TRANS-TEXAS WATER PROGRAM

SOUTHEAST AREA

Technical Memorandum

Wastewater Reclamation

March 19, 1998

Sabine River Authority of Texas
Lower Neches Valley Authority
San Jacinto River Authority
City of Houston
Brazos River Authority
Texas Water Development Board

Preface

This document is a product of the Trans-Texas Water Program: Southeast Area. The program's mission is to propose the best economically and environmentally beneficial methods to meet water needs in Texas for the long term. The program's three planning areas are the Southeast Area, which includes the Houston-Galveston metropolitan area, the South-Central Area (including Corpus Christi) and the West-Central Area (including San Antonio).

The Southeast Area of the Trans-Texas Water Program draws perspectives from many organizations and citizens. The Policy Management Committee and its Southeast Area subcommittee guide the program; the Southeast Area Technical Advisory Committee serves as program advisor. Local sponsors are the Sabine River Authority of Texas, the Lower Neches Valley Authority, the San Jacinto River Authority, the City of Houston and the Brazos River Authority.

The Texas Water Development Board is the lead Texas agency for the Trans-Texas Water Program. The Board, along with the Texas Natural Resource Conservation Commission, the Texas Parks & Wildlife Department and the Texas General Land Office, set goals and policies for the program pertaining to water resources management and are members of the Policy Management Committee.

This is the final version of this document.

Brown & Root and Freese & Nichols are consulting engineers for the Trans-Texas Water Program: Southeast Area. Blackburn & Carter and Ekistics provide technical support. This document was written by:

Brown & Root

Augusto Villalon
Bruce F. Leon, Ph.D.
Daniel Gise
Glenn Hughes, P.E.
Leisa Nelson, P.E.

Contents

Figures

Tables

1. Introduction

The Trans-Texas Water Program (TTWP) Southeast Area Phase I Report identified thirteen water management alternatives for possible inclusion in its final TTWP Southeast Area Water Management Plan. This current memorandum analyzes the viability of implementing one of these alternatives, wastewater reclamation.

The TTWP Planning Information Update report indicates that within the entire 32 county study area, the largest sub-area of water supply need is within the Houston region. Water supply shortages within the Houston region are projected to occur as early as year 2020 in the Brazos basin, and significant shortages are projected to occur within the San Jacinto basin by year 2040. This technical memorandum summarizes the results of the feasibility of implementing a wastewater reclamation plan for industrial water users within the San Jacinto basin.

Two earlier studies which investigated wastewater reuse in the Houston area are The Houston Water Master Plan (1), and the Feasibility of Wastewater Reuse (2). Both studies evaluated several alternative reuse plans. The specific alternative with the most potential included using wastewater effluent solely for industrial cooling water needs of industries along the Houston Ship Channel. This alternative called for supplying wastewater from the City of Houston 69th Street Wastewater Treatment Plant (WWTP). A new reclaimed water transmission line was proposed under this plan to extend from the 69th Street WWTP to supply reclaimed water to industries in the State Highway 225 (SH-225) corridor. Under this alternative, the existing Coastal Water Authority (CWA) system would continue to supply raw water for process needs. Thus two separate water supply systems would be proposed. The total capital cost of the conceptual alternative in 1985 dollars was estimated to be $66 million. This cost was viewed as excessive and the reclamation alternative was not recommended within the Houston Water Master Plan.

There are two conceptual distinctions between the two previous reclamation studies and this current TTWP analysis:

- Previous efforts focused on providing reclaimed wastewater for industrial cooling water use only. **This current TTWP effort is based on providing reclaimed wastewater for both industrial cooling and process water use.**

- Previous studies proposed a new separate reclaimed wastewater transmission main system, maintaining the existing CWA system for non-cooling water purposes and to act as a backup to the reuse system. **This TTWP effort proposes to use a portion of the existing CWA B-1 transmission main system in an effort to reduce the initial reclamation system capital cost.**

These two distinctions are related and may result in a facility cost trade-off. That is, use of reclaimed wastewater for industrial process water use requires additional treatment requirements and therefore additional costs in relation to only supplying industrial cooling water. Use of existing CWA mains for the reclaimed water system, however, should result in less transmission main construction and lower hydraulic system costs.

2. Wastewater Reuse

Wastewater reuse systems vary widely in effluent quality and reuse applications. Groundwater recharge, agricultural and landscape programs, as well as industrial reuse are some of the more common wastewater reuse programs. Wastewater reuse for agricultural irrigation or landscape purposes is generally the principal type of effluent application within the United States. Industrial reuse programs are relatively few in comparison to irrigation reuse programs. In general, wastewater reuse programs are a result of regional and/or municipal needs to meet identified water supply shortages.

2.1. Application

The following are some examples of existing industrial wastewater reuse programs:

- Harlingen, Texas. The City of Harlingen provides approximately 2.1 million gallons per day (mgd) of reclaimed wastewater to the Fruit of the Loom Corporation. Secondary effluent from the City's wastewater treatment plant receives additional treatment which includes filtration followed by reverse osmosis.
- Lubbock, Texas. The City of Lubbock supplies about 20 mgd of secondary effluent for irrigation and industrial uses. Approximately 15 mgd is used for irrigation purposes while 5 mgd is used for industrial cooling water demands.
- Odessa, Texas. The City of Odessa delivers approximately 2-3 mgd of secondary effluent for irrigation purposes and industrial cooling water needs.
- San Francisco, California. The East Bay Municipal Water District (EBMWD) delivers approximately 5.5 mgd of reclaimed water to the Chevron Richmond refinery. Secondary effluent from the West Contra Costa sanitary district treatment plant is diverted to a water reclamation plant where lime/soda ash softening produces a quality makeup water for the refinery's cooling towers. The reclaimed water meets the California Department of Health Services (DHS) Title 22 requirements for the most stringent use of reclaimed water.

2.2. Regulatory Issues

Chapter 210, Sections 210.1-210.55 of the Texas Administrative Code (TAC) (3) establishes reclaimed water quality criteria, and design and operational requirements for reclaimed water systems. Reclaimed water is defined as "Domestic municipal wastewater which has been treated to a quality suitable for beneficial use."

The major points addressing industrial reuse applications, contained in Chapter 210 of the TAC are: Texas Natural Resources and Conservation Commission (TNRCC) notification and authorization; general requirements for the production; and facility design criteria for conveyance, storage and use.

Section 210.4 of the TAC stipulates that prior to the reuse of reclaimed water, the Executive Director of the TNRCC must be notified by both the reclaimed water provider and end user. State regulatory approval must be obtained. The notification shall describe the intent for wastewater reuse, the origin and reuse location of wastewater, a description of quantity and quality of wastewater, a description of the means for compliance with TAC 210, and an operations and maintenance plan. The operations and maintenance plan shall contain:

- Signed contracts between provider and user;
- Measures to prevent cross connections and unauthorized access to reclaimed facilities;
- A plan for monitoring reclaimed water;
- Descriptions on how to minimize potential human exposure;
- Schedules for maintenance programs;
- Employee training programs and contingency plans for system failures or upsets.

Section 210.31-36 of the TAC contains water quality requirements for two types of reclaimed water uses: Type 1 use includes irrigation and other uses where the public may be present or come into contact with the reclaimed water; Type II use includes irrigation or other uses where the public is not present or may not come into contact with the reclaimed water. Section 210.51-55 contain special requirements for use of industrial reclaimed water. For both use types, the only constituents with definitive minimum quality requirements are Biochemical Oxygen Demand (BOD_5) and Fecal Coliform. Reclaimed water may be used in place of a freshwater source if the BOD_5 is at a minimum quality of 20 mg/l for non-ponding systems, and/or 30 mg/l for pond systems, while Fecal Coliform is not to exceed 200 CFU/100ml (CFU-colony forming unit of fecal coliform test). Additionally, Section 210.21-25 of the TAC stipulates general requirements as to the conveyance and use of and public exposure to reclaimed water.

Minimum facility design requirements of the reclamation system are discussed throughout TAC Chapter 210. Some of the major design requirements include required separation distances between reclaimed piping and potable pipelines and prior approval by the TNRCC Executive Director of materials to be used in the construction of reclaimed systems.

TAC Section 210 principally addresses agricultural and landscape uses of reclaimed wastewater. The TNRCC does not maintain detailed hydraulic, water quality, or treatment standards specific to industrial use of reclaimed wastewater. The definition of reclamation system design is left to the project designer. The following proposed plan therefore is designed to meet the above listed TNRCC minimum standards. Additionally, a set of design standards for hydraulic, water quality, water treatment and waste stream discharge are proposed and discussed in the following sections.

3. Conceptual Plan

Determining a wastewater reclamation strategy is a function of:

- The quantity and quality of the source wastewater supply, and
- The location and demand characteristics of the receiving water customer base.

Based on identification of these two parameters, resultant treatment, conveyance and discharge systems can be configured for the reclamation system. Conceptually, the TTWP wastewater reclamation strategy consists of:

- Diverting effluent from three City of Houston wastewater treatment plants (WWTP's),
- Treating this wastewater to a quality acceptable to industrial customers for process and cooling water uses, and
- Transmitting the treated wastewater to the customers through a system of pump stations and pipelines.

This section will discuss each of these areas and propose a potential system.

3.1. Source Water Supply

The wastewater reclamation system under study includes diverting effluent from the 69th St. WWTP and the Sims Bayou North and South WWTP's to a new regional Wastewater Reclamation Plant (WRP). The selected wastewater treatment plants are the nearest municipal treatment facilities to the potential industrial customer-base along the Houston Ship Channel. Figure 1 illustrates the location of the existing WWTP's and the CWA transmission main system.

The Coastal Water Authority is a government agency of the State of Texas whose purpose is to finance, construct, own and operate raw surface water facilities for use in Harris, Liberty and Chambers counties. The CWA system provides Trinity River water to agricultural, industrial, and municipal customers. The CWA industrial raw water distribution system begins at the Lynchburg Pump station and contains approximately 30 miles of pressure pipe ranging from 48-inches to 108-inches in diameter.

The 69th St. WWTP is the City of Houston's largest municipal wastewater treatment facility and is located in the vicinity of Clinton Drive and North 69th St. The process train consists of a pre-treatment head-works, a pure oxygen activated sludge system, filtration, followed by chlorination and dechlorination.

The City of Houston also operates two wastewater treatment plants in the Sims Bayou wastewater service area. The original "North" plant is located at the confluence of Plum Creek and Sims Bayou. The more recently constructed "South" plant is located south of the Charles H. Milby Park along Sims Bayou. Both treatment plant process trains consist of a pre-treatment head-works, activated sludge systems, followed by chlorination and dechlorination.

Figure 1: Existing Coastal Water Authority Raw Water System

A sludge plant is located at the Sims Bayou North facility.

To determine wastewater supply availability, an analysis of existing and future WWTP flow was conducted for these three facilities. In order to determine existing flow, monthly summaries of the City of Houston Wastewater Treatment Operations were analyzed for two years of data, Jan. 1993 to December 1994 (See Table 1).

At present, the 69th St. WWTP has a service area of approximately 98 sq. mi. while both Sims Bayou WWTP's serve an area of approximately 41 sq. mi. The combined existing average daily flow of the three WWTP's is approximately 115 mgd. Based

Table 1: Wastewater Treatment Plant Daily Average Flows

	Flow (mgd)			
Date	***Sims-North***	***Sims-South***	***69th St.***	***Combined***
Jan-93	15.4	36.0	94.8	146.2
Feb-93	13.7	31.5	83.3	128.5
Mar-93	15.0	33.4	94.2	142.6
Apr-93	14.1	31.0	84.5	129.6
May-93	13.3	30.4	87.7	131.4
Jun-93	14.1	32.0	94.8	140.9
Jul-93	10.6	24.6	66.1	101.3
Aug-93	10.3	24.5	67.5	102.3
Sept-93	10.0	23.6	65.5	99.1
Oct-93	10.8	26.8	68.6	106.2
Nov-93	10.8	29.2	76.0	116.0
Dec-93	8.5	24.4	69.2	102.0
Jan-94	11.6	23.5	68.2	103.3
Feb-94	11.0	23.0	79.5	113.6
Mar-94	10.2	21.8	75.4	107.4
Apr-94	10.6	21.0	69.7	101.3
May-94	13.2	23.0	84.6	120.8
Jun-94	13.1	27.0	83.3	123.4
Jul-94	9.3	21.9	66.8	98.0
Aug-94	11.4	23.1	68.1	102.6
Sept-94	11.0	20.6	68.5	100.2
Oct-94	15.6	28.9	96.2	140.7
Nov.-94	7.8	20.7	66.5	95.0
Dec-94	11.5	22.9	84.0	118.5
Average	11.8	26.0	77.6	115.5

on wastewater treatment plant operations reports, minimum daily effluent for the two year period, for the three WWTP's is approximately 80 mgd.

Determination of future WWTP flows for the three facilities consists of projecting population and wastewater generation estimates within the service area of each WWTP. The Texas Water Development Board (TWDB) projected a total population for the City of Houston in 2050 to be 3,220,889. The total population growth from 1990 through 2050 within the WWTP's service area is projected to be 305,140 persons. Despite this increase in population over the study period, indoor water consumption is expected to be significantly reduced due to the effects of the Energy Policy Act of 1992. The Act mandates use of efficient low-flow water use fixtures in households. Significant planning implications are expected from the new standards on water demand and wastewater volumes (4). Future wastewater rates are based on a 34% reduction in indoor water consumption. Applying a per capita wastewater flow rate to the projected population increase within the WWTP service area results in the year 2050 effluent discharge projection.

Therefore, combined wastewater average daily flow of 115 mgd is expected to rise to 135 mgd in the year 2050. The minimum daily effluent flows for year 2050 are projected to be 95 mgd.

3.2. Potential Customers and Demands

Based on the estimated quantity of available wastewater supply, a review of potentially viable industrial customers was conducted. The purpose of the review was to determine the projected water quality and quantity requirements of the industries and compare those requirements to the available wastewater supply.

The industries targeted are CWA raw water users with existing contracts along the CWA B-1 line from Rohm & Haas Rd. westward to Sims Bayou (See Figure 2). The targeted area contains industries engaged in the following industrial activities:

- Petroleum refining
- Chemical manufacturing (specialty, synthetic organics, etc.)
- Co-generation
- Air separation
- Pulp & paper manufacturing

3.2.1. Wastewater Reuse Survey

The selected industrial customers along SH-225 are currently supplied with raw water from the CWA B-1 line, via the Lynchburg pumping station. A survey was sent to the eighteen industries listed in Figure 2. In addition to requesting basic information (consumptive use, future expansions and

Figure 2: Potential Industrial Facilities

conservation programs) the main purpose of the survey was to determine the issues and concerns which their facility would have in using reclaim wastewater as a replacement of their existing raw water supply. Of the 18 industries surveyed, 13 (over 70%) responded.

The following represents a synopsis of the industrial customer response to the survey:

- Existing on-site industrial water treatment facilities (precipitators, softeners, demineralizers) are designed based upon average Trinity River water quality.

- Any increase in nitrogen levels in the form of ammonia and nitrates, will result in increased chlorine demands, causing stress corrosion cracking of brass condensers. Additionally, increased nitrogen levels could increase industrial wastewater discharge concentrations of ammonia nitrogen to unacceptable levels. Some industries indicated difficulties treating wastewater containing nitrogen.

- Any increase in heavy metals (zinc, copper, chromium) will raise concerns regarding discharge permit limitations. Concerns were also raised on the potential increase in corrosion by sending tramp copper through their process systems.

- Concerns were raised regarding the increase in Total Dissolved Solids (TDS) on the operation of their cooling towers (lower cycles of operation, potential scaling and fouling). Higher TDS values would also increase their on-site cost for demineralization programs.

- Several industries stated that organic constituents would also need to be evaluated as well, since organics tend to foul ion-exchange resins.

- Any increase in water hardness would increase on-site plant treatment cost due to softener resin life.

In general, most industries reported that they would consider using wastewater effluent in place of their current raw water needs if their total cost of doing business would not increase. The survey respondents anticipated that increases in costs would occur for new equipment, process materials, and effluent treatment. Additionally, water quality changes were expected to increase manpower requirements for onsite industrial treatment operations and maintenance programs, which would add to their site-specific costs.

Most industries stated that since their raw water treatment facilities were designed to accommodate Trinity River water quality, the industries would require that reclaimed wastewater be equal in quality to CWA raw water, otherwise industry costs were thought to increase.

3.2.2. Industrial Water Quality and Demand

As a result of the industrial response to the survey, a conceptual reclamation plan was developed such that effluent from the City of Houston WWTP's would be treated to a quality equal to or better than the current CWA raw water supply. Table 2 provides a comparison of CWA water quality versus the effluent discharge quality from the referenced City of Houston WWTP's.

The CWA system provides raw water for the cooling and process needs for the 18 industries within the targeted area. Potable water needs are met by other sources. Analysis of City of Houston water billing records show that demands for the targeted industries have not changed significantly since 1990. The industrial facilities within the targeted area represent approximately 50% of the total existing heavy manufacturing raw water consumption within the San Jacinto watershed basin.

Table 3 shows the raw water consumption and the distribution of use of the 18 industries. Average raw water consumptive use for individual industries ranges from 0.033 mgd to 28.5 mgd. The raw water use of those industries that responded represented over 90% of the total existing consumption within the targeted area. Industrial demands for the targeted industries are fairly constant. Fluctuations in use are primarily a function of the manufacturing process at each facility. Heat loads developed in process units, ambient temperatures and level of production all tend to impact water consumption. Records of the Lynchburg pumping station show that monthly variations in demands are approximately 10-12%. Industry response to the survey showed a weighted peaking factor for maximum day consumption to be approximately equal to 1.2 times average daily use.

Future industrial demands are based on projections from the Consensus Water Planning effort for the manufacturing use category within Harris County, based on two-digit Standard Industrial Classification (SIC) codes (5). Consensus Water Planning numbers project that by the year 2050 there would be:

- A 97% increase in water use for chemicals and allied product industries,
- An 89% increase for rubber and miscellaneous plastics facilities,
- A 43% increase for petroleum refineries, and
- A 21% decrease in water use for paper and allied product industries.

These percentages were applied to each of the listed industries to determine their future projected demands. Industrial water use for the industries are projected for each study decade and are shown in Table 4. As shown, the projected 2050 average daily water demand for the targeted industries is approximately 135 mgd. The projected maximum daily use of the 18 industries is computed to be 162 mgd.

Table 2: Water Quality of CWA Raw Water and Wastewater Effluent

	Raw Water (2)		*Wastewater* (3)	
Parameter (1)	***Mean***	***Max***	***Mean***	***Max***
Total Dissolved Solids (TDS)	246	300	440	470
Calcium	39	44	26.7	27.9
Chloride	25	32	69.5	74.4
Sulfate (SO_4)	29	37	57	62
Hardness (as $CaCO_3$)	112	130	151	156
Total Alkalinity (as $CaCO_3$)	95	112	154	211
$CBOD_5$			3.00	3.00
NH_3-N			1.00	1.50
NO_3-N	0.34	0.81	10.7	11.1
Magnesium	4.32	4.92	7.289	8.514
Phosphate (as PO_4)	0.3	3.2	1.289	3.504
Silver	0.01		0.004	0.011
Arsenic	< 0.003		0.0038	0.008
Beryllium	< 0.02		0.0016	0.01
Cadmium	0.01		0.004	0.011
Chromium	< 0.02		0.0122	0.11
Copper	< 0.03		0.008	0.035
Mercury	< 0.0002		0.0002	0.0002
Nickel	0.02		0.0172	0.023
Lead	0.003		0.0025	0.009
Antimony	< 0.01		0.0242	0.035
Selenium	< 0.02		0.0035	0.005
Thallium	< 0.1		0.0023	0.005
Zinc	< 0.01		0.0479	0.1
Silica	7.20	13.00	8.90	11.00
Total Organic Carbon (TOC)	6.60	9.80	7.50	8.60
pH	8.00	8.20	7.30	7.30

(1) All units mg/l except pH

(2) COH Water Quality Control 1993 Annual Report, Trinity River Quality

(3) 69th St. & Sims Bayou WWTP Effluent

3.3. System Design Criteria

Two types of system design criteria are used to configure the wastewater reclamation plan: process treatment and hydraulics. The basic water treatment process criteria consist of designing the system to deliver a reclaimed water equal to or better than the current CWA raw water quality for all constituent parameters. Hydraulic criteria are defined for the facility component capacities.

In general, system facilities are designed using the same parameters as conventional water treatment plants, high service pump stations, and transmission mains. Due to the type of industrial customers served by this plan, a totally reliable supply system is proposed. The design criteria are configured to supply 100 percent of the demand, 100 percent of the time.

Hydraulic criteria are established for the proposed pump stations and treatment facilities proposed within the system as follows.

- Wastewater supply—the total amount of combined wastewater diverted to the WRP (95 mgd) based upon the projected year 2050 minimum daily flow available from the three WWTP's.
- Wastewater reclamation plant—treatment capacity equivalent to future WWTP maximum daily industrial demand.
- Transfer pump stations—firm capacity equivalent to future minimum daily WWTP flow.
- Wastewater reclamation transmission mains—pipelines are sized based on peak hourly flow with velocities ranging from 6-8 feet per second.

Table 3: Water Demand by Industry:

		1993 Average Consumptive Use (mgd)			
	Industry	***Use***	***Cooling***	***Process***	***Other***
1	Lubrizol Corp. [(1)]	0.96	0.53	0.14	0.29
2	Praxair, Inc	0.49	0.35	0.00	0.15
3	Abelmarle Corp.[(1)]	3.56	1.96	0.53	1.07
4	Georgia Gulf Corp.[(1)]	0.56	0.31	0.08	0.17
5	Occidental Chemical Corp.	4.61	0.74	3.88	0.00
6	Shell Oil Co.	22.85	11.65	2.28	8.91
7	Phillips Petroleum [(1)]	3.74	2.06	0.56	1.12
8	Mobil Mining & Minerals	2.31	1.11	0.39	0.81
9	Crown Central Petroleum	3.31	2.02	2.98	0.99
10	Simpson Pasadena Paper	28.39	1.42	26.97	0.00
11	Applied Energy Services	2.71	2.71	0.00	0.00
12	Lyondell PetroChemical Co.	12.61	7.19	2.40	3.03
13	Mobil Chemical [(1)]	1.87	0.28	1.59	0.00
14	Miles Inc.	0.61	0.26	0.35	0.00
15	Goodyear Tire & Rubber	1.31	0.30	0.99	0.03
16	Texas PetroChemical Co.	5.53	3.98	0.66	0.89
17	Phibro	2.84	1.11	1.65	0.06
18	Hickson Kerley Inc.	0.03	0.00	0.02	0.01
	Total	98.28	37.96	45.47	17.51

[(1)] Distribution of consumptive use estimated.

3.4. Proposed Reclamation System

The WRP includes the treatment components indicated below and as shown in Figure 3. The preferred WRP treatment process method is membrane treatment (reverse osmosis). However, pre-treatment filtering is required to prevent membrane fouling and supplement membrane treatment removals. Reverse osmosis (RO) is required to address the concerns voiced by the industries within the survey. RO is an extremely advanced treatment process that essentially removes all identified pollutants. Particularly, RO is needed to address the industry concerns regarding acceptable TDS, Nickel, and nitrogen (specifically nitrate-nitrogen; NO3-N) concentrations.

The process treatment train at the WRP would consist of a rapid mix chamber, flocculation, filtration with denitrification followed by reverse osmosis. In addition to the treatment processes listed above, auxiliary facilities are needed to support the operation and maintenance of the WRP. Such facilities include: administration, control and laboratory buildings, chemical storage and feed facilities, a maintenance building and a vehicle parking garage.

Table 4: Industrial Water Demand Projections:

	Projected Industrial Demands For Each Study Decade (mgd)						
Industry	*1990*	*2000*	*2010*	*2020*	*2030*	*2040*	*2050*
Lubrizol Corp.	0.96	1.11	1.28	1.39	1.51	1.70	1.89
Praxair, Inc	0.49	0.57	0.66	0.72	0.77	0.88	0.97
Abelmarle Corp.	3.56	4.13	4.75	5.17	5.59	6.31	7.01
Georgia Gulf Corp.	0.56	0.65	0.74	0.81	0.87	0.99	1.10
Occidental Chemical Corp.	4.61	5.35	6.15	6.71	7.24	8.19	9.09
Shell Oil Co.	22.85	24.70	26.43	27.48	28.31	30.57	32.71
Phillips Petroleum	3.74	4.34	4.99	5.44	5.88	6.64	7.37
Mobil Mining & Minerals	2.31	2.68	3.08	3.35	3.62	4.09	4.54
Crown Central Petroleum	3.31	3.57	3.82	3.98	4.10	4.42	4.73
Simpson Pasadena Paper	28.39	26.40	24.29	23.32	21.92	22.14	22.36
Applied Energy Services	2.71	3.15	3.62	3.94	4.26	4.81	5.34
Lyondell PetroChemical Co.	12.61	13.63	14.58	15.17	15.62	16.87	18.05
Mobil Chemical	1.87	2.17	2.49	2.71	2.93	3.31	3.68
Miles Inc.	0.61	0.71	0.81	0.89	0.96	1.08	1.20
Goodyear Tire & Rubber	1.31	1.52	1.74	1.90	2.05	2.32	2.57
Texas PetroChemical Co.	5.53	5.98	6.40	6.66	6.86	7.41	7.92
Phibro	2.84	3.07	3.28	3.42	3.52	3.80	4.07
Hickson Kerley Inc.	0.03	0.04	0.04	0.05	0.05	0.06	0.07
Total	98.28	103.75	109.17	113.11	116.06	125.60	134.67

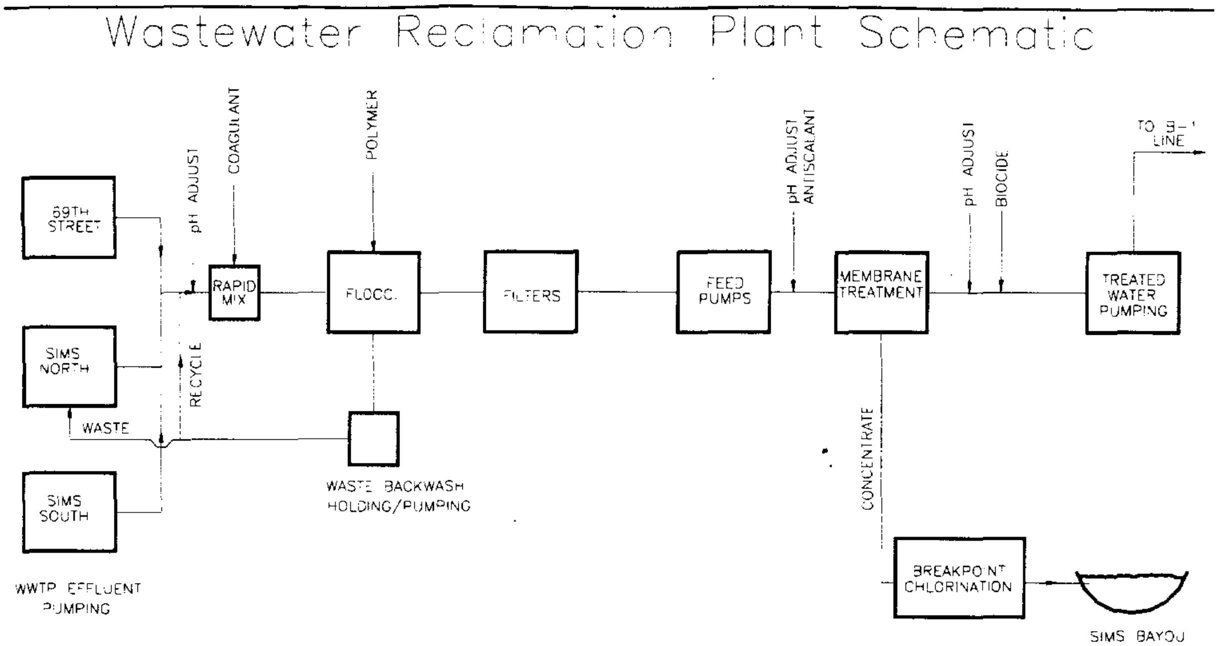


Figure 3: Wastewater Reclamation Plant Schematic

The rapid mix chamber serves as the critical contact or coagulation step in the treatment process. A coagulant (lime, ferric sulfate, or alum) is added and thoroughly mixed with the secondary effluent. Lime or sulfuric acid are added ahead of the coagulant to adjust pH to optimize the coagulation/filtration process.

Following the rapid mix chamber, flocculation or slow mixing provides for the agglomeration of particles and builds the particles into larger "floc" which is subsequently removed in the filtration process. To improve flocculation, a polymer may be added to the flocculation basins to enhance the process.

After flocculation the water is conveyed to filters which, operating in the "direct" filtration mode, remove the flocculated particles, clarifying the water. In addition, the filter media will also serve to assist the subsequent membrane treatment in the removal of nitrates. The filters are configured in several rectangular shaped basins containing granular mixed media consisting of coal and sand. This "dual media" is particularly designed to store relatively large quantities of solids that can be generated by wastewater treatment plant upsets. The effluent from the filters is conveyed to a sump which serves as storage of filter backwash supply. Periodically, the filters are backwashed to remove accumulated solids and nitrogen gas. The waste backwash is routed to a sump that serves to equalize the flow and allows for recycling to the head of the reclamation plant. Accumulated solids will be pumped to the Sims North WWTP for co-processing.

After the filtration pretreatment step, water is pumped to the RO membrane treatment complex. The membranes are configured in a cylindrical form as elements. Several elements are placed in pressure vessels or

Table 5: Reverse Osmosis Permeate Quality (mg/l, mean)

Parameter	*Raw Water* (1)	*RO Permeate* (2)
Total Dissolved Solids (TDS)	246	12.4
Calcium	39	0.2
Chloride	25	1.6
Sulfate (SO_4)	29	0.2
Total Alkalinity (as $CaCO_3$)	95	9
NH_3-N		0.2
NO_3-N	0.34	0.34
Magnesium	4.32	0.1
Silica	7.2	0.3

(1) COH Water Quality Control 1993 Annual Report, Trinity River Quality
(2) Based on R.O. 85% Recovery Performance Projection

tubes. These tubes are then grouped together into an array and mounted on skids in modular fashion. An appropriate number of skids is supplied to provide the needed flow capacity.

The treated water, or permeate, flows on to the finished water pump station for distribution to users. The proposed system uses an 85% recovery rate from the R.O. process. The wastestream from the reverse osmosis process, called concentrate or brine, will require treatment to remove ammonia nitrogen before being discharged to the receiving body of water.

The waste-stream brine will be deposited into Sims Bayou after treatment to remove ammonia nitrogen. To meet the anticipated discharge requirement of 3 mg/l ammonia nitrogen (6), facilities for breakpoint chlorination are included in the treatment costs. A total of 14.0 mgd of brine (15% of flow) would be produced from the configured treatment facility.

Table 5 presents a comparison of anticipated permeate quality to the current CWA quality for key parameters. For all parameters except for nitrate-nitrogen the permeate water quality is significantly better than the currently provided Trinity River water. The survey revealed that each industry is incurring a significant additional on-site cost to treat the Trinity River water to achieve necessary industrial process water quality standards. It is anticipated that the enhanced quality may become an incentive for industries to accept reclaimed water since their on-site pre-treatment costs would be expected to drop. Additionally, it is expected that improved cooling tower operations resulting from the improved quality may reduce water demand needs. Increased cycles of concentration may be achieved through use of the reclaimed water. Scaling within the cooling towers may be decreased thereby allowing multiple use (cycles) of cooling tower water.

The nominal design flow of the WRP permeate (85% of wastewater supply) available to industrial customers is 81 mgd in year 2050. This quantity of permeate supply which meets maximum daily industrial demands results in a corresponding reduction of surface water demand on a daily basis meeting 50 percent of the computed industrial demand need of 162 mgd in year 2050. Computation of the WRP capacity reveals that there is not a sufficient quantity of reclaimed water to serve all of the industries located on State Highway 225. The wastewater reclamation strategy is limited by the quantity of available municipal wastewater effluent.

This conceptual plan therefore assumes that the service limits of the reclaimed water system only extend to a point immediatley east of Vince Bayou up to and including those industries at valve location no. 5 (See Figure 4). Those industries located east of valve location no. 5 would not be included in this reclaimed water strategy, and would therefore continue to receive Trinity River water.

In addition to the WRP, the reclamation system will include proposed pump stations and transmission lines that will lift and convey effluent from the three WWTP's to the new WRP located north of the Sims Bayou North WWTP. After treatment at the WRP, the reclaimed water, or permeate, is pumped to users using a portion of CWA's B-1 main for distribution. The wastewater reclamation plan requires that the portion of the CWA B-1 raw water main which parallels State Highway 225 extending east to Vince Bayou, be converted to a reclaimed water main. Other transmission mains are also included to convey water from the WRP to the CWA B-1 line.

Figure 4: Wastewater Reclamation Facilities

4. Environmental Impacts

A wastewater reclamation project can affect water quality in two ways. First, the project would divert discharges of secondary effluent from Buffalo Bayou, Sims Bayou and the Houston Ship Channel to the WRP. (The short reach of Sims Bayou between the Sims WWTP and the Houston Ship Channel is hydrologically linked with the Ship Channel.) Second, the discharge of brine concentrate from the WRP into the Houston Ship Channel could affect water quality. The potential impacts to aquatic species in the Houston Ship Channel from potential changes to water quality are not considered here and may require further study.

4.1. Water Quality Impacts to Receiving Water Bodies

The proposed reclamation strategy would redirect secondary effluent discharges from the three WWTP's from Buffalo Bayou and Sims Bayou to the WRP. During wet-weather conditions some of the effluent from these plants would continue to discharge through existing outfalls to Buffalo Bayou (69th Street) and Sims Bayou (Sims North and Sims South). Current levels of wastewater discharges by industries into the Houston Ship Channel would remain unchanged.

The municipal (reclaimed) effluent would flow to the WRP. The WRP treatment processes will:

- filter suspended solids (including oxygen-demanding particulate organic matter);
- reduce the volume to 15 percent of the flow, creating a brine concentrate;
- treat concentrate to remove excess ammonia.

After reverse osmosis treatment, the resulting brine concentrate will be discharged into Sims Bayou. Potential impacts from this strategy result from changes in the location, quantity and quality of effluent discharged to these bayous. Changes in water quality and quantity could affect the aquatic habitat of Buffalo and Sims Bayous and the Houston Ship Channel.

The waste concentrate would discharge to Stream Segment 1006, the Houston Ship Channel. This segment consists of the Houston Ship Channel from its confluence with the San Jacinto River upstream to a point just upstream of Greens Bayou. Stream Segment 1006 is designated for two uses: Industrial Water Supply and Navigation. Currently, Segment 1006 maintains a stream classification as "Water Quality Limited" which requires that wastewater discharges use advanced wastewater treatment processes. Texas Clean Rivers Program data indicate that heavy metal and dioxin levels have been high in this segment. However, Segment 1006 water uses and stream standard criteria are generally attained.

Stream Segment 1006 is a sluggish, tidally influenced bayou. The water column consists of a pronounced stagnant salt wedge under a flowing freshwater layer. The salt wedge will have a salt concentration equivalent to seawater (35,000 ppm).

The proposed brine concentrate effluent is classified as an industrial waste. It is regulated as part of the NPDES permitting program by the U.S. Environmental Protection Agency and the Texas Natural Resource Conservation Commission. The proposed discharge is subject to the provisions of Section 403c of the Clean Water Act (Ocean Discharge Criteria) and must comply with the Texas Water Quality Criteria for Marine Discharges.

The brine concentrate would consist primarily of dissolved solids and heavy metals. Dissolved solids and metals are conservative water pollutants and do not degrade into other substances in the water column. The brine concentrate would have a concentration of 2,400 ppm of total dissolved solids, which is the average summer concentration of dissolved solids in the freshwater layer of the Houston Ship Channel at the Sims Bayou confluence.

4.2. Environmental Conclusions

Simple stream models were developed to estimate the impacts of removing secondary effluent from the receiving streams. These models assume fully mixed reaches of receiving streams to estimate general impacts to ambient water quality; the models do not estimate local impacts within effluent mixing zones. This study used stream water quantity and quality data for July and August, typically the driest months in the Houston region. This study also estimates impacts at extreme (record) low flow periods for comparison. Details of the methods to determine water quality impacts and results are presented in Appendix A.

Based on these models several conclusions are drawn.

1. Effluent discharge from the 69th Street and Sims South and North wastewater treatment plant create both beneficial and adverse water quality impacts on Buffalo Bayou and the Houston Ship Channel. The benefits include reduced concentration of suspended solids and increased amounts of dissolved oxygen. The adverse impacts are increased levels of nitrate and ammonia. Reclaiming this effluent, and removing nitrogen from the brine concentrate, would greatly reduce the impacts, but also remove the benefits, of the current effluent discharges.

2. Withdrawal of wastewater effluent from either of the two bayous will have little effect on terrestrial habitats or terrestrial organisms living in areas adjacent to the bayous. The incised nature of the bayous within the project area, the lack of adjacent wetland within the area of potential impact, and the small contribution of sewage treatment to stream elevations within the receiving streams support this conclusion.

5. Cost Estimate

The total construction cost is estimated as approximately $103.4 million with an associated annual operations and maintenance cost of approximately $19.0 million. The annual average water cost is approximately $825 per acre-foot. Table 6 summarizes the probable project costs for the reclamation system.

A life cycle cost analysis was performed to illustrate the present worth cost of this strategy. The following financial factors were used in the life cycle cost analysis:

- Capital costs were assumed to be financed over 30 years at an interest rate of 8.5 percent per year.
- The discount rate was set at 4.5 percent.
- The inflation rate was set at 4.5 percent.

Table 7 shows that the total present worth cost of the wastewater reclamation strategy ranges from $0.97 per thousand gallons in the first year of operation to $0.73 per thousand gallons in the last year.

Table 7 assumes initial operation of the wastewater reclamation facility in year 2005. This period was used to equitably compare the total cost of this strategy to the other TTWP water management strategies. In fact, the reclamation strategy would not be put into operation until actually needed in year 2030. A reclamation facility constructed in year 2030 would have a significantly higher capital, and operation and maintenance cost than is shown in Table 7. Projecting unit cost values inflated to year 2030 for this strategy would show very large capital costs which would appear excessive in comparison to the other TTWP water strategies. The computed present value cost, shown in Table 7, represents the approximate present worth cost to begin operation of the reclamation facility in year 2005. The present value cost therefore can be used to compare this strategy to the other TTWP management strategies.

Table 6: Probable Costs of Wastewater Reclamation Facilities

Facility	*Size*	Cost (Thousands of Dollars) *Construction (2)*	*O & M*
Pump Stations	**(mgd)**		
69th Street	63	\$2,775	1,610
Sims South	24	\$1,500	\$351
Sims North	8	\$844	\$144
WRP	81	\$3,463	\$2,053
Subtotal		**\$8,582**	**\$4,158**
Transmission Mains	**(Dia., Inch)**		
Reclaimed	54	\$3,453	\$17
69th Street	48	\$11,650	\$58
Sims South	30	\$1,150	\$7
Sims North	18	\$160	\$1
Subtotal		**\$16,413**	**\$83**
WRP Treatment			
Filters, Flocculation & Denitrification		\$11,340	\$4,331
Membrane Treatment		\$43,683	\$10,227
Chemical Storage & Feed		\$4,776	*(1)*
Lab & Admin. Bldgs.		\$2,037	*(1)*
Land		\$545	
Maintenance Bldg.		\$1,502	*(1)*
Site Work & Yard Piping		\$4,989	*(1)*
Treated Water line		\$1,320	\$26
Storage Tanks		\$8,250	\$165
Subtotal		**\$78,442**	**\$14,749**
TOTAL		**\$103,437**	**\$18,990**

(1) Cost included in Filter and Flocculation O&M

(2) Construction costs include Engineering and Contingency of 25%

Table 7: Life Cycle Cost Analysis

YEAR	*YIELD (ac-ft / yr)*	*BOND PAYMENTS ($1,000)*	*O & M COSTS ($1,000)*	*TOTAL COST ($1,000)*	*UNIT COST ($/1,000 gal)*	*PRESENT VALUE (1995$ / 1,000 gal)*
2005	90,738	$14,947	$29,491	$44,438	$1.50	**$0.97**
2006	90,738	$14,947	$30,818	$45,765	$1.55	**$0.95**
2007	90,738	$14,947	$32,205	$47,152	$1.59	**$0.94**
2008	90,738	$14,947	$33,654	$48,601	$1.64	**$0.93**
2009	90,738	$14,947	$35,168	$50,116	$1.69	**$0.92**
2010	90,738	$14,947	$36,751	$51,698	$1.75	**$0.90**
2011	90,738	$14,947	$38,405	$53,352	$1.80	**$0.89**
2012	90,738	$14,947	$40,133	$55,080	$1.86	**$0.88**
2013	90,738	$14,947	$41,939	$56,886	$1.92	**$0.87**
2014	90,738	$14,947	$43,826	$58,773	$1.99	**$0.86**
2015	90,738	$14,947	$45,798	$60,746	$2.05	**$0.85**
2016	90,738	$14,947	$47,859	$62,807	$2.12	**$0.84**
2017	90,738	$14,947	$50,013	$64,960	$2.20	**$0.83**
2018	90,738	$14,947	$52,264	$67,211	$2.27	**$0.83**
2019	90,738	$14,947	$54,616	$69,563	$2.35	**$0.82**
2020	90,738	$14,947	$57,073	$72,020	$2.44	**$0.81**
2021	90,738	$14,947	$59,641	$74,589	$2.52	**$0.80**
2022	90,738	$14,947	$62,325	$77,272	$2.61	**$0.80**
2023	90,738	$14,947	$65,130	$80,077	$2.71	**$0.79**
2024	90,738	$14,947	$68,061	$83,008	$2.81	**$0.78**
2025	90,738	$14,947	$71,124	$86,071	$2.91	**$0.78**
2026	90,738	$14,947	$74,324	$89,271	$3.02	**$0.77**
2027	90,738	$14,947	$77,669	$92,616	$3.13	**$0.77**
2028	90,738	$14,947	$81,164	$96,111	$3.25	**$0.76**
2029	90,738	$14,947	$84,816	$99,763	$3.37	**$0.76**
2030	90,738	$14,947	$88,633	$103,580	$3.50	**$0.75**
2031	90,738	$14,947	$92,621	$107,569	$3.64	**$0.75**
2032	90,738	$14,947	$96,789	$111,737	$3.78	**$0.74**
2033	90,738	$14,947	$101,145	$116,092	$3.93	**$0.74**
2034	90,738	$14,947	$105,696	$120,644	$4.08	**$0.73**
TOTAL	***2,722,140***	***$448,414***	***$1,799,153***	***$2,247,567***		

6. Water Supply and Availability

The TTWP *Planning Information Update* determined the period of time for which existing water supplies (groundwater and surface water) within the Southeast Area can satisfy future projected water needs. This analysis as conducted for each river basin is shown in Table 12 of that report. Table 13 of that report then assessed the availability of existing Southeast Area water supplies to meet the future projected water demands for the state-wide TTWP region. These two referenced tables are shown in Appendix B. Tables 12 and 13 support the following conclusions:

- Current existing Southeast Area water supplies can meet all projected Southeast Area demands through year 2010.

- The Brazos river basin will experience the earliest water supply shortfalls within the Southeast Area by year 2020.

- The San Jacinto River basins (San Jacinto, San Jacinto-Brazos, and Trinity-San Jacinto) within the Houston Metro region will experience initial water supply shortages by year 2030 and these shortfalls will become increasingly significant thereafter.

The value of the wastewater reclamation strategy can be measured by assessing its impact on the above referenced Tables 12 and 13.

The wastewater reclamation strategy will supply approximately 90,700 afy beginning in year 2030 to the San Jacinto basin. This strategy will therefore satisfy the projected water demand needs of the San Jacinto basin for an approximately 10 year period through year 2040. Even after implementing this strategy, water supply deficits will remain in all of the coastal basins, the Brazos basin and the San Jacinto basin at the end of the planning period. Table 12 illustrates that the total shortfall in basins serving the Houston region (Trinity - San Jacinto, San Jacinto, and San Jacinto-Brazos) in year 2050 is approximately 256,000 afy. This wastewater reclamation strategy will provide 35 percent of the Houston region shortage thereby reducing, but not eliminating, the supply shortfall.

Use of this strategy will increase the total Southeast Area's projected year 2050 water supply surplus from 670,400 afy to 761,100 afy (see Appendix B.) For the entire State of Texas TTWP, under Scenario 1, the worst case scenario, after meeting all of the projected water demands, an additional 161,100 acre-feet per year would exist in year 2050 within the Southeast Area using this strategy.

7. Conclusions

This analysis evaluated delivering reclaimed water to industries at a quality which would not impact their existing treatment programs, as well as plant process equipment. Thus, the approach was to deliver reclaimed water at a quality equal to or better than current Trinity river quality through the use of filtration and reverse osmosis demineralization.

The key findings of the wastewater reclamation management strategy analysis consist of the following:

- There is not a sufficient quantity of municipal wastewater effluent to supply all of the year 2050 State Highway 225 industry demands with reclaimed water.

- A reclaimed water system can however be developed that serves a significant quantity of future industrial process and cooling water demand with a finished water quality significantly better than is currently obtained by these industries.

- A wastewater reclamation system can be located within the San Jacinto River basin, situated to supply the Highway 225 corridor industries generally west of Vince Bayou with reclaimed wastewater.

- A 81 mgd capacity facility was investigated. This facility would provide approximately 90,700 acre-feet per year of water to meet future demands of approximately 9 industries.

- The environmental impacts associated with this strategy do not appear to be significant. The additional WRP salt concentrate disposal into the Houston Ship Channel is similar to existing water quality. Localized environmental impacts from the discharge of nitrate-nitrogen may be mitigated through the removal of ammonia-nitrogen by use of breakpoint chlorination treatment facilities.

- This wastewater reclamation plan would have a total capital cost of $103.4 million. This equates to an average per unit water cost of approximately $825 per acre-foot.

8. References

(1) Houston Water Master Plan. 1986. Metcalf and Eddy

(2) Feasibility of Wastewater Reuse. 1992. Espey, Huston & Associates, Inc.

(3) Texas Administrative Code, Chapter 210 - Use of Reclaimed Water...

(4) Vickers, Amy, "The Energy Policy Act: Assessing Its Impact on Utilities", Journal AWWA. August 1993.

(5) Fax Transmittal, Texas Water Development Board. April 12, 1995. Water Resources Planning.

(6) Texas Department of Water Resources. 1989. Wasteload Evaluation for the Houston Ship Channel System in the San Jacinto River Basin.

Appendix A
Water Quality Analysis

Contents

Figures

Tables

Appendix A
Water Quality Analysis

Reclamation would reduce the discharge of treated sewage at the 69th Street, Sims North and Sims South wastewater treatment plants, while maintaining wastewater discharges by industries into the Ship Channel nearly unchanged. During low flow conditions, all treated sewage effluent would flow to the wastewater reclamation plant, which would filter suspended solids (including oxygen-demanding particulate organic matter), concentrate the dissolved materials into 15% of the flow, and discharge this reduced, concentrated effluent to Sims Bayou at the site of the Sims North discharge. During normal and high flow conditions, some of the effluent would discharge through existing outfalls to Buffalo Bayou (69th Street) and Sims Bayou (Sims North and Sims South). The potential for environmental impacts is that changes in the location, quantity and quality of effluent discharged to these bayous could result in changes in water quantity and quality and aquatic habitat of Buffalo Bayou, Sims Bayou and the Houston Ship Channel.

This appendix examines the potential impact to water quality of reducing the discharge of treated sewage effluent to Buffalo Bayou and the Houston Ship Channel for a future wastewater reclamation system. (The short reach of Sims Bayou between the Sims wastewater plants and the Houston Ship Channel is hydrologically linked with the Ship Channel and is not considered here.) Simple stream models estimate the impacts of removing effluent to water quality. These models assume fully mixed reaches of receiving streams to estimate general impacts to ambient water quality; the models do not estimate local impacts within effluent mixing zones. This analysis is intended to help determine the relative merits of wastewater reclamation compared to other water supply methods, and to assist in planning future wastewater reclamation systems.

Water quality is most affected when stream flow is at its minimum and effluent flow is at its relative maximum. This condition occurs in the summer months when stream flows are at their lowest; wastewater effluent flows vary less. This analysis uses stream water quantity and quality data for July and August, typically the driest months in the Houston region. This report also estimates impacts at extreme (record) low flow for comparison.

Conservative water pollutants, such as dissolved solids, do not degrade into other substances while in the water column. Nonconservative pollutants, such as oxygen and organic matter, degrade in the stream to other substances. Suspended solids, nitrate and metals are relatively conservative pollutants in water and are released in potentially polluting quantities by wastewater treatment plants. (Ammonia, although nonconservative, is treated here as conservative for worst-case analysis, as discussed below.) The concentrations of conservative pollutants are set at their average summer levels at each ½-mile monitoring point along Buffalo Bayou and the Ship Channel for which data exist, and kept constant downstream until affected by a new source or reset by a data point.

Oxygen is a non-conservative pollutant that is vitally important to aquatic life. While oxygen is 20% of air, it is only about 0.001%, or 10 parts per million, of water. The concentration of dissolved oxygen in streams decreases as the water temperature rises because the gas is less soluble at higher temperatures. Biological degradation of organic matter consumes oxygen, as does chemical oxidation of some substances and respiration by plants and animals. Wastewater treatment plants add both dissolved oxygen and matter subject to biological or chemical degradation (biochemical oxygen demand).

Ammonia and pathogens are non-conservative pollutants that may be significant pollutants from wastewater treatment plants. Ammonia readily dissolves in water and naturally degrades to nitrogen and nitrate in oxidized environments. In severe low flow conditions with little oxygenation of water, ammonia remains in its reduced form for extended periods. Therefore, this analysis treats ammonia as a conservative pollutant. If oxidizing conditions exist in the water, the actual ammonia levels will be lower than predicted here. Pathogens in sewage effluent, such as the cholera virus and the streptococcus bacterium, can survive the wastewater treatment process and pollute streams. Chlorine destroys these bacteria, and chlorine is added to wastewater effluent at 69th Street and Sims North and South plants. No pathogen data are available for streams in the Houston area and pathogens are not modeled here.

1. Water Quality of Buffalo Bayou

Table A-1 shows the average water quality of Buffalo Bayou and its tributaries during July and August from 1991 to 1994 as monitored by the United States Geological Survey,[1] the Texas Natural Resource Conservation Commission,[2] and the Galveston Bay National Estuary Program.[3] The volume of flowing water in Buffalo Bayou is estimated from upstream data, as described below. Missing data are indicated by blank entries.

Buffalo Bayou from Main Street to the Turning Basin is a sluggish, tidally influenced bayou with a pronounced stagnant salt wedge under a flowing fresh water layer. Downstream from the Turning Basin, the depth of Buffalo Bayou (called the Houston Ship Channel at this point) is deeper and the salt wedge more pronounced. The analysis assumes that the lighter fresh water does not mix with the denser salt wedge under normal and drought conditions (this is corroborated by salinity data) and that all effluent mixes with the fresh water layer only.

Water quality in the Buffalo Bayou above the salt wedge is poor, with low levels of dissolved oxygen, an essential substance for aquatic life. Dissolved oxygen at the Turning Basin and downstream occasionally reaches zero, potentially resulting in foul odors and fish kills. Within the salt wedge, the water is often devoid of oxygen.

Table A-1: Water Quality of Buffalo Bayou and Tributaries, Normal Summer

	Buffalo Bayou at				
Parameter	***Main St***	***Hirsh/York***	***69th St***	***Turning Basin***	***Sims Bayou***
Water Volume (cfs)	1,490	1,890	1,994	1,994	2,203
Temperature (°C)	29	29	30	30	30
Biochemical Oxygen Demand (mg/l)					
Suspended Solids (mg/l)		27.4	13.6	8.5	9.8
Dissolved Solids (mg/l)		560	1,620	2,475	5,675
Ammonia (mg/l)		0.1	0.7	0.6	0.4
Nitrate (mg/l)		1.9	5.3	2.8	1.8
Dissolved Oxygen (mg/l)	3.7	3.5	4.3	3.5	2.1
Dissolved Oxygen (% saturated)	49%	46%	59%	47%	28%

	Sims Bayou at		*Brays Bayou*	*White Oak Bayou*
Parameter	***Telephone Rd***	***Lawndale Rd***	***at Main St***	***at Heights Blvd.***
Water Volume (cfs)	177	253	134	83
Temperature (°C)	24	29	31	29
Biochemical Oxygen Demand (mg/l)	5.9	3.8	1.6	1.9
Suspended Solids (mg/l)	30.3	7.0	20.0	2.7
Dissolved Solids (mg/l)		2,900	1,000	
Ammonia (mg/l)	0.6	0.4	0.5	0.1
Nitrate (mg/l)	4.5	6.5	6.7	7.4
Dissolved Oxygen (mg/l)	3.6	6.8	16.1	13.0
Dissolved Oxygen (% saturated)	47%	94%	221%	171%

White Oak Bayou, Brays Bayou and Sims Bayou are tributaries of Buffalo Bayou. The tributaries affect water quality of Buffalo Bayou where they join it. Summer oxygen levels in most tributaries are well above saturated due to oxygen production by algae growing in the nutrient-rich waters.

2. Effluent Quality of 69th Street and Sims Bayou Treatment Plants

Table A-2 shows average effluent quantity and quality data for the three wastewater treatment plants during summer conditions.[4]

Figure A-1 shows the relative concentrations of water quality parameters of effluent and receiving streams during normal summer conditions. In this chart, the average

Table A-2: Quality of 69th Street, Sims South and Sims North Wastewater Treatment Effluent

Parameter	Wastewater Effluent 69th St	Sims South	Sims North
Water Volume (cfs)	104	42	17
Biochemical Oxygen Demand (mg/l)	2.6	2.4	2.9
Suspended Solids (mg/l)	3.1	4.5	4.3
Dissolved Solids (mg/l)	470	410	410
Ammonia (mg/l)	1.1	0.6	0.5
Nitrate (mg/l)	10.8	10.9	9.7
Dissolved Oxygen (mg/l)	6.4	6.2	5.9

stream concentration of each parameter is a band of unit height, and the wastewater concentration of that parameter is a band whose height varies as its percentage of the stream concentration. Wastewater effluent from the three treatment plants is higher in oxygen and lower in suspended solids and dissolved solids than the receiving waters, but it is higher in ammonia and nitrate.

3. Proposed Reclamation Effluent Quality

The proposed wastewater reclamation system will treat 95 million gallons per day

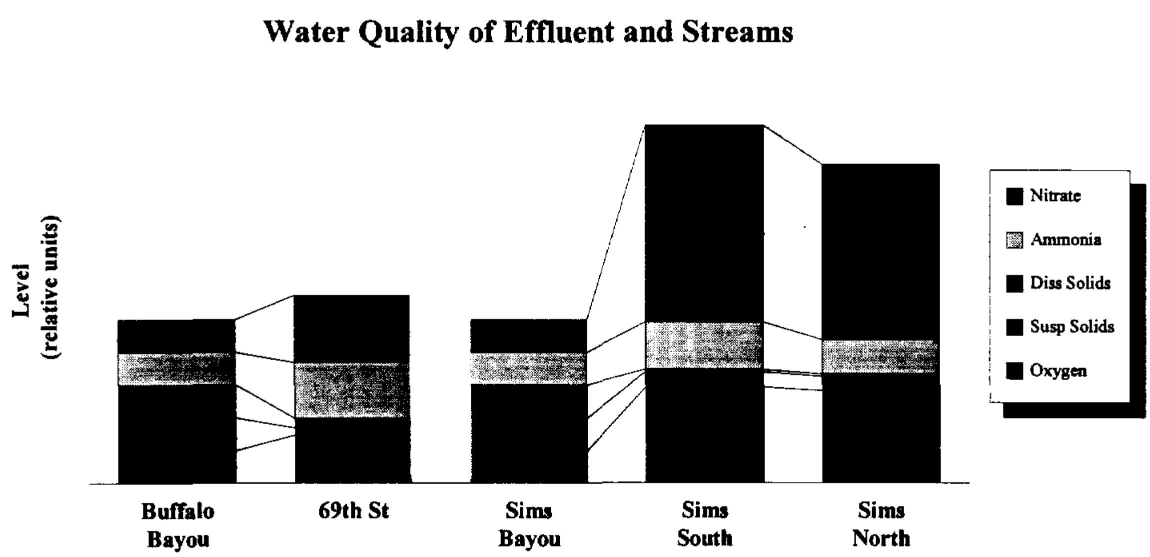


Figure A-1: Relative Water Quality of Normal Wastewater Effluent

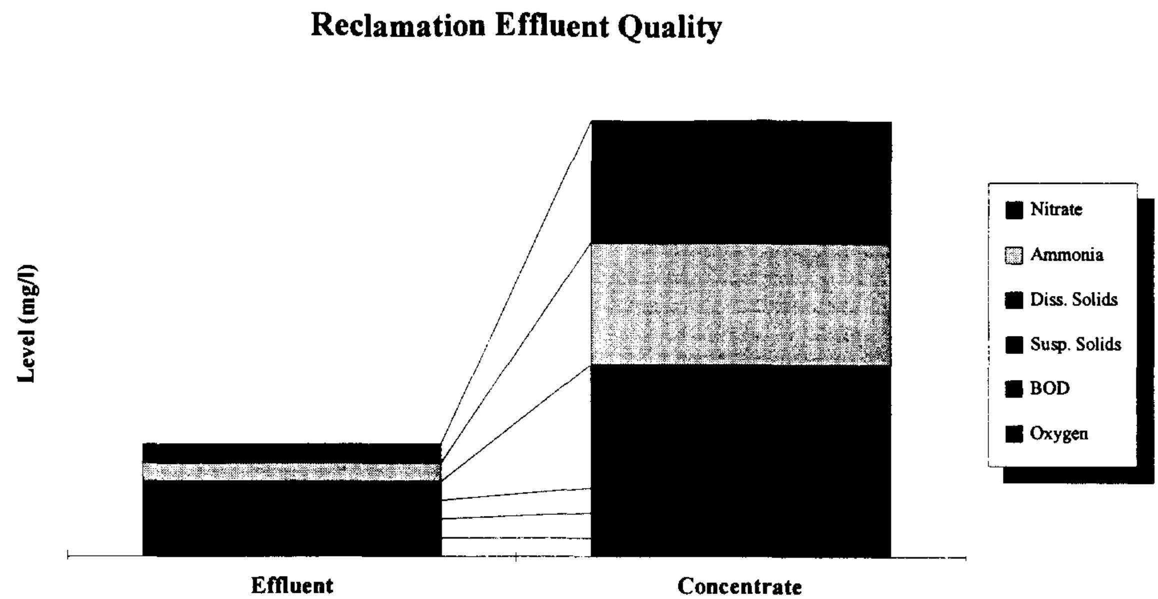


Figure A-2: Relative Water Quality of Reclamation Effluent

from the 69th Street, Sims South and Sims North wastewater treatment plants at the site of the Sims North plant by reverse osmosis. Eighty-five percent of the water will be treated to Trinity River water quality and distributed to industrial users; fifteen percent will be discharged as effluent at the Sims North effluent outfall. This fifteen percent will concentrate almost all of the dissolved substances and about 20% of the suspended solids, and biochemical oxygen demand (Figure A-2). The resulting effluent quality is high in dissolved solids, nitrate and ammonia, but relatively similar to normal wastewater effluent for suspended solids, biochemical oxygen demand and oxygen.

The resulting concentration of dissolved solids is about 2,400 mg/l, or about the same as the water above the salt wedge in Sims Bayou and the Ship Channel near the outfall during summer conditions. However, the levels of nitrate and ammonia are about twenty times that of receiving waters.

4. Water Quality Modeling

Conservative Pollutants do not degrade over time. Their concentration is predicted by the standard mass-balance model:

$$C_n = C_{n-1}\left(1 - \frac{Q_n - Q_{n-1}}{Q_n}\right) + \frac{M_n}{(Q_n - Q_{n-1})}$$

where

C_n = concentration of the pollutant at point n, in milligrams per liter

Q_n = water volume at point n, in cubic feet per second

M_n = load of the pollutant at point n

Dissolved Oxygen is a non-conservative substance that is vitally important to aquatic fauna and is often scarce in stagnant, polluted waters. We use the Streeter-Phelps model of dissolved oxygen dynamics:

$$DO_n = DO_{sat} - \left[\left(\frac{K_1 BOD_{n-1}}{K_2 - K_1} \right) \left(e^{-K_1 t} - e^{-K_2 t} \right) + DO_{n-1} e^{-K_2 t} \right]$$

where

DO_n = dissolved oxygen at point n, in milligrams per liter

DO_{sat} = dissolved oxygen saturation concentration at water's temperature and salinity

BOD = ultimate biochemical oxygen demand, in milligrams per liter

t = time for water to flow from point n-1 to point n, in days

K_1 = deoxygenation coefficient, in reciprocal days:

$$K_1 = 0.23\left(1.25^{temp-20}\right)$$

K_2 = reaeration coefficient, in reciprocal days:

$$K_2 = \frac{\sqrt{0.00191\left(1.037^{temp-20}\right)\left(86400v\right)}}{\sqrt{d}}$$

$temp$ = water temperature, in degrees Celsius

v = water velocity, in feet per second

d = water depth, in feet

The data sources provide most of these factors. We assume 30°C is the summer water temperature throughout the area. We divide Buffalo Bayou into ½ mile reaches, from Milepost 0 at the junction of the San Jacinto River to Milepost 22 at the I-45 crossing in downtown Houston.

We compute stream velocity from stream width, measured from USGS 7½' topographic maps, and stream volume, computed by summing the average summer flow of Buffalo Bayou at Shepherd Drive to the flows of its major downstream tributaries (White Oak, Brays, Sims and Greens Bayous). For normal summer conditions, we assume that minor tributaries and storm sewers add 20 cubic feet per second per mile; this number gives the best fit with the available monitoring data. Under extreme drought conditions, there is no flow from minor tributaries or storm sewers. The data sources record stream depth in the non-tidal reaches of streams; in the tidal reaches, the effective depth of the stream that mixes with wastewater effluent is above the salt water wedge; we set the effective stream depth as the depth at which salinity exceeds 150% of its surface concentration. Velocity is volume multiplied by width multiplied by depth, and the time for water to flow across a reach is distance divided by velocity. Biochemical oxygen demand data for potentially affected streams are absent from the data sources. The average BOD in area streams is fairly consistent around 2 to 5 mg/l, and we use 3.5 mg/l for initial BOD in Buffalo Bayou. We also set initial dissolved oxygen at a typical summer level of five mg/l at Milepost 22. A Microsoft Excel spreadsheet performs the calculations.

5. Results

The models simulate the impact of effluent (and effluent removal) on stream water quality. The models are based on stream water volume and velocity, which are estimated for this analysis (Figures A-3 and A-4). Normally, sewage effluent is not a significant component of bayou flow. However, in extreme drought conditions, Buffalo Bayou upstream of Shepherd Drive receives almost all of its water from sewage effluent, lawn sprinkler runoff and similar urban sources. About 25% of the volume of

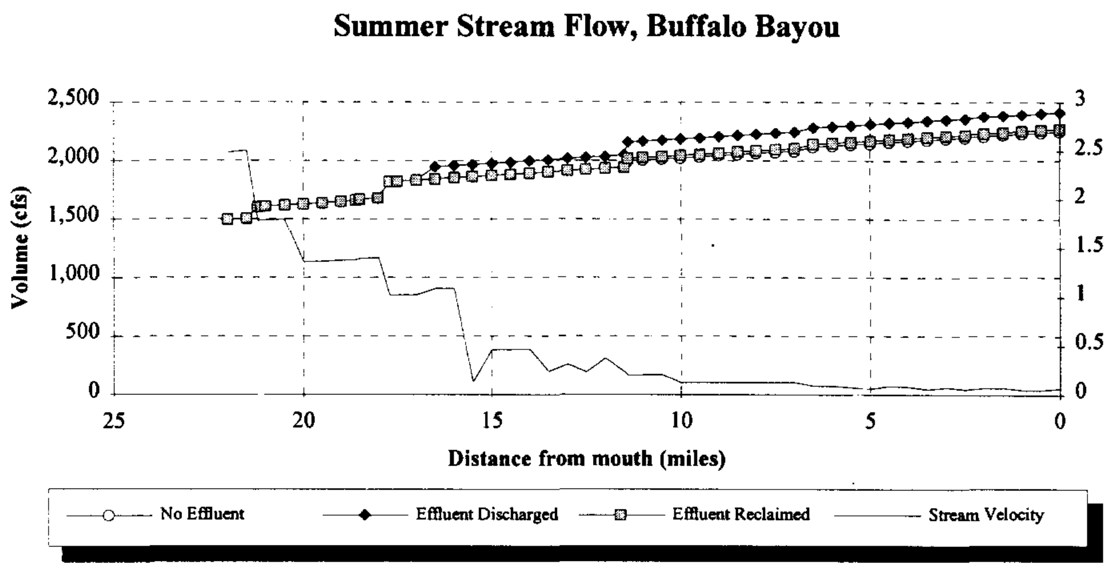


Figure A-3: Buffalo Bayou Stream Flow and Velocity, Normal Summer

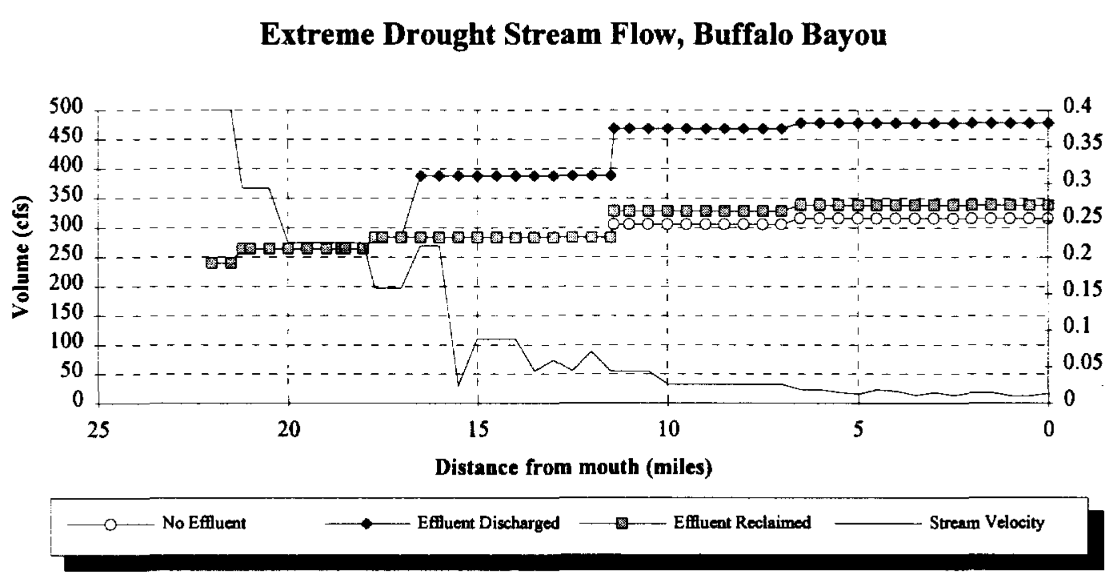


Figure A-4: Buffalo Bayou Stream Flow and Velocity, Extreme Drought

Buffalo Bayou at 69th Street is sewage effluent during extreme drought.

Effluent from the 69th Street and Sims North and South wastewater treatment plants affects several pollutants in Buffalo Bayou and the Ship Channel, especially in extreme dry weather. Figure A-5 shows the expected concentration of suspended solids in Buffalo Bayou with and without the effluent discharges, under normal summer conditions. The concentration of suspended solids in effluent is low compared to bayou water, and the effluent discharge marginally lowers the bayou's levels of suspended solids. However, under extreme drought conditions, the relative contribution of effluent to lowering the level of suspended solids in the Ship Channel is greater (Figure A-6).

The treatment plants contribute a significant amount of the nutrient nitrogen, in its nitrate form, to the Ship Channel. Figure A-7 shows that the nitrate concentration of the Ship Channel is increased almost 20% during normal summer conditions and almost 100% during extreme drought conditions due to the treatment plants. Reclaiming the water and discharging the concentrated effluent at the Sims North outfall lowers nitrate between 69th Street and Sims Bayou, then raises it beyond current condi-

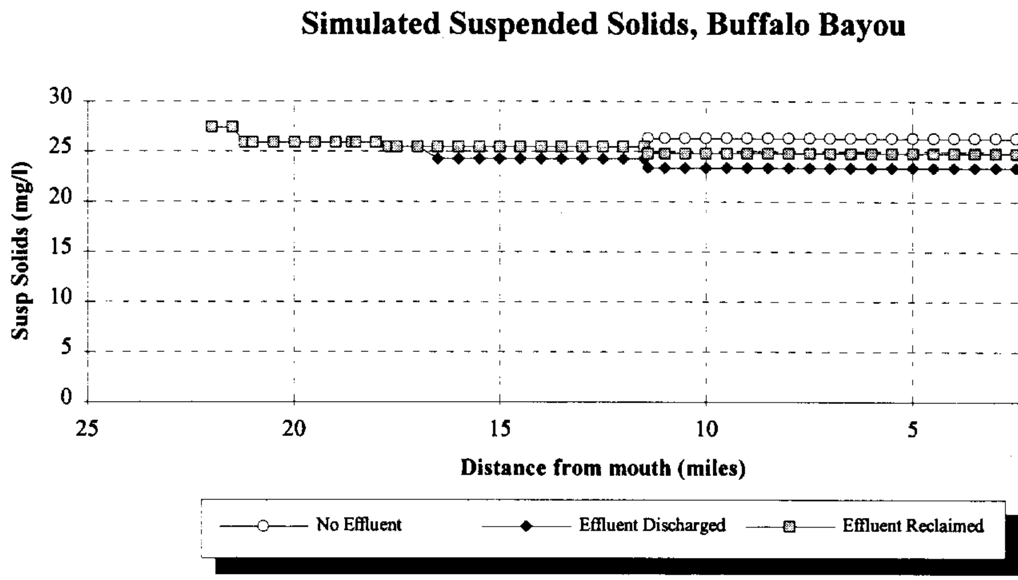


Figure A-5: Buffalo Bayou Simulated Suspended Solids Concentrations, Normal Summer

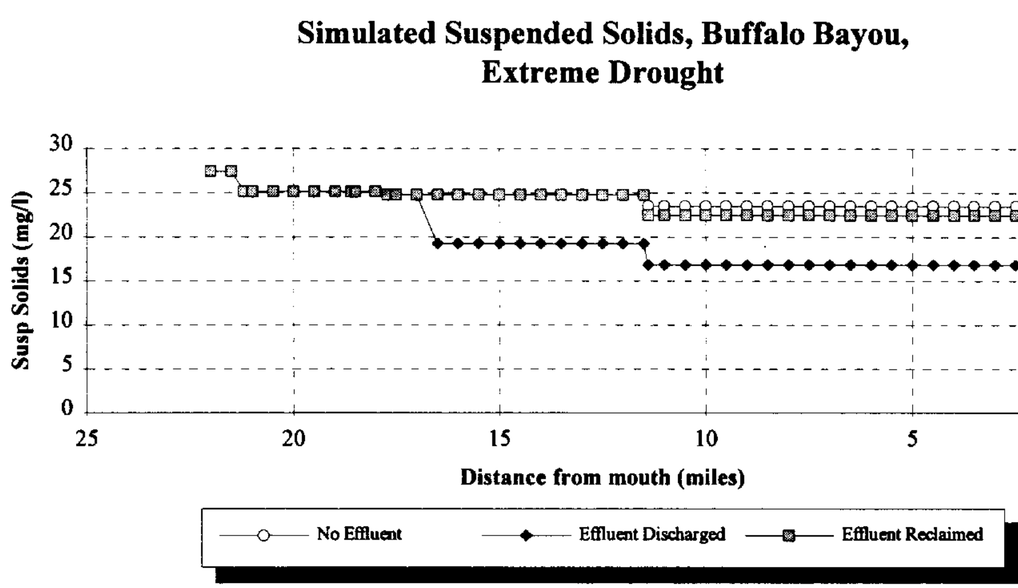


Figure A-6: Buffalo Bayou Simulated Suspended Solids Concentrations, Extreme Drought tions. The effect is heightened during extreme drought conditions (Figure A-8). The added nitrate may contribute to the growth of phytoplankton, floating algae and aquatic vascular plants in Galveston Bay and in the parts of the Ship Channel that are relatively oxygenated.

Dissolved oxygen is critical for the survival of most aquatic animals. Oxygen is typically low in the Ship Channel during the summer months due to sluggish flows and high oxygen demand from pollutants and

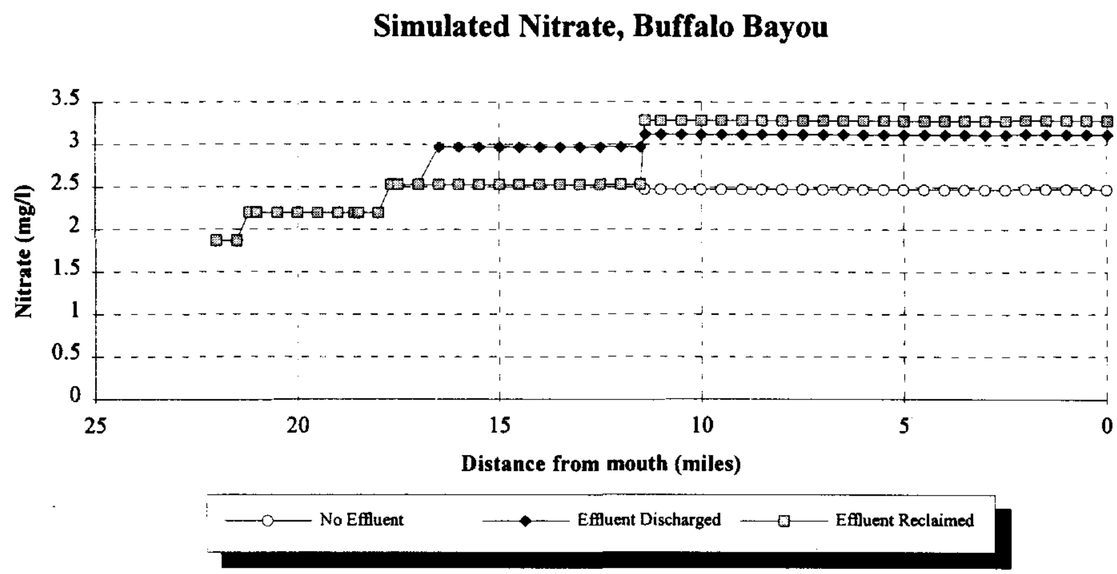


Figure A-7: Buffalo Bayou Simulated Nitrate Concentrations, Normal Summer

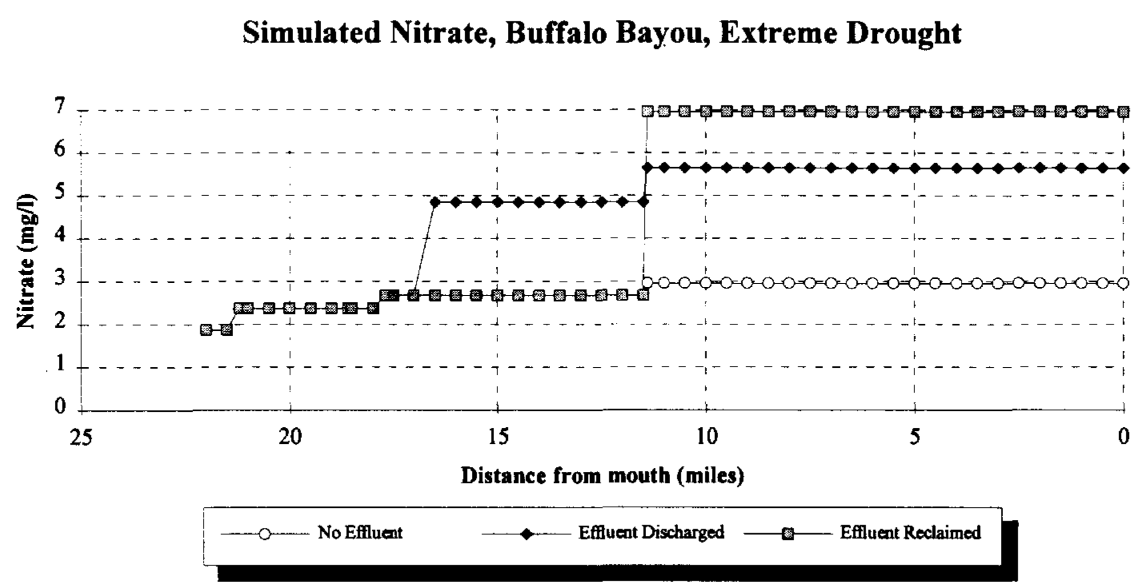


Figure A-8: Buffalo Bayou Simulated Nitrate Concentrations, Extreme Drought sediments. The model calculates that dissolved oxygen should decrease as water flows downstream along the Ship Channel due to reduced oxygenation from slower velocities and shallower gradients than upstream of downtown Houston. The 69th Street wastewater treatment plant increases oxygen in the Ship Channel because its oxygen concentration is often several times higher than in the receiving waters; however, the effect is not significant in normal summer conditions at the resolution of the model (Figure A-9).

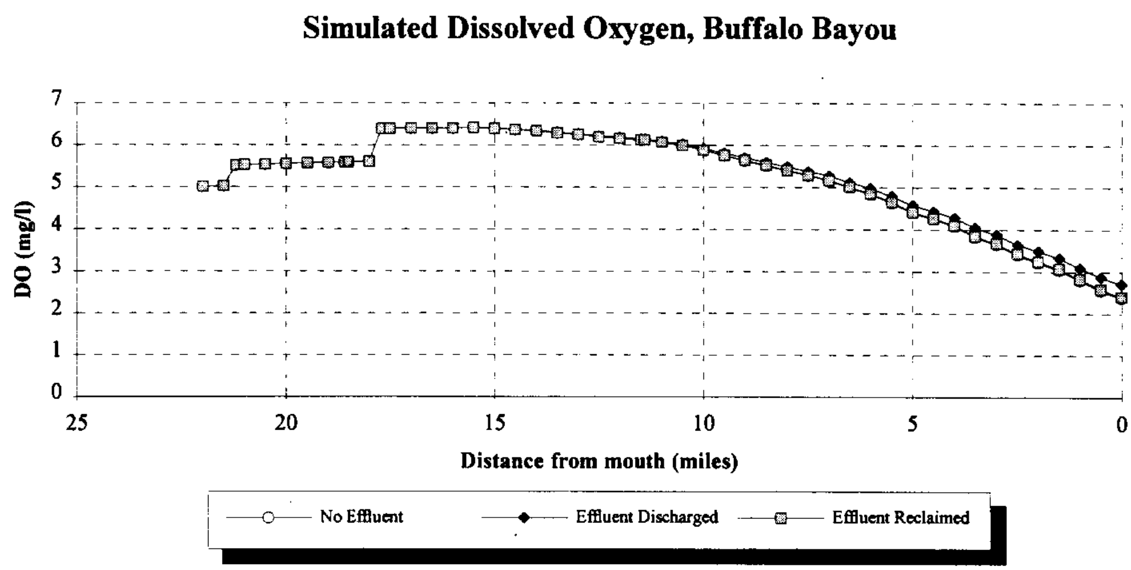


Figure A-9: Buffalo Bayou Simulated Dissolved Oxygen Concentrations, Normal Summer

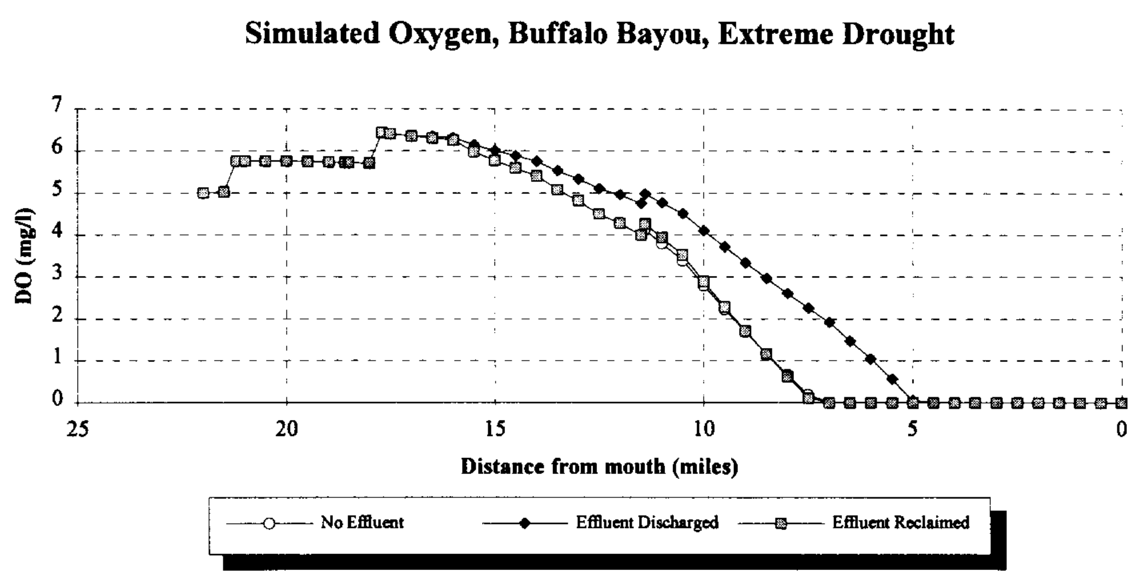


Figure A-10: Buffalo Bayou Simulated Dissolved Oxygen Concentrations, Extreme Drought

However, during extreme drought conditions, there is a significant increase in dissolved oxygen due to the discharge of normal wastewater effluent (Figure A-10). The oxygen level in Buffalo Bayou is enriched within the mixing zone (about 200 feet) of the 69th Street treatment plant's effluent discharge; the enriched water supports populations of carp, mullet and gar. The effect would vanish if wastewater is reclaimed.

The Sims South and North wastewater treatment plants do not affect the summer oxygen concentration of Sims Bayou significantly because the bayou is already supersaturated with oxygen during the summer, probably due to photosynthesis by algae.

Ammonia is modeled here as a conservative pollutant that does not degrade over time; as stated above, oxidizing conditions in the water would allow ammonia to change to the nitrate form. The model calculates that during normal summer conditions (Figure A-11) the concentration of ammonia increases significantly in the Ship Channel at 69th Street (normal effluent discharge) and at Sims Bayou (reclamation effluent discharge). During extreme drought conditions (Figure A-12), ammonia levels rise much higher. Since completely anaerobic conditions for the entire Ship Channel are rare, the actual concentration of ammonia will not be as high as the model predicts.

No data exist on pathogens in Buffalo Bayou or the Ship Channel on which to base modeling. Storm water discharges and sanitary sewer overflows are probably a larger source of pathogens than the disinfected effluent of the wastewater treatment plants.

6. Conclusions

Buffalo Bayou and the Houston Ship Channel receive both beneficial and adverse water quality impacts from the 69th Street and Sims South and North wastewater treatment plants. The effluent reduces the concentration of suspended solids and increases the amount of dissolved oxygen. The potentially adverse impacts are the increases in nitrate and ammonia. Reclaiming the effluent would shift the discharge of ammonia and nitrate downstream but not eliminate it. The elimination of the 69th Street effluent discharge would also eliminate a significant source of oxygenated, low solids content water from the Ship Channel during low flows. While the reclaimed water plant effluent would not significantly affect the concentration of dissolved solids or oxygen in the Ship Channel at the discharge point, it would add a concentrated load of ammonia and nitrate which could cause toxicity, undesirable algae blooms and nuisance conditions. Nitrogen removal, as recommended in this report, will minimize this impact.

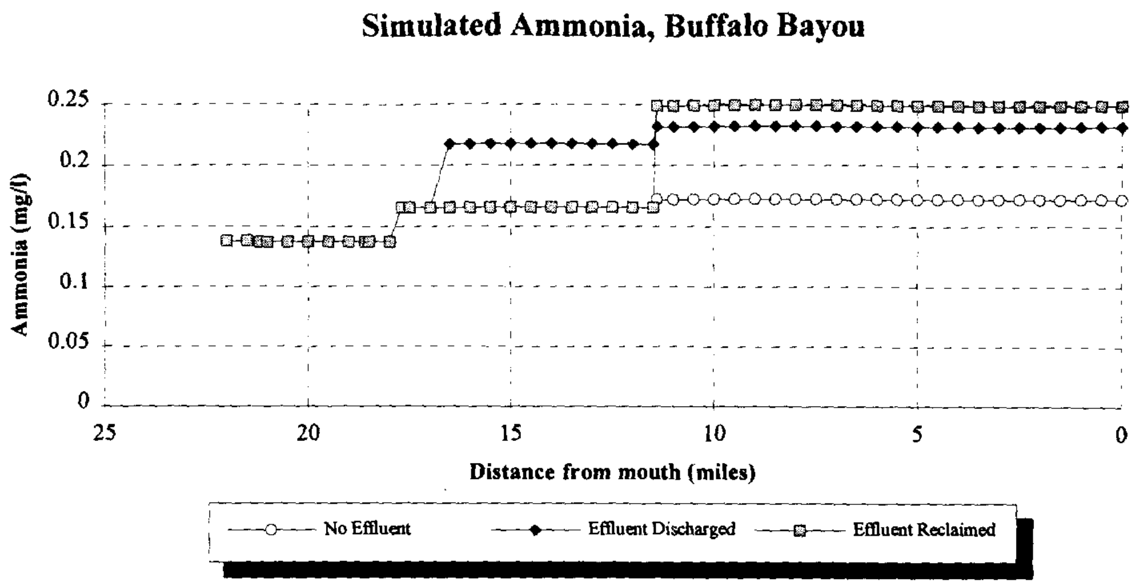


Figure A-11: Buffalo Bayou Simulated Ammonia Concentrations, Normal Summer

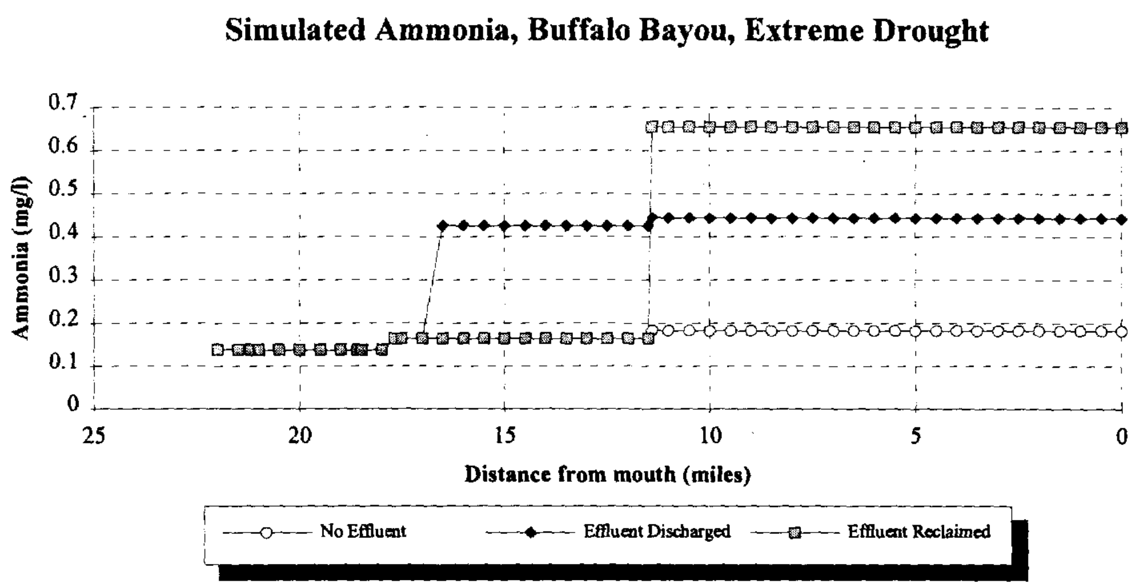


Figure A-12: Buffalo Bayou Simulated Ammonia Concentrations, Extreme Drought

Appendix B
TTWP Water Availability

Table 12: Southeast Area Water Supply Availability: 2000—2050

Category	Sabine	Neches	Neches -Trinity	Trinity	Trinity-San Jacinto	San Jacinto	San Jacinto -Brazos	Brazos	Total Southeast
	Amount (Thousands of Acre-Feet/Year)								
2000									
In-Basin Demands	86.0	261.4	329.9	138.5	143.2	949.7	464.2	427.3	2800.2
In-Basin Supplies									
Groundwater	23.3	110.5	7.5	34.3	26.6	451.7	74.9	130.5	859.3
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	488.2	4197.6
TOTAL	1213.7	957.4	7.5	1390.7	26.6	709.4	132.7	618.7	5056.7
Transfers									
Imported Supplies	0.9	1.4	322.4	0.0	116.6	300.3	331.5	0.0	1073.1
Export Demands	1.4	280.5	0.0	582.5	0.0	60.0	0.0	142.9	1073.1
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**844.3**	**207.8**	**0.0**	**669.7**	**0.0**	**0.0**	**0.0**	**42.7**	**1764.5**
2010									
In-Basin Demands	93.9	275.4	316.6	141.0	147.9	1,030.9	497.8	463.4	2966.9
In-Basin Supplies									
Groundwater	23.3	111.6	7.9	36.6	25.7	292.3	80.9	141.9	720.2
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	487.6	4196.8
TOTAL	1213.7	958.5	7.9	1393.0	25.7	550.0	138.7	629.5	4917.0
Transfers									
Imported Supplies	1.0	2.0	308.7	0.0	122.2	540.9	359.1	0.0	1333.9
Export Demands	2.0	279.5	0.0	839.2	0.0	60.0	0.0	153.2	1333.9
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**835.8**	**196.5**	**0.0**	**412.8**	**0.0**	**0.0**	**0.0**	**12.9**	**1458.1**
2020									
In-Basin Demands	102.4	287.3	304.4	144.0	152.6	1,128.7	529.7	492.7	3141.9
In-Basin Supplies									
Groundwater	23.3	112.8	8.3	38.7	31.1	251.1	87.1	156.1	708.5
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	487.1	4196.3
TOTAL	1213.7	959.7	8.3	1395.1	31.1	508.8	144.9	643.2	4904.8
Surface Water Transfers									
Imported Supplies	1.0	2.6	296.1	0.0	121.5	679.9	384.8	0.0	1485.9
Export Demands	2.6	266.9	0.0	993.4	0.0	60.0	0.0	163.0	1485.9
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**826.7**	**199.0**	**0.0**	**257.7**	**0.0**	**0.0**	**0.0**	**-12.5**	**1271.0**

Table 12: Southeast Area Water Supply Availability: 2000 2050, Continued.

Category	Amount (Thousands of Acre-Feet/Year)								
	Sabine	*Neches*	*Neches -Trinity*	*Trinity*	*Trinity-San Jacinto*	*San Jacinto*	*San Jacinto -Brazos*	*Brazos*	*Total Southeast*
2030									
In-Basin Demands	111.0	299.4	303.1	148.1	156.9	1,201.4	567.7	529.1	3316.7
In-Basin Supplies									
Groundwater	23.4	114.6	8.7	41.2	27.9	266.3	87.8	169.4	739.3
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	486.6	4195.8
TOTAL	1213.8	961.5	8.7	1397.6	27.9	524.0	145.6	656.0	4935.1
Surface Water Transfers									
Imported Supplies	1.0	4.1	294.4	0.0	129.0	726.2	422.1	0.0	1576.8
Export Demands	4.1	265.3	0.0	1072.6	0.0	60.0	0.0	174.7	1576.7
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**816.8**	**191.8**	**0.0**	**176.9**	**0.0**	**-11.2**	**0.0**	**-47.8**	**1126.5**
2040									
In-Basin Demands	123.1	321.7	306.7	159.3	167.0	1,298.3	617.9	583.2	3577.2
In-Basin Supplies									
Groundwater	23.5	116.3	8.8	43.8	29.6	280.5	88.8	181.1	772.4
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	486.0	4195.2
TOTAL	1213.9	963.2	8.8	1400.2	29.6	538.2	146.6	667.1	4967.6
Surface Water Transfers									
Imported Supplies	1.0	4.6	297.7	0.0	123.5	710.9	460.8	0.0	1598.7
Export Demands	4.6	268.7	0.0	1075.3	0.0	60.0	0.0	190.1	1598.7
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**804.3**	**168.3**	**0.0**	**165.6**	**-13.9**	**-109.2**	**-10.5**	**-106.2**	**898.4**
2050									
In-Basin Demands	135.8	344.8	310.6	174.5	179.9	1,386.4	668.4	639.2	3839.6
In-Basin Supplies									
Groundwater	23.6	118.3	9.0	46.7	31.0	291.8	89.7	197.3	807.4
Surface Water	1190.4	846.9	0.0	1356.4	0.0	257.7	57.8	485.4	4194.6
TOTAL	1214.0	965.2	9.0	1403.1	31.0	549.5	147.5	682.7	5002.0
Transfers									
Imported Supplies	1.1	5.1	301.6	0.0	123.5	710.9	476.3	0.0	1618.5
Export Demands	5.3	272.2	0.0	1075.4	0.0	60.0	0.0	205.6	1618.5
In-Basin Reserves	282.9	209.1	0.0	0.0	0.0	0.0	0.0	0.0	492.0
Net Surface Water Availability	**791.0**	**144.2**	**0.0**	**153.2**	**-25.4**	**-186.0**	**-44.6**	**-162.1**	**670.4**

Table 13: Trans-Texas Water Program Supply Availability: 2000-2050

Category	**Amount (Thousands of Acre-Feet/Year)** *2000*	*2010*	*2020*	*2030*	*2040*	*2050*
Scenario 1						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	-	-	150	300	450	600
Net Surface Water Availability	**1764.5**	**1458.1**	**1121**	**826.5**	**448.4**	**70.4**
Scenario 2						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	-	-	-	100	200	300
Net Surface Water Availability	**1764.5**	**1458.1**	**1271**	**1026.5**	**698.4**	**370.4**
Scenario 3						
Available Southeast Supply	1764.5	1458.1	1271	1126.5	898.4	670.4
West-Central Demand	0	0	0	0	0	0
Net Surface Water Availability	**1764.5**	**1458.1**	**1271**	**1126.5**	**898.4**	**670.4**

References

[1]U.S. Geological Survey, *Water Resources Data for Texas,* Water Years 1989–1993.

[2]Texas Natural Resource Conservation Commission, *Texas Natural Resource Information System,* Houston Ship Channel, Buffalo Bayou and tributaries, January 1990–December 1994.

[3]Galveston Bay National Estuary Program, *Water Quality Segment Summaries, Texas Surface Water Quality Standards,* Houston-Galveston Area Council and GBNEP, May 1993.

[4]City of Houston, Department of Public Works and Engineering, Monthly Summaries of Effluent Quantity and Quality, 1991–1994.

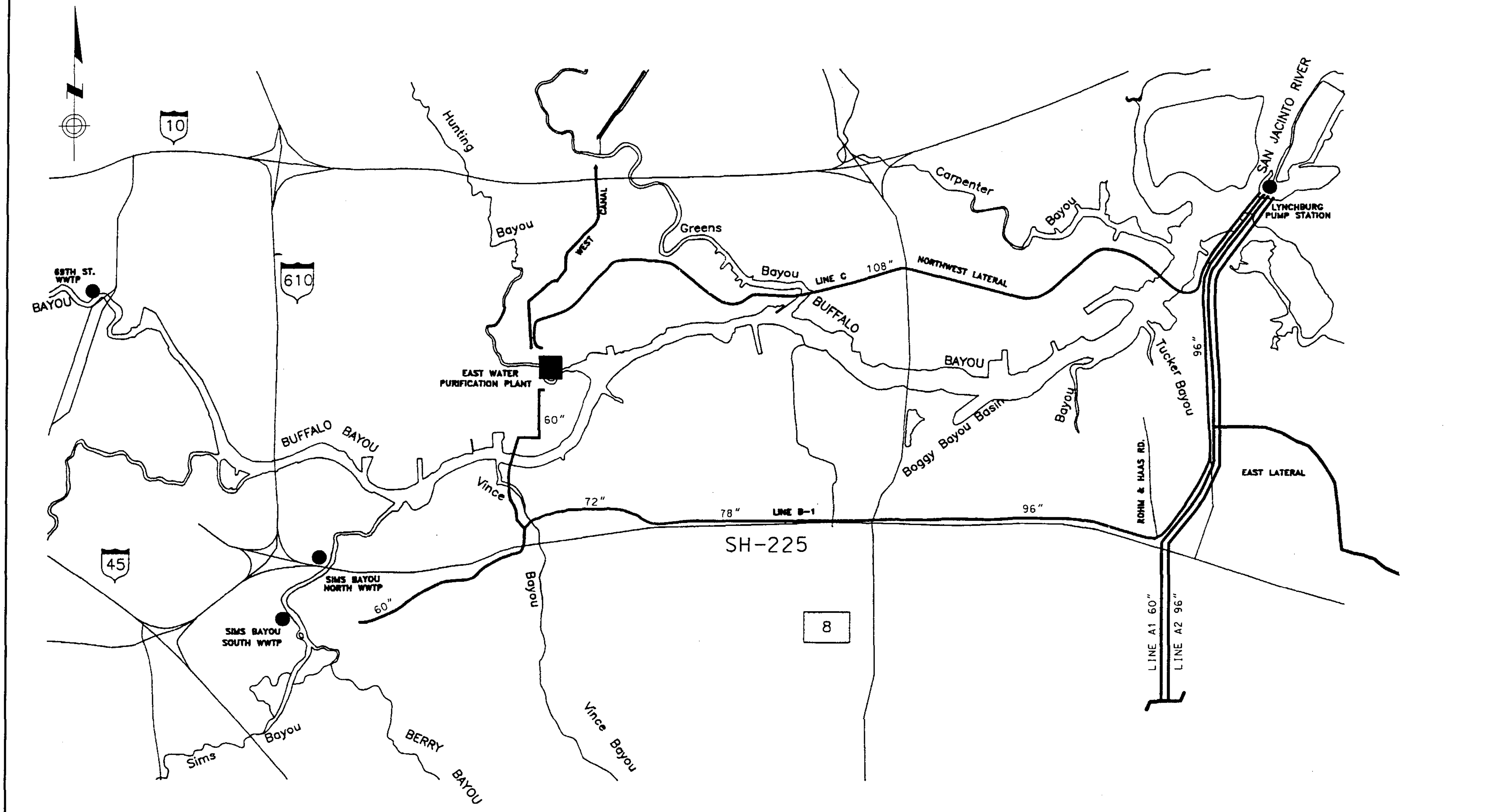
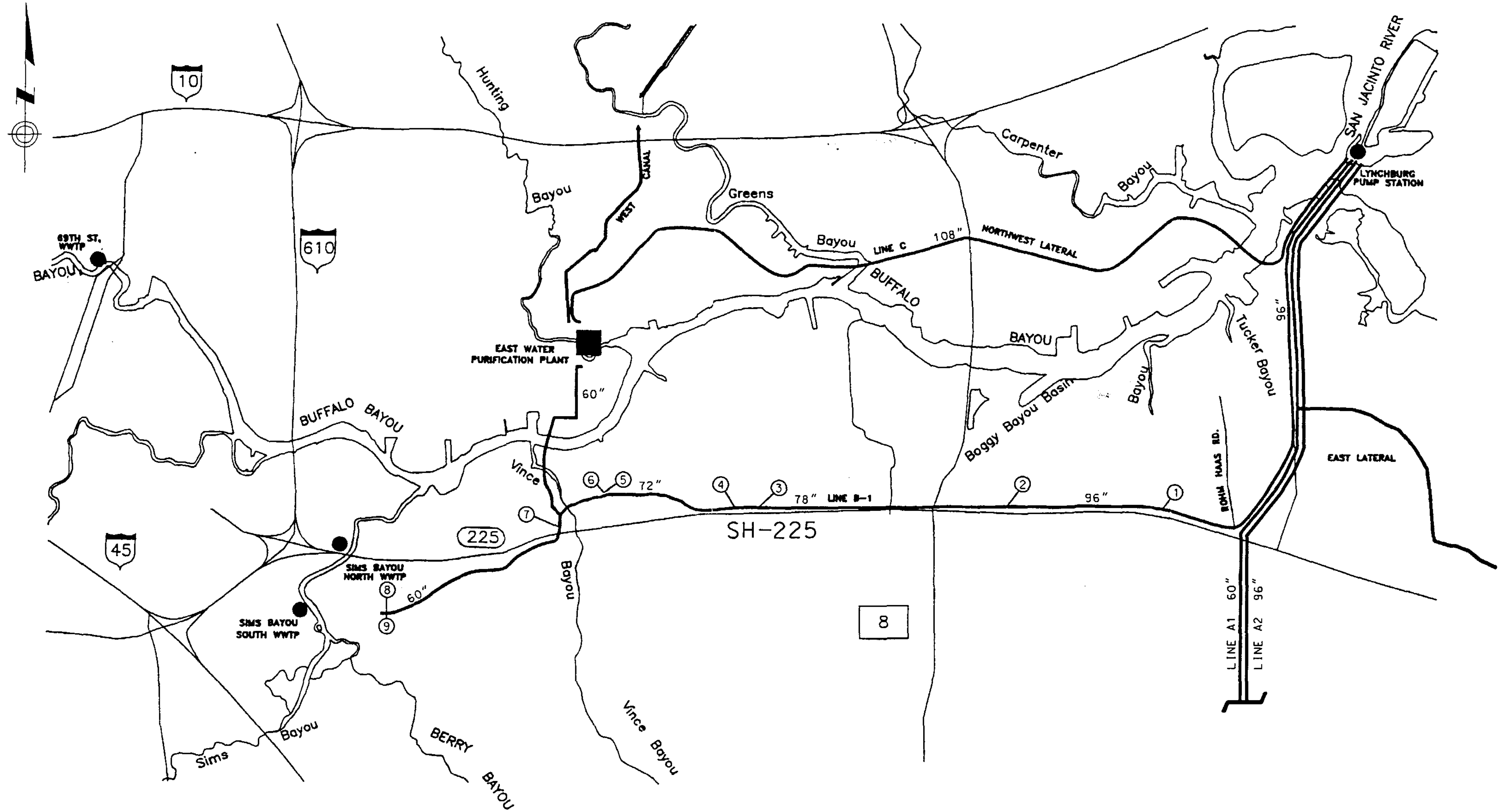


FIGURE 1

TRANS-TEXAS WATER PROGRAM
EXISTING CWA RAW WATER SYSTEM

BAR_HO_GS1 JR1492/RECLAIM/FIG1.DGN-01



LEGEND

1) LUBRIZOL CORP.
PRAXAIR, INC.

2) ABELMARLE CORP.
GEORGIA GULF CORP.
OCCIDENTAL CHEMICAL CORP.
SHELL OIL CO.

3) SHELL OIL CO.
HICKSON KERLEY, INC.
PHILLIPS PETROLEUM

4) MOBIL MINING & MINERALS

5) CROWN CENTRAL PETROLEUM

6) SIMPSON PASADENA PAPER

7) APPLIED ENERGY SERVICES
LYONDELL PETROCHEMICAL CO.

8) MOBIL CHEMICAL
PHIBRO

9) MILES, INC.
GOODYEAR TIRE & RUBBER
TEXAS PETROCHEMICAL CO.

FIGURE 2

TRANS-TEXAS WATER PROGRAM
POTENTIAL INDUSTRIAL FACILITIES

BAR_HO_GS1 JR1492/RECLAIM/FIG2.DGN-01

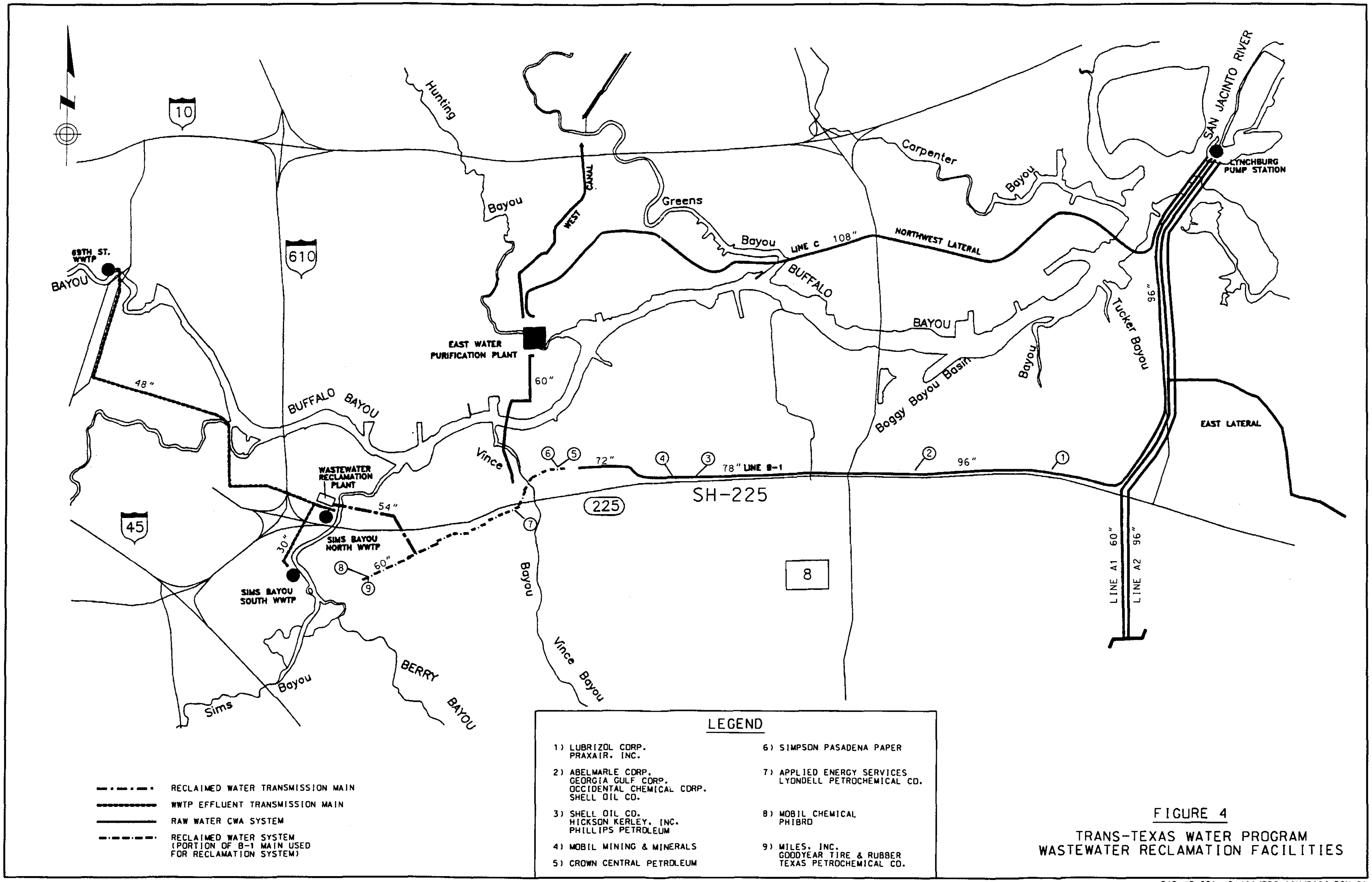


FIGURE 4
TRANS-TEXAS WATER PROGRAM
WASTEWATER RECLAMATION FACILITIES

BAR_HO_GS1 JR1492/RECLAIM/FIG4.DGN-01