction/Discharge Piping	6.80	0.30	**2.04**
CC1 - Cedar Creek Lake Pump Station - Pump Station Structure	4.25	0.44	**1.87**
RC1 - Richland Chambers Pump Station - Building	4.25	0.43	**1.84**
RC3 - Waxahachie Booster Pump Station - Building	5.25	0.30	**1.58**
CC3 - Hydraulic Accumulator System	5.30	0.28	**1.48**
BR1 - Balancing Reservoir Embankment & Structures	7.40	0.20	**1.48**

Component Name	C	p	RI
CC3 - Suction/Discharge Piping	6.80	0.20	**1.36**
SCADA	1.30	1.00	**1.30**
CC3 #2 Unit - Pump, Motor, Cone/Ball Valve (Waxahachie Booster Station #2)	5.20	0.24	**1.25**
RCP1 - Richland Chambers Pipeline, Section I - Station 301+00 to 1249+00	5.45	0.22	**1.21**
CC1 - HVAC - Exhaust Fans & Air Handling Units	2.85	0.40	**1.14**
CA3 - Cedar Creek Lake Pump Station -Chemical System (Chlorine)	7.00	0.16	**1.12**
CC3 #3 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)	5.20	0.20	**1.04**
CC1 #4 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.20	**1.04**
AO1 - Outlet Structure - Arlington	4.25	0.24	**1.02**
CC3 - Waxahachie Booster Pump Station - Pump Station Structure	4.25	0.24	**1.02**
CCP3 - Cedar Creek Pipeline - Section III, Station 2100+00 to 3002+00	3.50	0.29	**1.02**
CCP2 - Cedar Creek Pipeline - Section II, Station 1200+00 to 2100+00	3.80	0.25	**0.95**
CC1 - Hydraulic Accumulator System	5.30	0.17	**0.90**
RC3 - HVAC - Echaust Fans & Air Handling Units	2.85	0.31	**0.89**
CC1 #2 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.16	**0.83**
CC1 #6 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.16	**0.83**
CC3 #1 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)	5.20	0.16	**0.83**
CC1 #3 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.16	**0.83**
CC3 - HVAC- Exhaust Fans & Air Handling Units	2.85	0.28	**0.80**
AO1 - Discharge/Suction Piping	2.95	0.24	**0.71**
CC1 #1 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.12	**0.62**
CC1 #5 Unit - Pump, Motor, Ball/Cone Valve	5.20	0.12	**0.62**
CC3 #4 Unit - Pump Motor Cone Value	5.20	0.12	**0.62**
CC1 - Cedar Creek Lake Pump Station - Instrumentation & Control	1.60	0.37	**0.60**
RCP5 - Richland Chambers Pipeline - Section V - Station 301+00 to 1249+10	5.95	0.10	**0.60**
CC3 - Waxahachie Booster Pump Station - Instrumentation & Control	1.60	0.33	**0.53**
CC2 - Ground Storage Tanks	3.85	0.12	**0.46**
RC3 - Waxahachie Booster Pump Station- Instrumentation & Control	1.60	0.27	**0.43**

Component Name	C	p	RI
RC1 - Richland Chambers Lake Pump Station - Instrumentation & Control	1.60	0.27	**0.43**
CC3 #5 Unit - Pump Motor, Cone Valve	5.20	0.08	**0.42**
CC2 - Ennis Booster Pump Station - Instrumentation & Control	1.60	0.25	**0.41**
CCP5 - Cedar Creek Pipeline - Section V, Station -0+50 to 310+00	4.15	0.09	**0.37**
CC3 - Ground Storage Tanks	3.85	0.08	**0.31**
AO1 - Instrumentation & Control	1.90	0.16	**0.30**
CCP4 - Cedar Creek Pipeline - Section IV, Station 3002+00 to 3896+00	3.20	0.09	**0.29**
Cedar Creek/Richland Chambers PL Xovers @ Ennis, Waxahachie, Rolling Hills, Bala	4.25	0.06	**0.26**
CC2 - Cedar Creek Ennis Booster Pump Station -Medium Voltage Electrical System	6.00	0.04	**0.24**
CC3 #6 Unit Pump, Motor, Cone Valve	5.20	0.04	**0.21**
CC3 #8 Unit - Pump, Motor, Cone Valve	5.20	0.04	**0.21**
CC3 #7 Unit Pump, Motor, Cone Valve	5.20	0.04	**0.21**
CC3 #9 Unit Pump, Motor, Cone Valve	5.20	0.04	**0.21**
RCP3 - Richland Chambers Pipeline - Section III - Station 2207+25 to 3165+50	3.45	0.05	**0.17**
RCP2 - Richland Chambers Pipeline - Section II Station 1249+00 to 2207+25	3.45	0.05	**0.17**
RCPMV - Richland Chambers Pipeline - Mainline Valves	1.45	0.11	**0.16**
CCPV - Cedar Creek Pipeline - blow-off and air valves (numerous)	1.20	0.10	**0.12**
CCPMV - Cedar Creek Pipeline - mainline valves (11)	1.45	0.04	**0.06**
RCPV - Richland Chambers Pipeline - blow-off and air valves (numerous)	0.20	0.10	**0.02**

Risk and Reliability Assessment

Attachment No. 3
Risk Index by System

Tarrant Regional Water District
Risk Index by System

09-Nov-97

System / Facility Type / Name	C	p	RI
Arlington Outlet Works			
Building/Structure			
AO1 - Outlet Structure - Arlington	4.25	0.24	1.02
Control System			
AO1 - Instrumentation & Control	1.9	0.16	0.30
Discharge/Suction Piping or Structures			
AO1 - Discharge/Suction Piping	2.95	0.24	0.71
Cedar Creek			
Building/Structure			
CC1 - Cedar Creek Lake Pump Station - Pump Station Structure	4.25	0.44	1.87
CC3 - Waxahachie Booster Pump Station - Pump Station Structure	4.25	0.24	1.02
Chemical Systems			
CA3 - Cedar Creek Lake Pump Station - Chemical System (anhydrous ammonia)	7	0.486	3.40
CA3 - Cedar Creek Lake Pump Station - Chemical System (Sodium Hydroxide)	4.55	0.72	3.28
CA3 - Cedar Creek Lake Pump Station -Chemical System (Chlorine)	7	0.16	1.12
Control System			
CC1 - Cedar Creek Lake Pump Station - Instrumentation & Control	1.6	0.373	0.60

System Facility Type Name	C	p	RI
CC3 - Waxahachie Booster Pump Station - Instrumentation & Control	1.6	0.333	0.53
CC2 - Ennis Booster Pump Station - Instrumentation & Control	1.6	0.253	0.41
Discharge/Suction Piping or Structures			
CC1 - Cedar Creek Lake Pump Station - Suction/Discharge Piping	6.8	0.3	2.04
CC3 - Suction/Discharge Piping	6.8	0.2	1.36
Electrical Transmission			
CC1 - Cedar Creek Lake Pump Station - Medium Voltage Electrical System	5.2	1	5.20
CC3 - Medium Voltage Electrical System	5.2	1	5.20
CC1- Low Voltage Electrical System	3.7	1	3.70
CC2 - Cedar Creek Ennis Booster Pump Station -Medium Voltage Electrical System	6	0.04	0.24
Mechanical Systems			
CC1 - HVAC - Exhaust Fans & Air Handling Units	2.85	0.4	1.14
CC3 - HVAC- Exhaust Fans & Air Handling Units	2.85	0.28	0.80
Pipeline			
CCP1 - Cedar Creek - Section I, Station 310+00 to 1200+00	4.95	0.55	2.72
CCP3 - Cedar Creek Pipeline - Section III, Station 2100+00 to 3002+00	3.5	0.29	1.02
CCP2 - Cedar Creek Pipeline - Section II, Station 1200+00 to 2100+00	3.8	0.25	0.95
CCP5 - Cedar Creek Pipeline - Section V, Station -0+50 to 310+00	4.15	0.09	0.37

System				
Facility Type	Name	C	p	RI
	CCP4 - Cedar Creek Pipeline - Section IV, Station 3002+00 to 3896+00	3.2	0.09	0.29
Pipeline Valve				
	CCPV - Cedar Creek Pipeline - blow-off and air valves (numerous)	1.2	0.1	0.12
	CCPMV - Cedar Creek Pipeline - mainline valves (11)	1.45	0.04	0.06
Pumping Equipment				
	CC3 - Hydraulic Accumulator System	5.3	0.28	1.48
	CC3 #2 Unit - Pump, Motor, Cone/Ball Valve (Waxahachie Booster Station #2)	5.2	0.24	1.25
	CC3 #3 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)	5.2	0.2	1.04
	CC1 #4 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.2	1.04
	CC1 - Hydraulic Accumulator System	5.3	0.17	0.90
	CC1 #3 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.16	0.83
	CC1 #2 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.16	0.83
	CC1 #6 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.16	0.83
	CC3 #1 Unit - Pump, Motor, Ball/Cone Valve (Waxahachie Booster Station #2)	5.2	0.16	0.83
	CC1 #5 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.12	0.62
	CC3 #4 Unit - Pump Motor Cone Value	5.2	0.12	0.62
	CC1 #1 Unit - Pump, Motor, Ball/Cone Valve	5.2	0.12	0.62

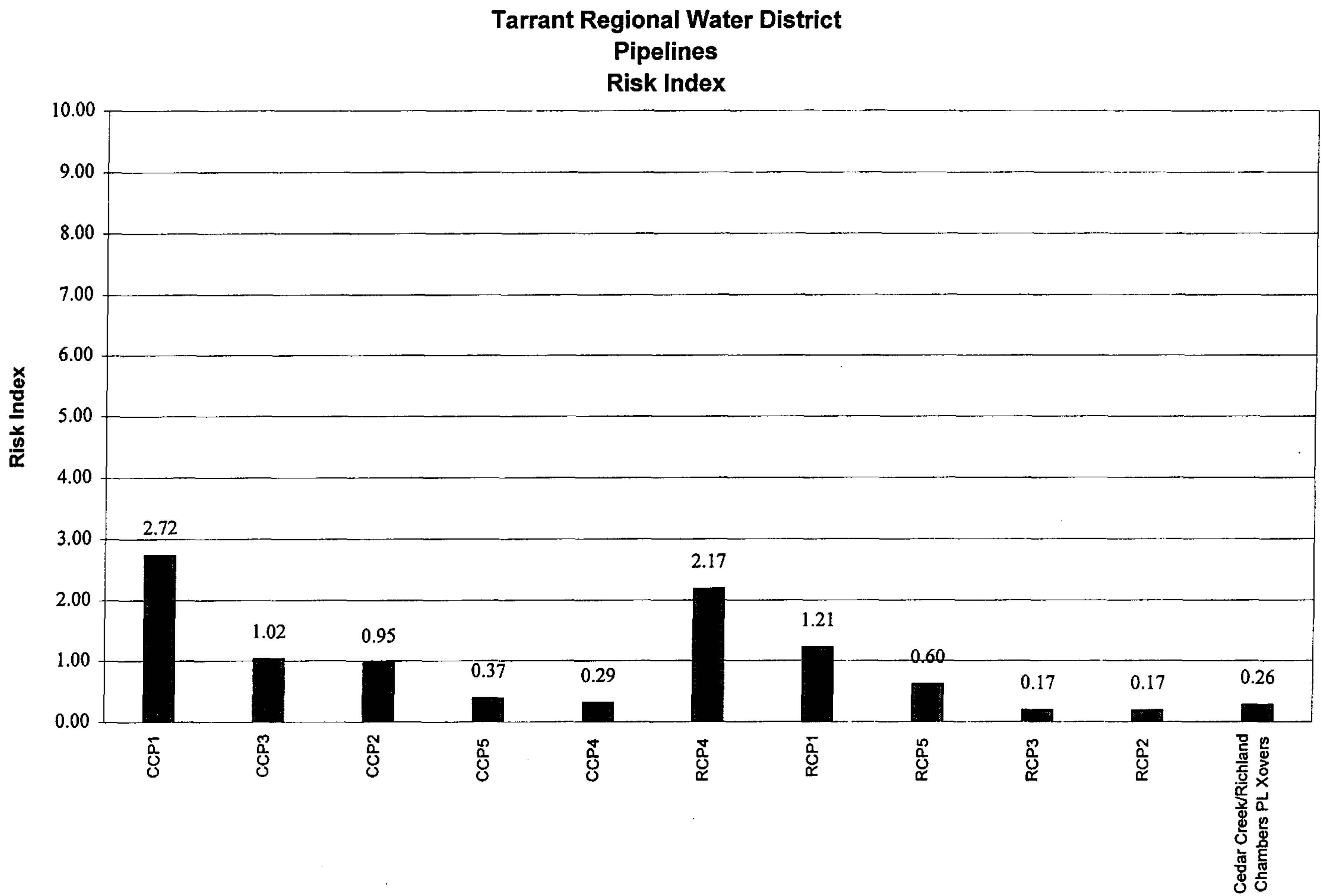
System Facility Type Name	C	p	RI
CC3 #5 Unit - Pump Motor, Cone Valve	5.2	0.08	0.42
CC3 #7 Unit Pump, Motor, Cone Valve	5.2	0.04	0.21
CC3 #6 Unit Pump, Motor, Cone Valve	5.2	0.04	0.21
CC3 #8 Unit - Pump, Motor, Cone Valve	5.2	0.04	0.21
CC3 #9 Unit Pump, Motor, Cone Valve	5.2	0.04	0.21
Storage Tanks			
CC2 - Ground Storage Tanks	3.85	0.12	0.46
CC3 - Ground Storage Tanks	3.85	0.08	0.31
East Texas			
Communications Equipment			
SCADA	1.3	1	1.30
Dam Structure			
BR1 - Balancing Reservoir Embankment & Structures	7.4	0.2	1.48
Pipeline			
Cedar Creek/Richland Chambers PL Xovers @ Ennis, Waxahachie, Rolling Hills, Balancing Reserv	4.25	0.06	0.26
Richland Chambers			
Building/Structure			
RC1 - Richland Chambers Pump Station - Building	4.25	0.433	1.84
RC3 - Waxahachie Booster Pump Station - Building	5.25	0.3	1.58

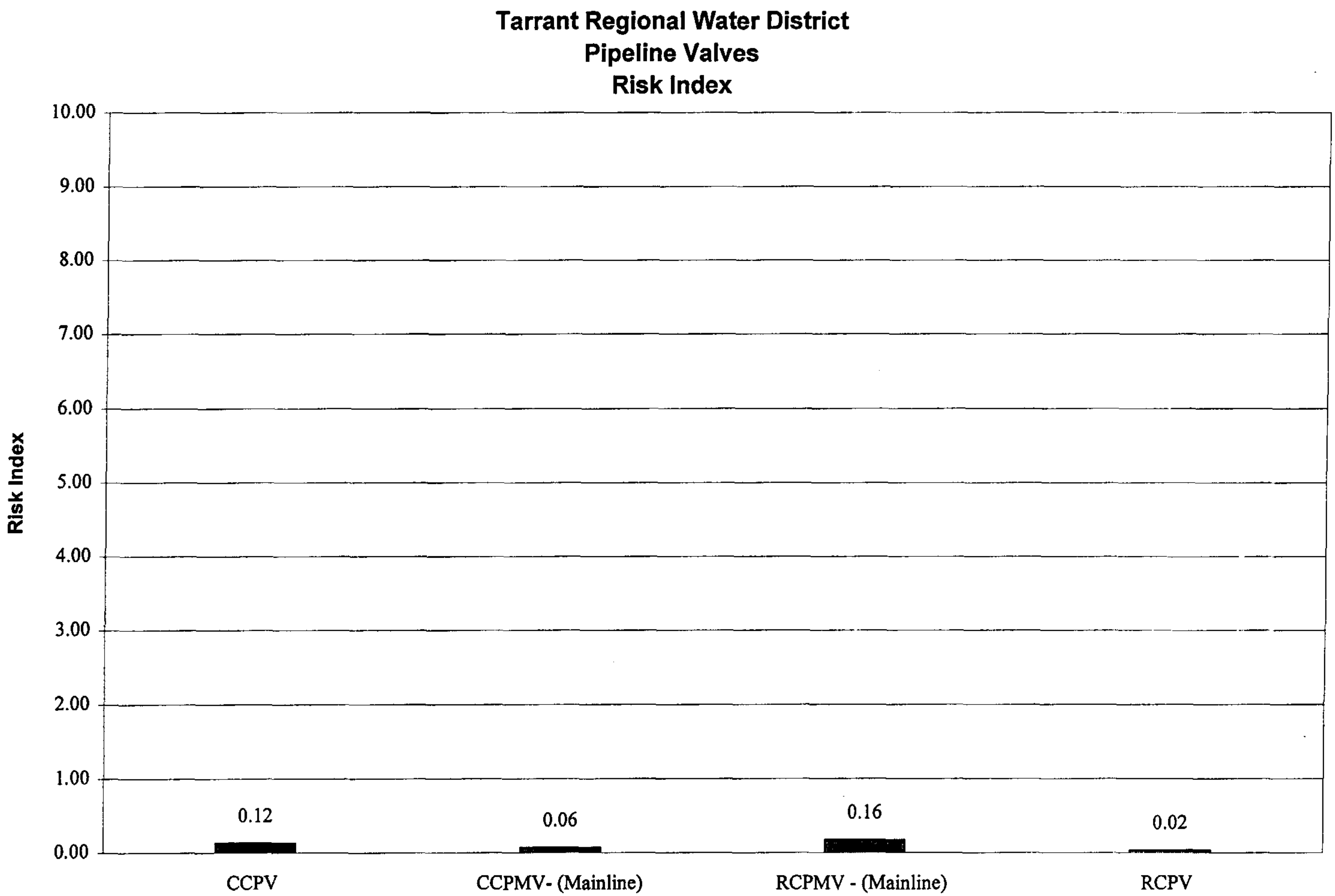
System Facility Type Name	C	p	RI
Chemical Systems			
CA4 - Richland Chambers Lake Pump Station - Chemical System (Chlorine)	7	0.511	3.58
CA4 - Richland Chambers Lake Pump Station - Chemical System (aqua Ammonia)	3.6	0.867	3.12
Control System			
RC1 - Richland Chambers Lake Pump Station - Instrumentation & Control	1.6	0.267	0.43
RC3 - Waxahachie Booster Pump Station- Instrumentation & Control	1.6	0.267	0.43
Discharge/Suction Piping or Structures			
RC1- Suction/Discharge Piping	6.8	0.433	2.95
Electrical Transmission			
RC1 - Medium Voltage Electrical System	5.2	1	5.20
RC3 - Medium Voltage Electrical System	5.2	1	5.20
Mechanical Systems			
RC1 - HVAC- Exhaust Fans & Air Handling Units	2.85	1	2.85
RC3 - HVAC - Echaust Fans & Air Handling Units	2.85	0.311	0.89
Pipeline			
RCP4 - Richland Chambers Pipeline - Section IV - Station 3165+50 to 4124+00	3.9	0.556	2.17
RCP1 - Richland Chambers Pipeline, Section I - Station 301+00 to 1249+00	5.45	0.222	1.21
RCP5 - Richland Chambers Pipeline - Section V - Station 301+00 to 1249+10	5.95	0.1	0.60
RCP2 - Richland Chambers Pipeline - Section II Station 1249+00 to 2207+25	3.45	0.05	0.17

System				
Facility Type	**Name**	**C**	**p**	**RI**
	RCP3 - Richland Chambers Pipeline - Section III - Station 2207+25 to 3165+50	3.45	0.05	0.17
Pipeline Valve				
	RCPMV - Richland Chambers Pipeline - Mainline Valves	1.45	0.111	0.16
	RCPV - Richland Chambers Pipeline - blow-off and air valves (numerous)	0.2	0.1	0.02
Pumping Equipment				
	RC1 #2 Unit - Pump, Motor, Ball Valve	5.4	0.7	3.78
	RC1 #3 Unit - Pump, Motor, Ball Valve	5.4	0.7	3.78
	RC1 #1 Unit Pump & Motor Ball Value	5.4	0.7	3.78
	RC3 #11 Unit - Pump, Motor, Ball Valve	5.4	0.667	3.60
	RC3 #13 Unit - Pump, Motor, Ball Valve	5.4	0.444	2.40
	RC3 #12 Unit - Pump, Motor, Ball Valve	5.4	0.444	2.40

Risk and Reliability Assessment

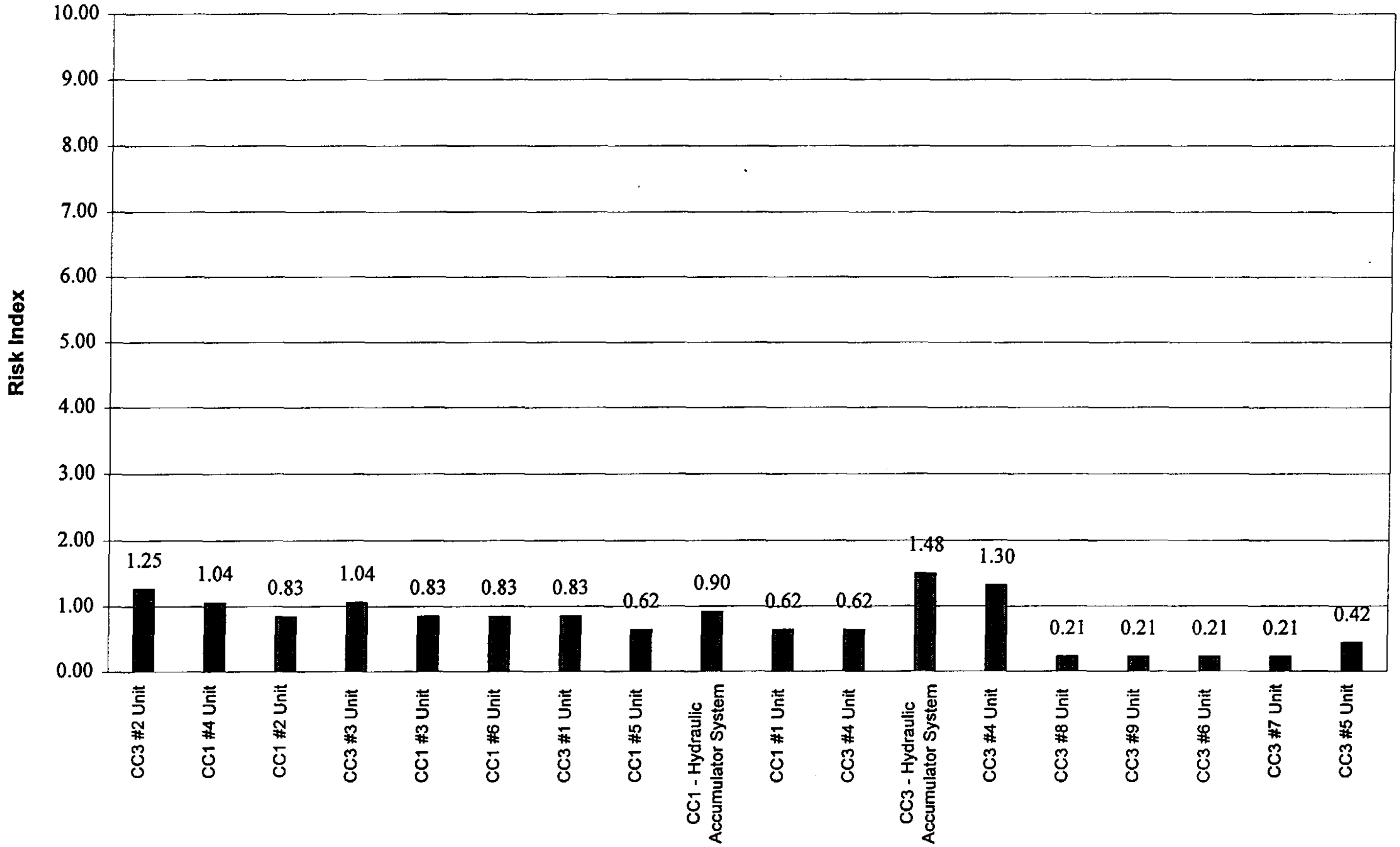
Attachment No. 4
Key System Components
Risk Index Bar Graphs by Facility Type


Tarrant Regional Water District
Pipelines
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2.72
1.02
0.95
0.37
0.29
2.17
1.21
0.60
0.17
0.17
0.26
CCP1
CCP3
CCP2
CCP5
CCP4
RCP4
RCP1
RCP5
RCP3
RCP2
Cedar Creek/Richland Chambers PL Xovers

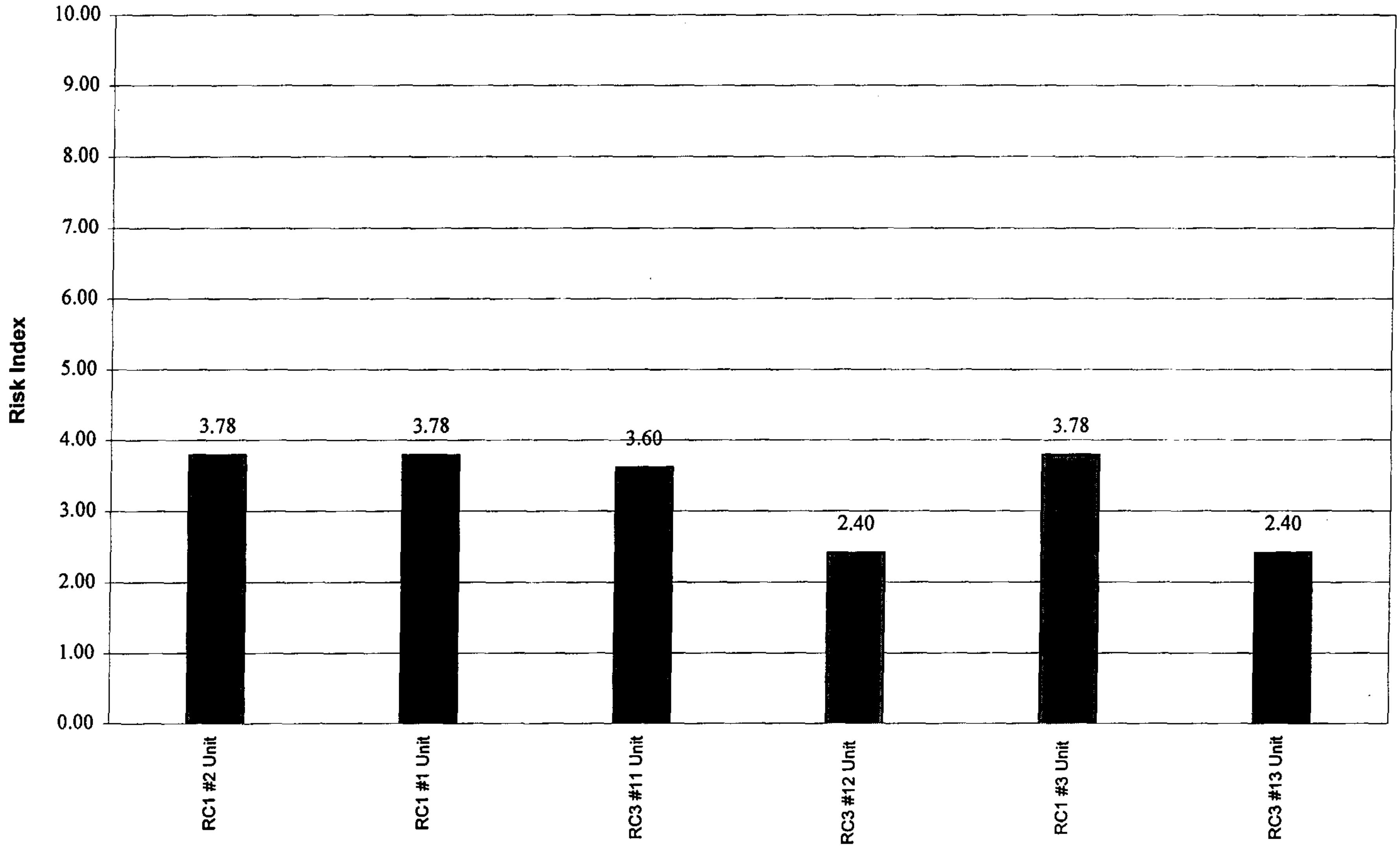


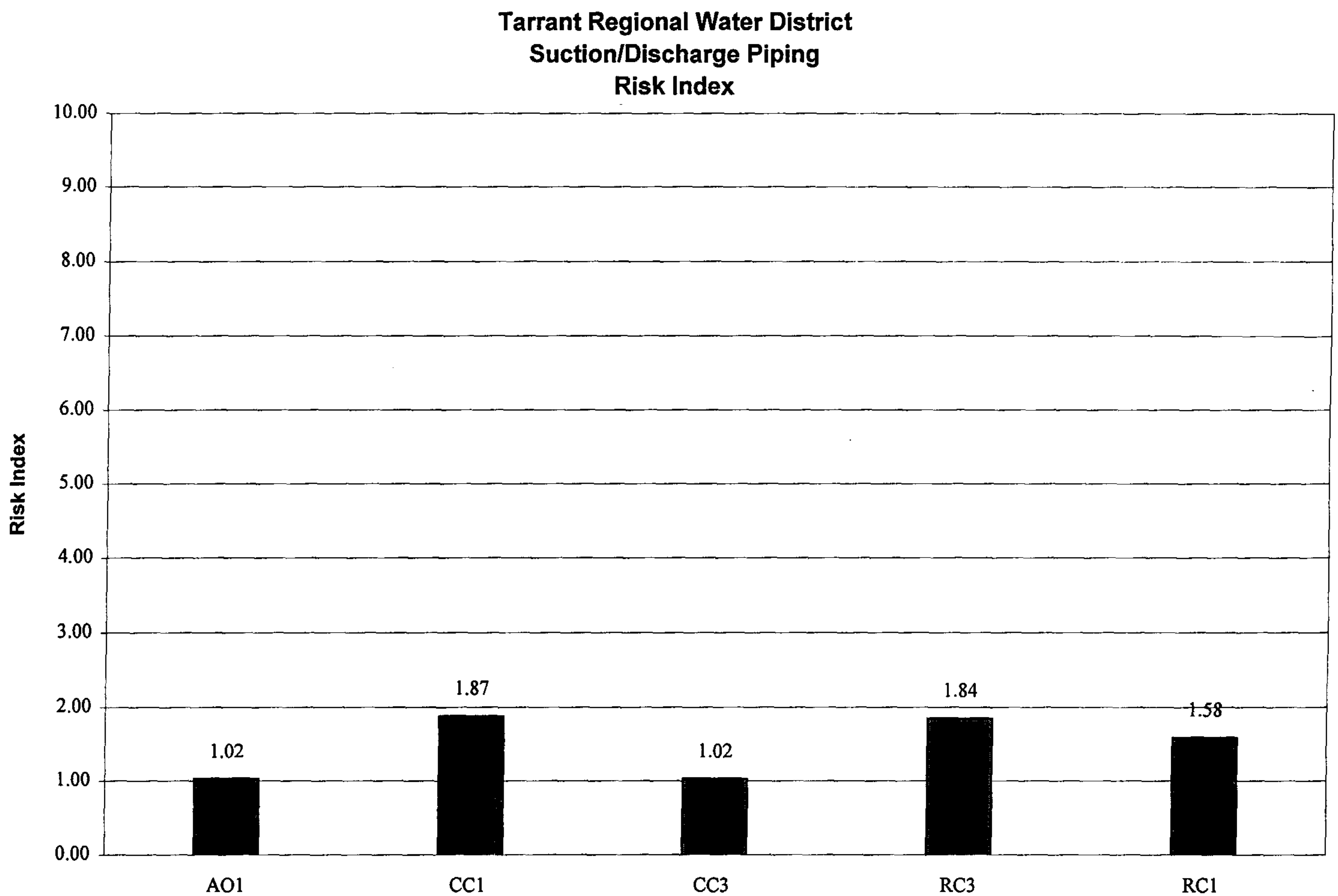
Tarrant Regional Water District
Pipeline Valves
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
Risk Index
0.12
0.06
0.16
0.02
CCPV
CCPMV- (Mainline)
RCPMV - (Mainline)
RCPV

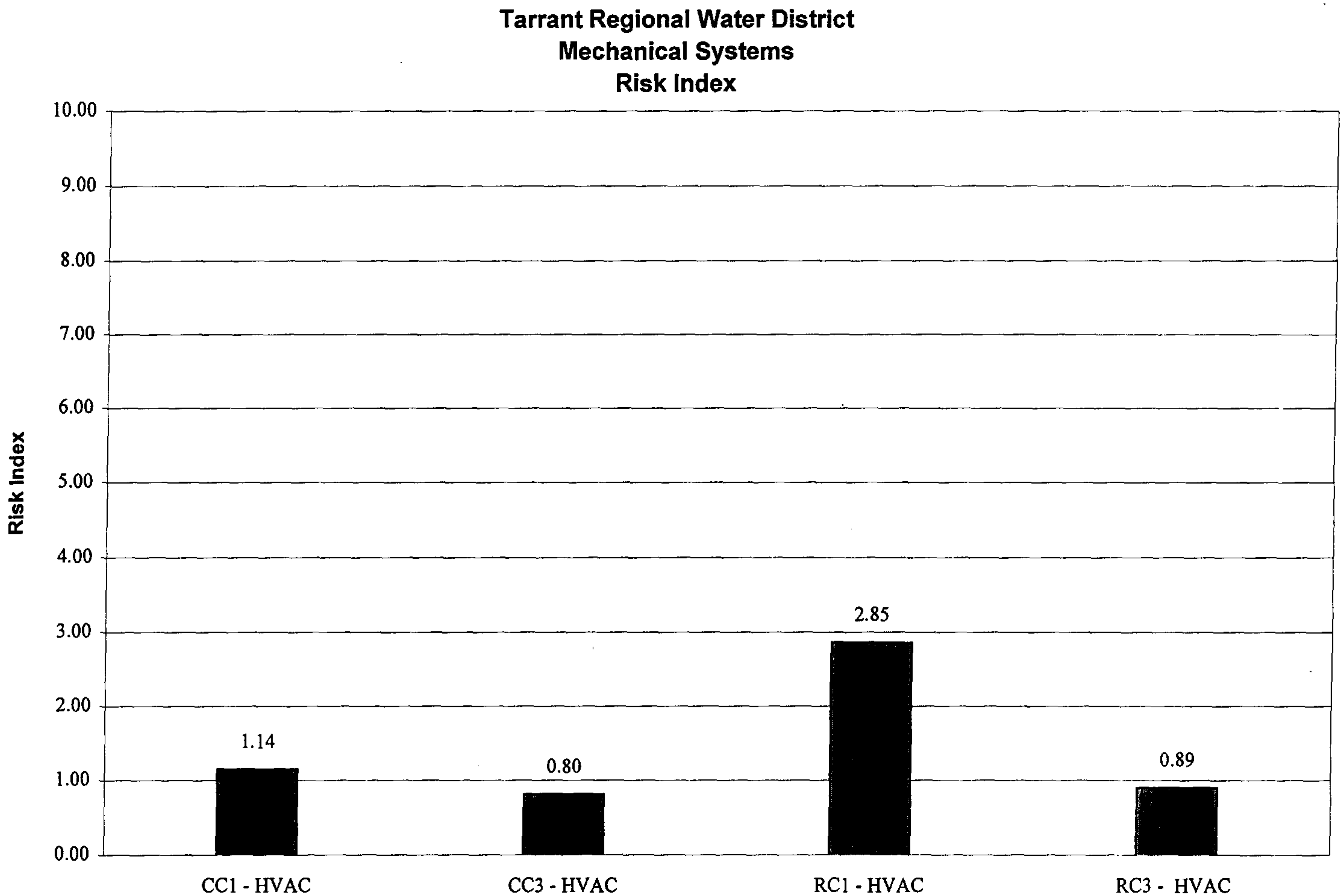
Tarrant Regional Water District
Pumping Equipment -1
Risk Index

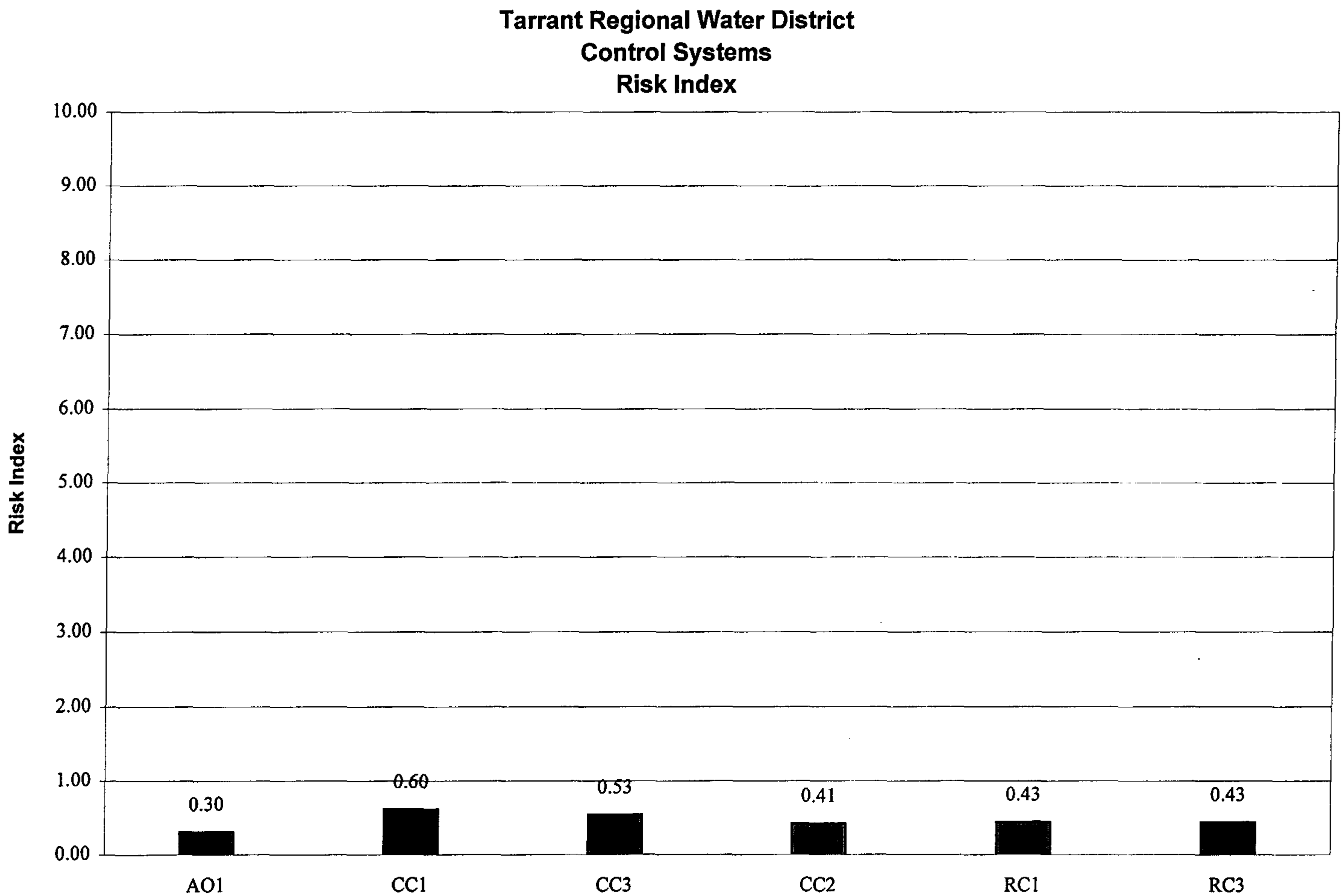


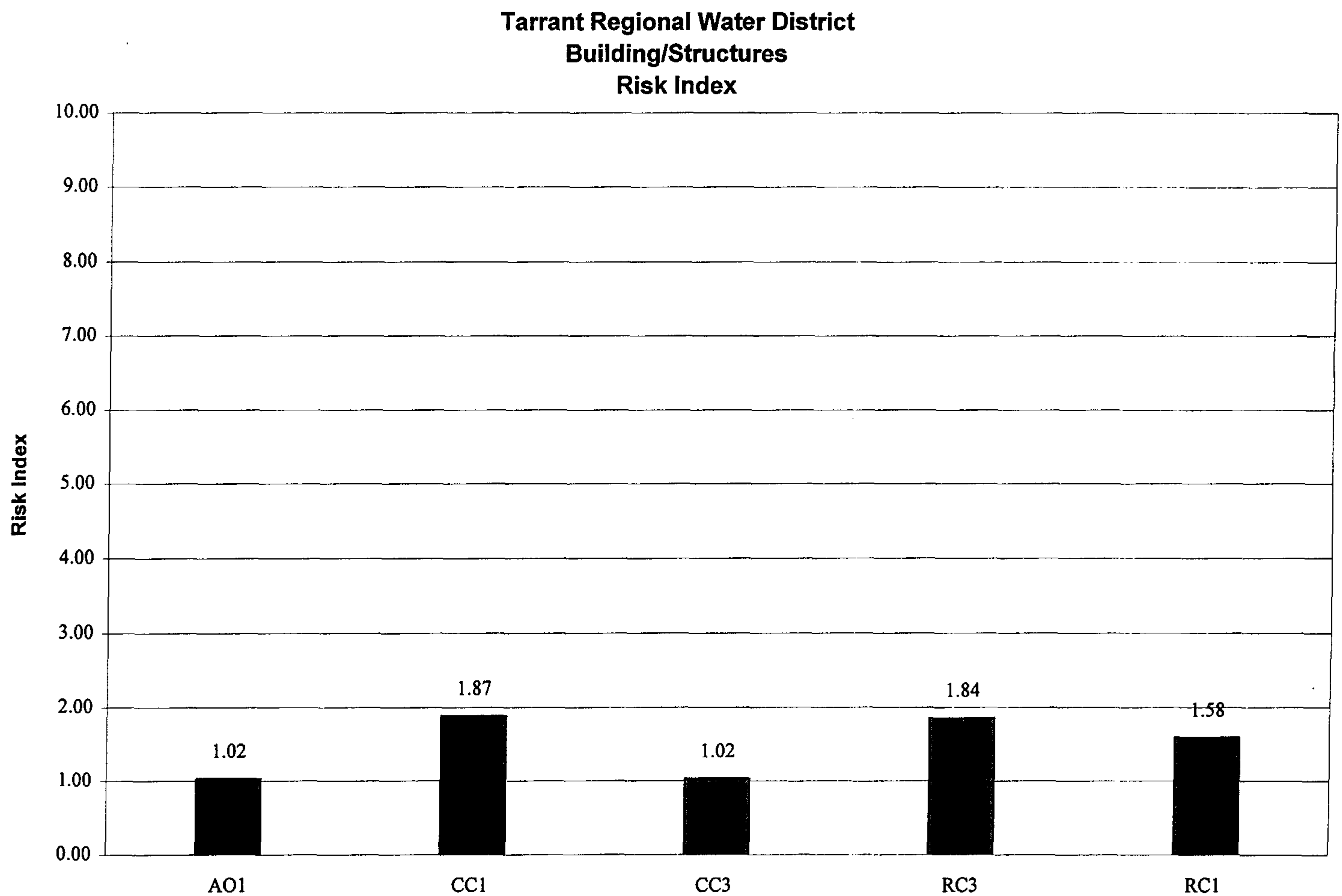
Tarrant Regional Water District
Pumping Equipment - 2
Risk Index

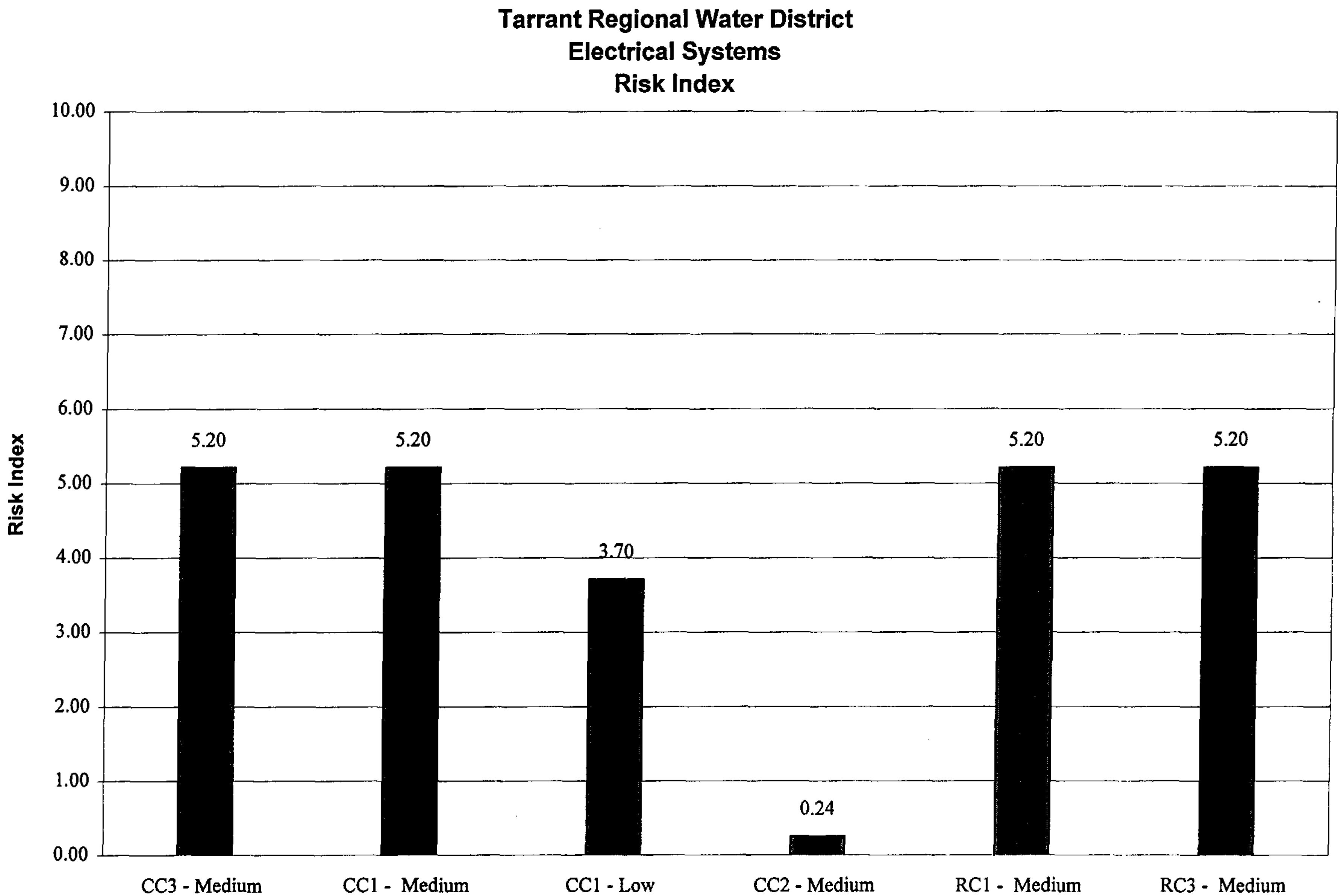


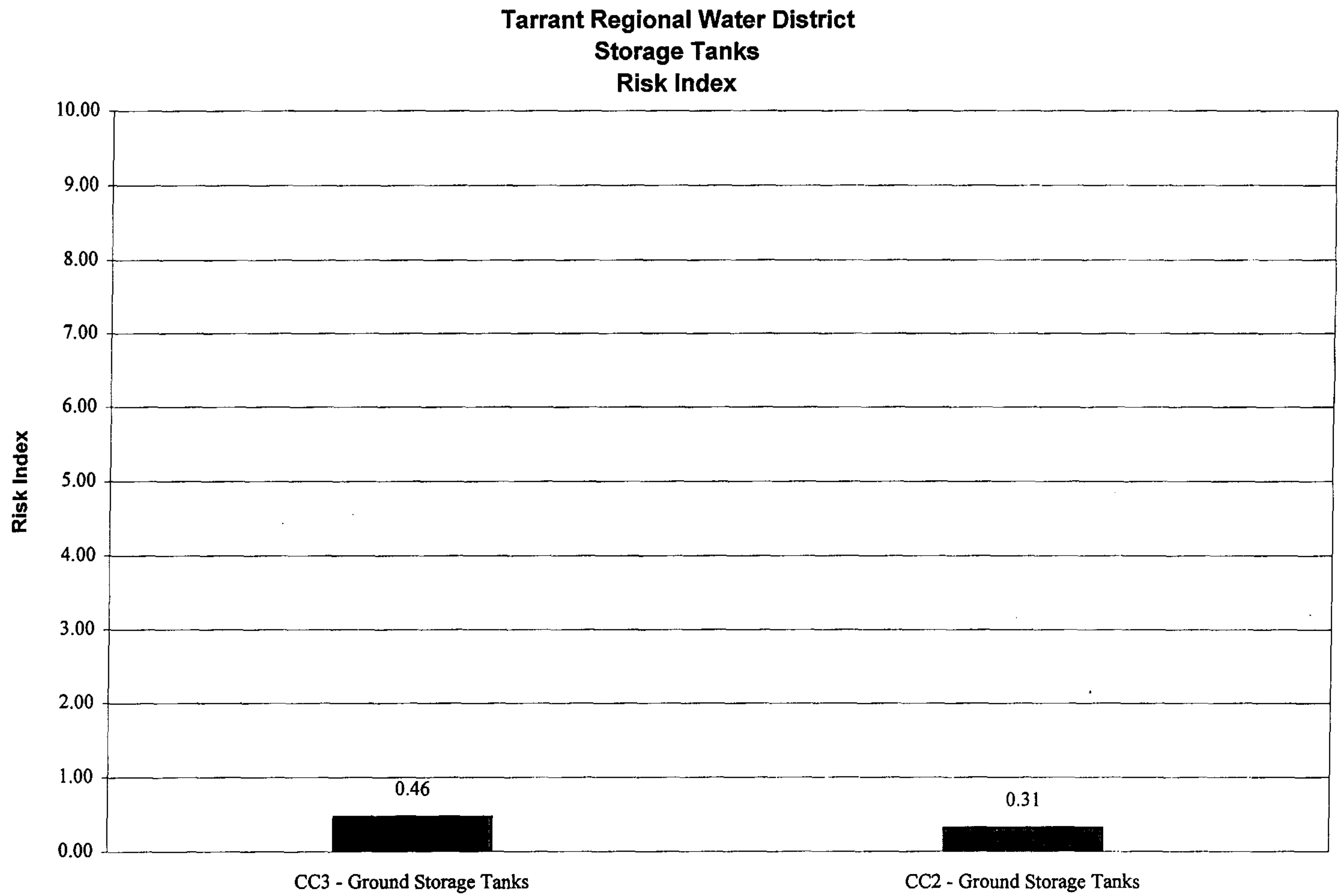

Tarrant Regional Water District
Suction/Discharge Piping
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.02
1.87
1.02
1.84
1.58
AO1
CC1
CC3
RC3
RC1

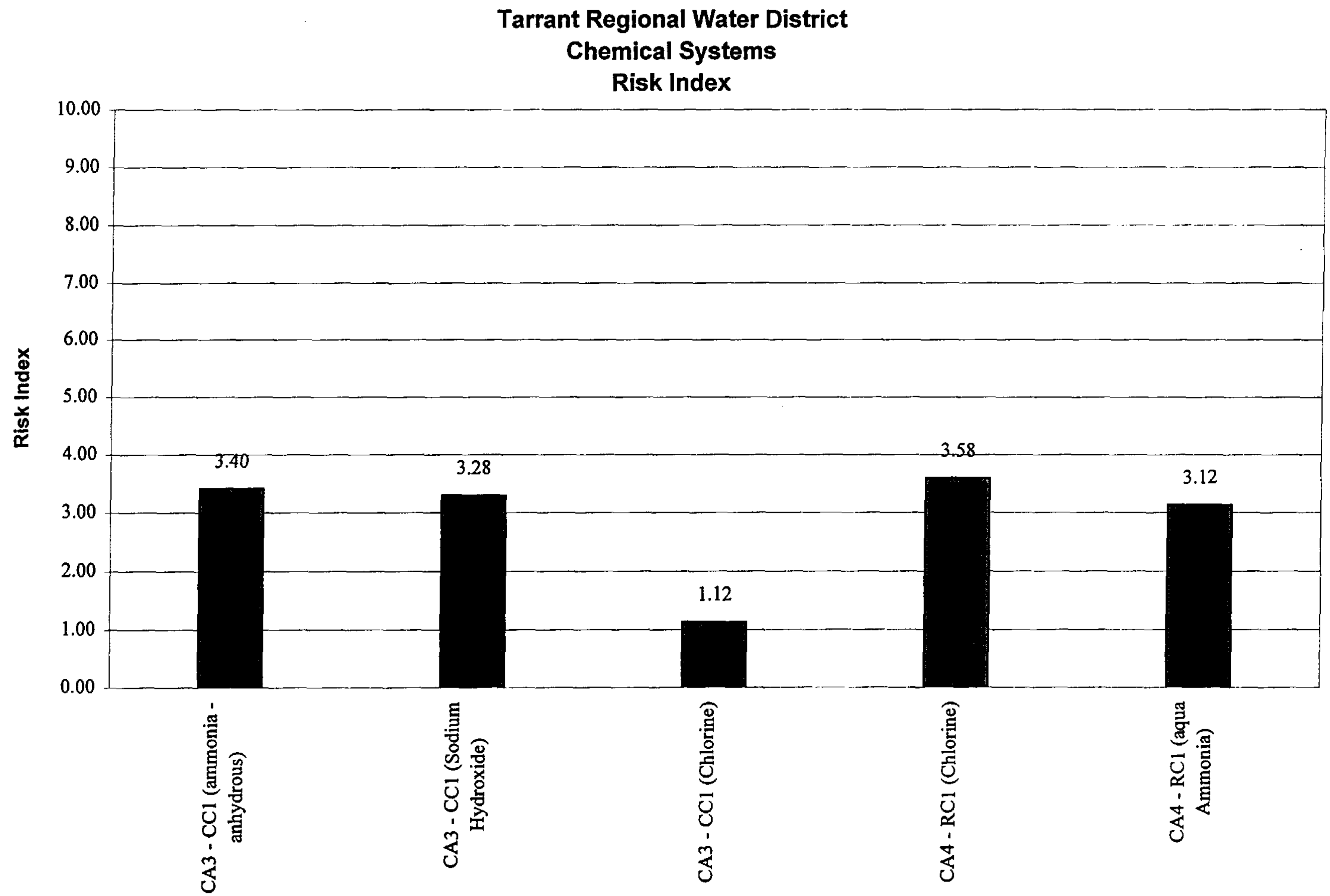

Tarrant Regional Water District
Mechanical Systems
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.14
0.80
2.85
0.89
CC1 - HVAC
CC3 - HVAC
RC1 - HVAC
RC3 - HVAC

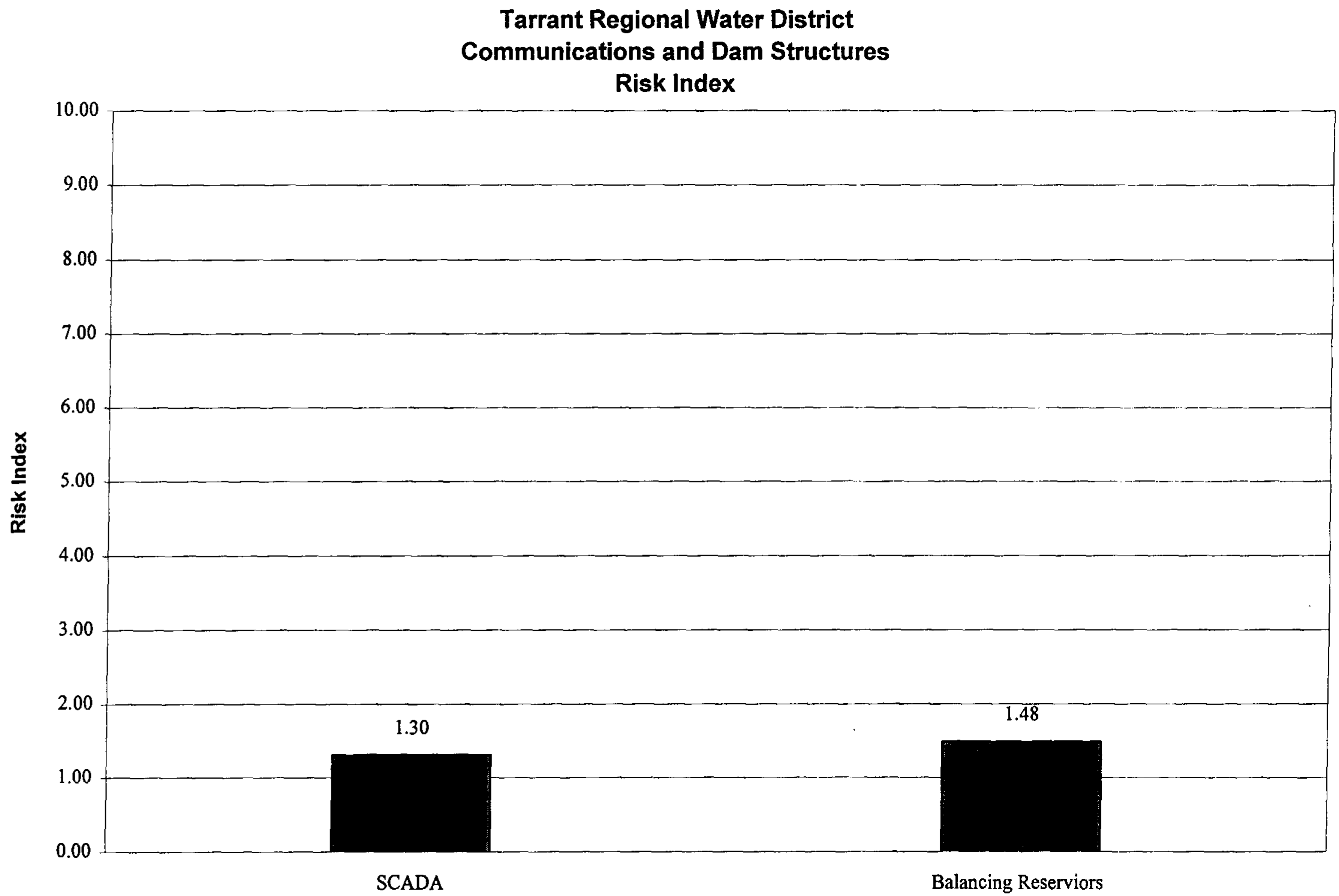

Tarrant Regional Water District
Control Systems
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.30
0.60
0.53
0.41
0.43
0.43
AO1
CC1
CC3
CC2
RC1
RC3


Tarrant Regional Water District
Building/Structures
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.02
1.87
1.02
1.84
1.58
AO1
CC1
CC3
RC3
RC1


Tarrant Regional Water District
Electrical Systems
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
5.20
5.20
3.70
0.24
5.20
5.20
CC3 - Medium
CC1 - Medium
CC1 - Low
CC2 - Medium
RC1 - Medium
RC3 - Medium


Tarrant Regional Water District
Storage Tanks
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
0.46
0.31
CC3 - Ground Storage Tanks
CC2 - Ground Storage Tanks


Tarrant Regional Water District
Chemical Systems
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
3.40
3.28
1.12
3.58
3.12
CA3 - CC1 (ammonia - anhydrous)
CA3 - CC1 (Sodium Hydroxide)
CA3 - CC1 (Chlorine)
CA4 - RC1 (Chlorine)
CA4 - RC1 (aqua Ammonia)


Tarrant Regional Water District
Communications and Dam Structures
Risk Index
Risk Index
10.00
9.00
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1.30
1.48
SCADA
Balancing Reserviors

Appendix E

Survey Questionnaires
Water Quality and Treatment Issues

TARRANT REGIONAL WATER DISTRICT
CEDAR CREEK/RICHLAND CHAMBERS RESERVOIRS
SURVEY TO IDENTIFY WATER QUALITY/TREATMENT ISSUES

The goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail you can provide in responding to the questions, the more valuable the information and beneficial the results.

Please call Betty Jordan, Alan Plummer Associates, Inc. (817/284-2724) if you have any questions regarding the questionnaire and what information is being requested.

1. **Plant Name:** Southwest Water Plant

2. **Plant Contact:**

   Name: Chuck Vokes
   Title: Plant Manager
   Address: 7001 US Hwy 287
   City/State/Zip Arlington, Texas 76001
   Phone: 817-478-5702
   Fax: Metro 572-0781

3. **Cost of Water Treatment**

   Have you experienced differences in the costs of water treatment for raw water from Richland Chambers or Cedar Creek Reservoirs? ☒ Yes ☐ No
   Do these differences always occur? ☒ Yes ☐ No
   If no, are they: ☐ seasonal or ☐ associated with some climatic condition?
   If climatic condition, please describe?

   If there are differences, which raw water source is more costly to treat?
   ☐ Richland Chambers ☒ Cedar Creek

   In which area of treatment costs do you see differences? (Check all that apply)
   ☒ Chemical costs
   ☐ Operations costs
   ☒ Sludge management and disposal costs
   ☒ Pumping costs
   ☐ Other ______________________
   ☐ Other ______________________

If available, please provide the following information:

Richland Chambers Raw Water Treatment Costs:
Chemical costs: $ Varies ___ MG finished water
Operations costs: $__________ MG finished water
Sludge management and disposal costs: $__________ MG finished water
Pumping costs: $__________ MG finished water
Other __________ costs: $__________ MG finished water

Cedar Creek Raw Water Treatment Costs:
Chemical costs: $ Varies ___ MG finished water
Operations costs: $__________ MG finished water
Sludge management and disposal costs: $__________ MG finished water
Pumping costs: $__________ MG finished water
Other __________ costs: $__________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $__________ MG finished water
Operations costs: $__________ MG finished water
Sludge management and disposal costs: $__________ MG finished water
Pumping costs: $__________ MG finished water
Other __________ costs: $__________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $__________ MG finished water
Operations costs: $__________ MG finished water
Sludge management and disposal costs: $__________ MG finished water
Pumping costs: $__________ MG finished water
Other __________ costs: $__________ MG finished water

Balancing Reservoir
Raw Water Treatment Costs:
Chemical costs: $ No info ___ MG finished water
Operations costs: $__________ MG finished water
Sludge management and disposal costs: $__________ MG finished water
Pumping costs: $__________ MG finished water
Other __________ costs: $__________ MG finished water

How do you know what water source(s) you are receiving?

Reports from district.
Water quality.

4. Raw Water Characteristics Affecting Treatment

Please rank the following raw water characteristics from the most (#1) to least significant with regard to water treatment costs and operations. Check which reservoir or blend that the characteristic can apply to.

Rank	Characteristic	RC	Blend	CC	Bal Res
___	Rapid changes in turbidity.	☐ RC	☐ Blend	☐ CC	☐ Bal Res
4	Rapid changes in alkalinity. ☒ Drop ☒ Rise	☐ RC	☐ Blend	☐ CC	☐ Bal Res
3	Rapid changes in changes pH. ☒ Drop ☒ Rise	☐ RC	☐ Blend	☐ CC	☐ Bal Res
___	Rapid drop in dissolved oxygen.	☐ RC	☐ Blend	☐ CC	☐ Bal Res
5	Unexpected changes in raw water source.	☐ RC	☐ Blend	☐ CC	☐ Bal Res
1	Taste and Odor	☒ RC	☒ Blend	☒ CC	☒ Bal Res
2	Particles in the size range 5 to 20 μm	☐ RC	☐ Blend	☒ CC	☐ Bal Res
___	Iron and/or Manganese	☐ RC	☐ Blend	☐ CC	☐ Bal Res
___	Other ________	☐ RC	☐ Blend	☐ CC	☐ Bal Res
___	Other ________	☐ RC	☐ Blend	☐ CC	☐ Bal Res

5. Addressing Water Quality Problems

Please complete Table 1 with regard to the seasonality of, public respose to, and treatment for the water quality problems experienced at the plant.

6. Determining Chemical Dosages

Please check all that apply with regard to determining chemical dosages for treatment. Note the process or processes to which the response applies in the blank to the right of the response. (For example, if "Charts Developed for Plant" are used to determine chemical dosages for both sedimentation and filtration, write "sedimentation and filtration" in the blank.

Diagnostic	Process to Which it Applies
☒ Raw Water Source Identity	________
☒ Experience	________
☐ Jar Tests	________
☐ Charts Developed for Plant	________
☐ Raw Water Characteristics	________
☐ pH	
☒ turbidity	
☒ alkalinity	
☐ TOC	
☒ taste and odor	
☐ other ________	
☐ other ________	
☐ Other ________	________
☐ Other ________	________

Table 1
Water Quality Problems and Strategy

Potential Problem	Check if Applies to Your Plant	Problem Time of Year	Customer Complaints? (Yes/No?	Treatment Strategy to Combat Problem
Turbidity				
Algae				
Taste and Odor	✓	Summer	Yes	PAC, $KMnO_4$
Iron				
Lead				
Manganese				
Copper				
Arsenic				
THMs				
Other:				
Other:				
Other:				
Other:				

7. **Operations Impacts**

When additional treatment costs are incurred in one raw water source over another, which of the following areas contribute to the increased costs: (Check all that apply.)

☒ Increased chemical dosages. List chemicals and increased dosage requirements.

Alum	Increase dosage by	15	mg/l
NaOH	Increase dosage by	2.5	mg/l
Carbon (PAC)	Increase dosage by	5	mg/l
	Increase dosage by		mg/l
	Increase dosage by		mg/l
	Increase dosage by		mg/l
	Increase dosage by		mg/l

☒ Reduced sedimentation performance --> higher filter loads/shorter filter run times.
☒ Larger backwash volume requirements.
☒ Greater sludge volumes.
☒ Other Higher pumping costs from relying more on the other plant for production.
☐ Other ______________

8. **Data**

If you have developed data that illustrates your responses to the questions above, please provide representative periods of two to four weeks that demonstrate increased chemical additions, sludge production, or treatment costs. As stated above, the goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail and documentation you can provide, the better the decisions that will be made. Attach all supporting data to this questionnaire.

9. **Additional Information**

If there is additional information or areas which you think should be addressed, please provide this information below or on a separate sheet of paper.

Thank you for your time and effort in providing this information.

Tarrant Regional Water District
Cedar Creek/Richland-Chambers Reservoirs
Survey to Identify Water Quality Treatment Issues

Rolling Hills

TARRANT REGIONAL WATER DISTRICT
CEDAR CREEK/RICHLAND CHAMBERS RESERVOIRS
SURVEY TO IDENTIFY WATER QUALITY/TREATMENT ISSUES

The goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail you can provide in responding to the questions, the more valuable the information and beneficial the results.

Please call Betty Jordan, Alan Plummer Associates, Inc. (817/284-2724) if you have any questions regarding the questionnaire and what information is being requested.

1. **Plant Name:** Rolling Hills

2. **Plant Contact:**

Name:	Charles Byrd
Title:	Supervisor
Address:	2500 S.E. Loop 820
City/State/Zip	Fort Worth, TX 76140
Phone:	(817) 293-5036
Fax:	(817) 293-0774

3. **Cost of Water Treatment**

Have you experienced differences in the costs of water treatment for raw water from Richland Chambers or Cedar Creek Reservoirs? ☒ Yes ☐ No
Do these differences always occur? ☒ Yes ☐ No
If no, are they: ☐ seasonal or ☐ associated with some climatic condition?
If climatic condition, please describe?

If there are differences, which raw water source is more costly to treat?
☐ Richland Chambers ☒ Cedar Creek

In which area of treatment costs do you see differences? (Check all that apply)
☒ Chemical costs
Operations costs
☒ Sludge management and disposal costs
☐ Pumping costs
☐ Other ____________________
☐ Other ____________________

If available, please provide the following information:

Richland Chambers Raw Water Treatment Costs:
Chemical costs: $ 26.54 MG finished water
Operations costs: $ 11.43 MG finished water
Sludge management and disposal costs: $ 29.49 MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Cedar Creek Raw Water Treatment Costs:
Chemical costs: $ 36.00 MG finished water
Operations costs: $ 14.49 MG finished water
Sludge management and disposal costs: $ 39.85 MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Blend 70 % Richland Chambers/ 30 % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $ 21.91 MG finished water
Operations costs: $ 10.55 MG finished water
Sludge management and disposal costs: $ 16.25 MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Blend 65 % Richland Chambers/ 35 % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $ 34.47 MG finished water
Operations costs: $ 13.57 MG finished water
Sludge management and disposal costs: $ 40.34 MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Balancing Reservoir
Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

How do you know what water source(s) you are receiving?

4. Raw Water Characteristics Affecting Treatment

Please rank the following raw water characteristics from the most (#1) to least significant with regard to water treatment costs and operations. Check which reservoir or blend that the characteristic can apply to.

Rank	Characteristic	RC	Blend	CC	Bal Res
3	Rapid changes in turbidity.	☐	☐	☒	☒
4	Rapid changes in alkalinity. ☒ Drop ☐ Rise	☐	☐	☒	☐
5	Rapid changes in changes pH. ☒ Drop ☐ Rise	☐	☐	☒	☐
7	Rapid drop in dissolved oxygen.	☐	☒	☐	☐
1	Unexpected changes in raw water source.	☐	☐	☐	☐
2	Taste and Odor	☐	☒	☒	☒
6	Particles in the size range ____ to ____ μm	☐	☐	☐	☐
N/A	Iron and/or Manganese	☐	☐	☐	☐
	Other ________	☐	☐	☐	☐
	Other ________	☐	☐	☐	☐

5. Addressing Water Quality Problems

Please complete Table 1 with regard to the seasonality of, public respose to, and treatment for the water quality problems experienced at the plant.

6. Determining Chemical Dosages

Please check all that apply with regard to determining chemical dosages for treatment. Note the process or processes to which the response applies in the blank to the right of the response. (For example, if "Charts Developed for Plant" are used to determine chemical dosages for both sedimentation and filtration, write "sedimentation and filtration" in the blank.

Diagnostic	Process to Which it Applies
☒ Raw Water Source Identity	Coagulation, Sedimentation Filter,
☒ Experience	Disinfection, Coagulation, Sedi. & Filter
☒ Jar Tests	Coagulation, Sedimentation & Filter.
N/A ☐ Charts Developed for Plant	
☒ Raw Water Characteristics	Disinfection, Coagulation, Sed. & Filter.
☒ pH	
☒ turbidity	
☒ alkalinity	
☒ TOC	
☒ taste and odor	
☒ other End of Day reports	
☒ other Lab Analyses	
☐ Other ________	________
☐ Other ________	________

Table 1
Water Quality Problems and Strategy

Potential Problem	Check if Applies to Your Plant	Problem Time of Year	Customer Complaints? (Yes/No?	Treatment Strategy to Combat Problem
Turbidity	X	All the time		Raise Coagulant & (Filt. Aid)
Algae	X	Summer		Raise Coagulant &(Filt. Aid)
Taste and Odor	X	Spring & Summer	Yes	PAC
Iron	N/A			
Lead	N/A			
Manganese	N/A			
Copper	N/A			
Arsenic	N/A			
THMs	X	Summer		Chloramines
Other: Low Alk.	X	100% C.C.	Yes Commercial Cust.'s	Higher pH
Other:				
Other:				
Other:				

7. **Operations Impacts**

When additional treatment costs are incurred in one raw water source over another, which of the following areas contribute to the increased costs: (Check all that apply.)

☒ Increased chemical dosages. List chemicals and increased dosage requirements.

Fe3	Increase dosage by	63	mg/l
Polymer	Increase dosage by	.45	mg/l
Lime	Increase dosage by	4.9	mg/l
______	Increase dosage by	______	mg/l
______	Increase dosage by	______	mg/l
______	Increase dosage by	______	mg/l
______	Increase dosage by	______	mg/l

☒ Reduced sedimentation performance --> higher filter loads/shorter filter run times.
☒ Larger backwash volume requirements.
☒ Greater sludge volumes.
☐ Other ______________
☐ Other ______________

8. **Data**

If you have developed data that illustrates your responses to the questions above, please provide representative periods of two to four weeks that demonstrate increased chemical additions, sludge production, or treatment costs. As stated above, the goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail and documentation you can provide, the better the decisions that will be made. Attach all supporting data to this questionnaire.

9. **Additional Information**

If there is additional information or areas which you think should be addressed, please provide this information below or on a separate sheet of paper.

Thank you for your time and effort in providing this information.

Tarrant Regional Water District
Cedar Creek/Richland-Chambers Reservoirs
Survey to Identify Water Quality Treatment Issues

Tarrant County Water Supply Project

TARRANT REGIONAL WATER DISTRICT
CEDAR CREEK/RICHLAND CHAMBERS RESERVOIRS
SURVEY TO IDENTIFY WATER QUALITY/TREATMENT ISSUES

The goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail you can provide in responding to the questions, the more valuable the information and beneficial the results.

Please call Betty Jordan, Alan Plummer Associates, Inc. (817/284-2724) if you have any questions regarding the questionnaire and what information is being requested.

1. **Plant Name:** Tarrant County Water Supply Project

2. **Plant Contact:**

Name:	Sid McCain
Title:	O & M Supervisor
Address:	11201 Mosier Valley Rd.
City/State/Zip	Eulcss, Texas 76040
Phone:	817/267-4226
Fax:	817/267-8773

3. **Cost of Water Treatment**

Have you experienced differences in the costs of water treatment for raw water from Richland Chambers or Cedar Creek Reservoirs? ☒ Yes ☐ No
Do these differences always occur? ☐ Yes ☒ No
If no, are they: ☒ seasonal or ☐ associated with some climatic condition?
If climatic condition, please describe?

If there are differences, which raw water source is more costly to treat?
☒ Richland Chambers ☐ Cedar Creek

In which area of treatment costs do you see differences? (Check all that apply)
☒ Chemical costs
☐ Operations costs
☐ Sludge management and disposal costs
☐ Pumping costs
☐ Other ______
☐ Other ______

If available, please provide the following information:

Richland Chambers Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Cedar Creek Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $ ___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

Balancing Reservoir
Raw Water Treatment Costs:
Chemical costs: $___________ MG finished water
Operations costs: $___________ MG finished water
Sludge management and disposal costs: $___________ MG finished water
Pumping costs: $___________ MG finished water
Other ___________ costs: $___________ MG finished water

How do you know what water source(s) you are receiving?

4. **Raw Water Characteristics Affecting Treatment**

Please rank the following raw water characteristics from the most (#1) to least significant with regard to water treatment costs and operations. Check which reservoir or blend that the characteristic can apply to.

4	Rapid changes in turbidity.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
3	Rapid changes in alkalinity. ☒ Drop ☒ Rise	☐ RC ☐ Blend ☐ CC ☐ Bal Res
2	Rapid changes in changes pH. ☒ Drop ☒ Rise	☐ RC ☐ Blend ☐ CC ☐ Bal Res
____	Rapid drop in dissolved oxygen.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
5	Unexpected changes in raw water source.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
1	Taste and Odor	☐ RC ☐ Blend ☐ CC ☐ Bal Res
____	Particles in the size range ____ to ____ μm	☐ RC ☐ Blend ☐ CC ☐ Bal Res
____	Iron and/or Manganese	☐ RC ☐ Blend ☐ CC ☐ Bal Res
____	Other ____________________	☐ RC ☐ Blend ☐ CC ☐ Bal Res
____	Other ____________________	☐ RC ☐ Blend ☐ CC ☐ Bal Res

5. **Addressing Water Quality Problems**

Please complete Table 1 with regard to the seasonality of, public respose to, and treatment for the water quality problems experienced at the plant.

6. **Determining Chemical Dosages**

Please check all that apply with regard to determining chemical dosages for treatment. Note the process or processes to which the response applies in the blank to the right of the response. (For example, if "Charts Developed for Plant" are used to determine chemical dosages for both sedimentation and filtration, write "sedimentation and filtration" in the blank.

Diagnostic	Process to Which it Applies
☐ Raw Water Source Identity	____________
☒ Experience	Coag & SED
☒ Jar Tests	Coag & SED
☐ Charts Developed for Plant	____________
☒ Raw Water Characteristics	Coag & SED
☒ pH	
☒ turbidity	
☒ alkalinity	
☐ TOC	
☒ taste and odor	
☐ other ____________	
☐ other ____________	
☐ Other ____________	____________
☐ Other ____________	____________

Table 1
Water Quality Problems and Strategy

Potential Problem	Check if Applies to Your Plant	Problem Time of Year	Customer Complaints? (Yes/No?	Treatment Strategy to Combat Problem
Turbidity				
Algae	x	Spring & Summer		
Taste and Odor	x	Early to Mid-Fall & Spring	Yes	CL02, PAC, KMN04
Iron				
Lead				
Manganese				
Copper				
Arsenic				
THMs				
Other:				
Other:				
Other:				
Other:				

7. Operations Impacts

When additional treatment costs are incurred in one raw water source over another, which of the following areas contribute to the increased costs. (Check all that apply.)

☒ Increased chemical dosages. List chemicals and increased dosage requirements.

Alum	Increase dosage by	10-20	mg/l
Caustic	Increase dosage by	5-15	mg/l
CL02	Increase dosage by	1-1.5	mg/l
Polymer	Increase dosage by	1-2	mg/l
P.A.C.	Increase dosage by	10-20	mg/l
	Increase dosage by		mg/l
	Increase dosage by		mg/l

☒ Reduced sedimentation performance --> higher filter loads/shorter filter run times.
☒ Larger backwash volume requirements.
☒ Greater sludge volumes.
☐ Other ______________
☐ Other ______________

8. Data

If you have developed data that illustrates your responses to the questions above, please provide representative periods of two to four weeks that demonstrate increased chemical additions, sludge production, or treatment costs. As stated above, the goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail and documentation you can provide, the better the decisions that will be made. Attach all supporting data to this questionnaire.

9. Additional Information

If there is additional information or areas which you think should be addressed, please provide this information below or on a separate sheet of paper.

Need consistent PH of 7.0 to 7.5

Need consistently low T.O.N.

Thank you for your time and effort in providing this information.

Tarrant Regional Water District
Cedar Creek/Richland-Chambers Reservoirs
Survey to Identify Water Quality Treatment Issues

Pierce-Burch

TARRANT REGIONAL WATER DISTRICT
CEDAR CREEK/RICHLAND CHAMBERS RESERVOIRS
SURVEY TO IDENTIFY WATER QUALITY/TREATMENT ISSUES

The goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail you can provide in responding to the questions, the more valuable the information and beneficial the results.

Please call Betty Jordan, Alan Plummer Associates, Inc. (817/284-2724) if you have any questions regarding the questionnaire and what information is being requested.

1. **Plant Name:** Pierce - Burch

2. **Plant Contact:** Travis Andrews

   Name: Travis Andrews
   Title: Water Treatment Manager
   Address: 1901 Lakewood Dr.
   City/State/Zip Arlington, TX 76013
   Phone: 817-457-7550
   Fax: 817-496-4133

None of the following questions applies to Pierce Burch because the mixing of Lake Arlington watershed water with TRWD-supplied RC or CC water makes attributing treatment costs to either source problematic.

3. **Cost of Water Treatment**

N/A

Have you experienced differences in the costs of water treatment for raw water from Richland Chambers or Cedar Creek Reservoirs? ☐ Yes ☐ No
Do these differences always occur? ☐ Yes ☐ No
If no, are they: ☐ seasonal or ☐ associated with some climatic condition?
If climatic condition, please describe?

If there are differences, which raw water source is more costly to treat?
☐ Richland Chambers ☐ Cedar Creek

In which area of treatment costs do you see differences? (Check all that apply)
☐ Chemical costs
☐ Operations costs
☐ Sludge management and disposal costs
☐ Pumping costs
☐ Other ____________________
☐ Other ____________________

If available, please provide the following information:

Richland Chambers Raw Water Treatment Costs:
Chemical costs: $____________ MG finished water
Operations costs: $____________ MG finished water
Sludge management and disposal costs: $____________ MG finished water
Pumping costs: $____________ MG finished water
Other ____________ costs: $____________ MG finished water

Cedar Creek Raw Water Treatment Costs:
Chemical costs: $____________ MG finished water
Operations costs: $____________ MG finished water
Sludge management and disposal costs: $____________ MG finished water
Pumping costs: $____________ MG finished water
Other ____________ costs: $____________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $____________ MG finished water
Operations costs: $____________ MG finished water
Sludge management and disposal costs: $____________ MG finished water
Pumping costs: $____________ MG finished water
Other ____________ costs: $____________ MG finished water

Blend ____ % Richland Chambers/ _____ % Cedar Creek
Raw Water Treatment Costs:
Chemical costs: $____________ MG finished water
Operations costs: $____________ MG finished water
Sludge management and disposal costs: $____________ MG finished water
Pumping costs: $____________ MG finished water
Other ____________ costs: $____________ MG finished water

Balancing Reservoir
Raw Water Treatment Costs:
Chemical costs: $____________ MG finished water
Operations costs: $____________ MG finished water
Sludge management and disposal costs: $____________ MG finished water
Pumping costs: $____________ MG finished water
Other ____________ costs: $____________ MG finished water

How do you know what water source(s) you are receiving?

4. Raw Water Characteristics Affecting Treatment

N/A

Please rank the following raw water characteristics from the most (#1) to least significant with regard to water treatment costs and operations. Check which reservoir or blend that the characteristic can apply to.

_____	Rapid changes in turbidity.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Rapid changes in alkalinity. ☐ Drop ☐ Rise	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Rapid changes in changes pH. ☐ Drop ☐ Rise	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Rapid drop in dissolved oxygen.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Unexpected changes in raw water source.	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Taste and Odor	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Particles in the size range ____ to ____ μm	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Iron and/or Manganese	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Other ____________________	☐ RC ☐ Blend ☐ CC ☐ Bal Res
_____	Other ____________________	☐ RC ☐ Blend ☐ CC ☐ Bal Res

5. Addressing Water Quality Problems

√

Please complete Table 1 with regard to the seasonality of, public respose to, and treatment for the water quality problems experienced at the plant.

6. Determining Chemical Dosages

Please check all that apply with regard to determining chemical dosages for treatment. Note the process or processes to which the response applies in the blank to the right of the response. (For example, if "Charts Developed for Plant" are used to determine chemical dosages for both sedimentation and filtration, write "sedimentation and filtration" in the blank.

Diagnostic	Process to Which it Applies
N/A ☐ Raw Water Source Identity	____________
☑ Experience	All
☑ Jar Tests	Turbidity reduction (Coag./sed./filtration)
☑ Charts Developed for Plant	Turbidity " " " "
☑ Raw Water Characteristics	Turbidity reduction, PAC addition
☑ pH	
☑ turbidity	
☑ alkalinity	
☐ TOC	
☑ taste and odor	
☐ other ____________	
☐ other ____________	
☐ Other ____________	____________
☐ Other ____________	____________

7. Operations Impacts

N/A

When additional treatment costs are incurred in one raw water source over another, which of the following areas contribute to the increased costs: (Check all that apply.)

☐ Increased chemical dosages. List chemicals and increased dosage requirements.

______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l
______________ Increase dosage by __________ mg/l

☐ Reduced sedimentation performance --> higher filter loads/shorter filter run times.
☐ Larger backwash volume requirements.
☐ Greater sludge volumes.
☐ Other ______________
☐ Other ______________

8. Data

N/A

If you have developed data that illustrates your responses to the questions above, please provide representative periods of two to four weeks that demonstrate increased chemical additions, sludge production, or treatment costs. As stated above, the goal of this project is to provide information that will assist the District in providing the best raw water characteristics possible for the users from the available sources and managing the raw water sources in a way that minimizes negative impacts on the plants treating the water for distribution. The greater detail and documentation you can provide, the better the decisions that will be made. Attach all supporting data to this questionnaire.

9. Additional Information

If there is additional information or areas which you think should be addressed, please provide this information below or on a separate sheet of paper.

Thank you for your time and effort in providing this information.

Table 1
Water Quality Problems and Strategy

Potential Problem	Check if Applies to Your Plant	Problem Time of Year	Customer Complaints? (Yes/No?	Treatment Strategy to Combat Problem
Turbidity	✓	Rainfall events	No	Adjust coagulation chems. and process parameters.
Algae	✓	Year-round	Yes	PAC used.
Taste and Odor	✓	"	"	"
Iron	X			
Lead	X			
Manganese	X			
Copper	X			
Arsenic	X			
THMs	✓	Late spring-early fall	No	Adjust free-chlorine contact time + alum dose.
Other:				
Other:				
Other:				
Other:				

Appendix F

Environmental Water Needs Criteria and Implementation Method

To	Wayne Owen, David Marshall
From	Sam Vaugh, David Wheelock, Kelly Payne
Date	July 12, 1996
Subject	Methodology for Application of Environmental Water Needs Criteria to Modified Operations of Existing Reservoir Projects

HDR

Memorandum

It is our understanding that the Environmental Water Needs Criteria of the Consensus Planning Process (Consensus Criteria) may be applied to some of the various technical analyses outlined in the Scope of Work dated August 22, 1995 for the Tarrant County WCID#1 Water Management Plan. It is expected that any modified operations for Lake Bridgeport and/or Eagle Mountain Lake considered in this study will fall within the "four corners" of their existing permits and, therefore, need not address Consensus Criteria or daily reservoir operation simulation. The scope does, however, indicate that the effects of modified operations such as overdrafting/underdrafting and changing the drought supply reserves of the existing Cedar Creek and/or Richland-Chambers Reservoirs are to be evaluated. As some of these modified operations would likely require permit amendments to authorize increased annual and/or instantaneous diversion rates, the Consensus Criteria indicate that the "three-zoned planning criteria" for New Project On-Channel Reservoirs would need to be applied, but only to "that portion of the existing water right subject to change." This memorandum is provided to describe the methodology by which the Consensus Criteria could be applied in this study as neither the Consensus Criteria nor the TNRCC Regulatory Guidance Document provide specific direction.

The basis for the methodology described herein is found in the following statement from the Consensus Criteria:

> "An environmental assessment and any corresponding permit conditions relating to an application for an amendment are limited to addressing any new or additional environmental impacts which may result from granting the amendment, and where such impacts would be beyond that which are possible under the full, legal operation of the existing water right prior to its amendment."

The methodology for incorporation of Consensus Criteria as applied to modified operations of existing reservoirs managed by TCWCID#1 is summarized in the following two steps:

1) Simulate daily operations of each reservoir (or system of reservoirs) subject to authorized diversions and existing permit conditions. Tabulate daily spills and/or releases from each reservoir and compute pertinent statistics (mean, median, maximum, minimum, lower quartile, 7Q2, etc.) for each month.
2) Simulate daily operations of each reservoir (or system of reservoirs) subject to proposed diversions, existing permit conditions, and the Consensus Criteria for New Project On-Channel Reservoirs using the monthly median, lower quartile, and 7Q2 values from Step 1 as minima for inflow passage in each of the three specified storage zones (greater than 80%, 50% to 80%, or less than 50% of capacity). Flushing flow provisions in the Consensus Criteria will not be simulated in this study. Tabulate daily spills and/or releases from each reservoir and compute pertinent statistics for comparison with those from Step 1.

Appendix G

Comments and Responses on Final Report

TEXAS WATER DEVELOPMENT BOARD

June 16, 1999

Mr. James M. Oliver
General Manager
Tarrant Regional Water District
P.O. Box 4508
Ft. Worth, Texas 76164-0508

Re: Regional Water Supply Planning Contract Between the Tarrant Regional Water District (District) and the Texas Water Development Board (Board), Review Comments on "Water Management Plan, Tarrant Regional Water District", TWDB Contract No. 96-483-169

Dear Mr. Oliver:

Staff members of the Board have completed a review of the draft final report under TWDB Contract No. 96-483-169 and offer comments shown in Attachment I.

In addition, the scope of work for this study includes a review of flood management strategies for reservoir operations. However, this part of the scope was not included or addressed. Please submit this section for Board review prior to submitting the Final Report.

After review comments have been transmitted to the District regarding flood management strategies for reservoir operations, the District will consider incorporating all comments from the EXECUTIVE ADMINISTRATOR and other commentors on the draft final report into a final report.

Please contact Mr. Gilbert Ward, the Board's designated Contract Manager, at (512) 463-6418, if you have any questions about the Board's comments.

Sincerely,

Tommy Knowles, Ph.D., P.E.
Deputy Executive Administrator
Office of Planning

cc: Gilbert Ward, TWDB

ATTACHMENT 1
TEXAS WATER DEVELOPMENT BOARD

DRAFT REPORT REVIEW COMMENTS
TWDB Contract No. 96-483-169
"Water Management Plan, Tarrant Regional Water District"

In general, the report appears to satisfy the scope of work, however, Board staff offers the following comments:

- The scope of work calls for a review of flood management strategies for reservoir operations and block water rate increases as a demand management option. These two parts of the scope have not been addressed. Please submit these portions of the report for review.
- Please include a description of the three workshop meetings or the results thereof.
- The bibliography for Sections 1-5 of the report are missing. Please include.
- The report is unclear of what the Demand Management and Drought Contingency Plans are. Please clarify.

August 27, 1999

Mr. Wayne Owen
Planning and Development Manager
Tarrant Regional Water District
P.O. Box 4508
Fort Worth, Texas 76164-0508

Re: Final Revisions - Water Management Plan

Dear Mr. Owen:

We have received comments on the draft Water Management Plan from the Texas Water Development Board. This letter transmits the report in final form with revisions made as noted below. Here is the action taken on each comment:

Texas Water Development Board Comments (Attachment 1 to letter from Dr. Tommy Knowles, 6/16/99).

a. Flood Management (Scope of Work Task 7.0). The scope required that HDR provide data sets and reservoir storage traces (i.e. computer model output) for water supply management options to the District in support of on-going or future flood management analysis. The data sets and storage traces have been transmitted to the District as a stand-alone deliverable under separate cover. A portion of the data developed for this scope item is summarized in lake storage traces in Figures 3-5 through 3-13 in Section 3.
b. Demand Management Strategies and Workshops (Scope of Work Task 1). A list of potential demand management strategies was presented to the District's customers beginning with Workshop No. 1. The comment asks about increasing block water rates, which is one of the management methods listed in Task 1. Increasing block rates, as well as other water conservation techniques, was kept on the list of alternatives through the three customer workshops. The Water Conservation and Emergency Demand Management Plan briefly documents that the District customers have increasing block rates in place.
c. Water Conservation and Emergency Demand Management Workshops

    Workshop No. 1 (4/10/96). Presentation by Bill Hoffman and Kariann Sokulsky extensive participation from the District's customers.

    Workshop No. 2 (7/24/96) with the District's Primary Wholesale Customers. Presentation by HDR Engineering, and extensive participation of the District's wholesale customers in discussion of population and water usage projections and water conservation practices and techniques.

    Stella Drought Management Workshop (May 31, 1996) An object oriented drought model developed by the U.S. Army Corps of Engineers was utilized to simulate operational decisions generally encountered during an extended drought situation. Participation by wholesale customers, TWDB staff, and HDR Engineering.

HDR Engineering, Inc.

Employee-owned

2211 South IH 35
Suite 300
Forum Park
Austin, Texas
78741

Telephone
512 912-5100
Fax
512 442-5069

There was one additional workshop like meeting involving the District's customers on October 3, 1996 where additional water conservation plan issues were finalized.

d. Report References. The report style used for the Water Management Plan cites references by footnote rather than a concluding bibliography.
e. Water Conservation and Drought Contingency Plan. This plan was finalized and approved by the Texas Water Development Board on August 22, 1997. The plan was subsequently adopted by the TRWD Board in June, 1998, and then implemented by TRWD's wholesale water customers.

It has been a pleasure to complete this important work for the District and the Texas Water Development Board and we trust that the Water Management Plan will be a valuable planning document for the Tarrant County region for quite some time.

Very truly yours,

HDR Engineering, Inc.

David C. Wheelock, P.E.
Vice President

cc: Mr. Jonathan Young, Ph.D., P.E.