FINAL REPORT

POTENTIAL AQUATIC ECOLOGICAL IMPACTS OF INTERBASIN WATER TRANSFERS IN THE SOUTHEAST, WEST-CENTRAL, AND SOUTH-CENTRAL STUDY AREAS

Prepared for:

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And the

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LIST OF ACRONYMS AND ABBREVIATIONS

ac	=	acres
ac-ft	=	acre-feet
ac-ft/yr	=	acre-feet per year
A.D.	=	anno Domini (in the year of the Lord)
AGFD	=	Arizona Game and Fish Department
APC	=	Aquatic Plant Control
AWWA	=	American Water Works Association
B.C.	=	before Christ
BOD	=	Biological Oxygen Demand
Bot	=	Bottom
C1	=	Candidate Category 1
C2	=	Candidate Category 2
C3	=	Candidate Category 3
ca.	=	circa
Ca	=	Calcium
$CaCO_3$	=	Calcium Carbonate
CAP	=	Central Arizona Project
cells/ℓ	=	cells per liter
cells/mℓ	=	cells per milliliters
cfs	=	cubic feet per second
cm	=	centimeter
CO.	=	County
Col	=	Colorado
colonies/100 mℓ	=	colonies per 100 milliliters
CR	=	Creek
CWA	=	Clean Water Act/Coastal Water Authority
°C	=	degrees Celsius
D/DBPR	=	Disinfectants/Disinfection Byproducts Rule
DDD	=	Dichlorodiphenyldichloroethane
DDE	=	Dichlorodiphenylethylene
DDT	=	Dichlorodiphenyltrichloroethane
DO	=	Dissolved Oxygen
DOC	=	Dissolved Organic Carbon
E	=	Exotic/Endemic/Endangered
e.g.	=	exempli gratia (for example)
Ep	=	historically present but apparently extirpated
ERM	=	Enteric Redmouth
ESA	=	Endangered Species Act
ESE	=	Environment Science and Engineering
ESWTR	=	Enhanced Surface Water Treatment Rule
et al.	=	et alii (and others)
etc.	=	et cetera (and so forth)
et seq.	=	et sequens (and the following)
f.	=	form
FAO	=	Food and Agriculture Organization
FM	=	Farm Market

LIST OF ACRONYMS AND ABBREVIATIONS (Continued)

FR	=	Federal Register
ft	=	feet/foot
ft/sec	=	feet per second
g/m^2	=	grams per square meter
gal	=	gallon
GDU	=	Garrison Diversion Unit
GPO	=	Government Printing Office
GRAND	=	Grand Replenishment and Northern Development
I	=	Introduced
ICR	=	Information Collection Rule
i.e.	=	id est (that is)
IHNV	=	Infectious Hematopoietic Necrosis Virus
in	=	inch
ind/m^3	=	individuals per cubic meter
km^2	=	square kilometers
Lav-Nav	=	Lavaca-Navidad
LCRA	=	Lower Colorado River Authority
LO	=	Lowland
LNVA	=	Lower Neches Valley Authority
m	=	meter
m^3	=	cubic meters
MCL	=	Maximum Contaminant Level
MG	=	million gallons
MGD	=	million gallons per day
mg/kg	=	milligrams per kilogram
mg/l	=	milligrams per liter
mg/m^3	=	milligrams per cubic meter
mi	=	miles
mi^2	=	square mile
Mid	=	Middle
mm	=	millimeters
MRDL	=	Maximum Residual Disinfectant Level
msl	=	mean sea level
N	=	Native
NA	=	Not Applicable
NANPCA	=	Nonindigenous Aquatic Nuisance Prevention and Control Act
NAV	=	Not Available
NAWAPA	=	North American Water and Power Alliance
n.d.	=	no date
NH_3-N	=	Ammonia Nitrogen
NI	=	Native Introduced
no.	=	number
NMDFG	=	New Mexico Department of Fish and Game
NMFS	=	National Marine Fisheries Service
NS	=	Not Sampled

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

NTIS	=	National Technical Information Service
NTU	=	Nephelometric Turbidity Units
Nuec	=	Nueces
OCLC	=	Online Computer Library Center
OLS	=	Online Library System
oocysts/ℓ	=	oocysts per liter
OTA	=	Office of Technology and Assessment
P	=	Photosynthesis
PAR	=	Photosynthetically Active Radiation
PCB(s)	=	Polychlorinated Biphenyl(s)
PCP	=	Pentachlorophenol
pH	=	hydrogen-ion
P.L.	=	Public Law
POC	=	Particulate Organic Carbon
ppt	=	parts per thousand
R	=	Respiration
R.	=	River
RI	=	River
R.M.	=	River Mile
RSS	=	Reservoir and Stream
S	=	State
SARA	=	San Antonio River Authority
SB	=	Senate Bill
SC	=	Special Concern
SDWA	=	Safe Drinking Water Act
Sfc	=	Surface
SH	=	State Highway
sp.	=	species (singular)
spp.	=	species (plural)
SRA	=	Sabine River Authority
ST	=	Stream/State Threatened
SWQM	=	Surface Water Quality Monitoring
SWTR	=	Surface Water Treatment Rule
T	=	Threatened
TAC	=	Texas Administrative Code
TBD	=	To Be Determined
TDS	=	Total Dissolved Solids
TNRCC	=	Texas Natural Resource Conservation Commission
TOES	=	Texas Organization for Endangered Species
TO	=	TOES
TPW	=	Texas Parks and Wildlife
TPWD	=	Texas Parks and Wildlife Department
TSI	=	Trophic State Index
TSS	=	Total Suspended Solids
TSWQS	=	Texas Surface Water Quality Standards

LIST OF ACRONYMS AND ABBREVIATIONS
(Continued)

TTHM	=	Total Tirhalemethanes
TTWP	=	Trans-Texas Water Program
TWC	=	Texas Water Commission
TWDB	=	Texas Water Development Board
TWL	=	TOES Watch List
U	=	Unknown
μg/kg	=	micrograms per kilogram
μg/l	=	micrograms per liter
μmhos	=	micromhos
μmhos/cm	=	micromhos per centimeter
UP	=	Upland
μS/cm	=	microsiemens per centimeter
USACE	=	U.S. Army Corps of Engineers
U.S.	=	United States
U.S.C.	=	U.S. Code
USEPA	=	U.S. Environmental Protection Agency
USFWS	=	U.S. Fish and Wildlife Service
USGS	=	U.S. Geological Survey
UV	=	Ultra Violet
UTD	=	University of Texas at Dallas
var.	=	variety
WL	=	Watch List
X	=	Extinct/Exotic
yr	=	year
Zm	=	mixed layer
Zp	=	photic layer

SUMMARY OF WORK PERFORMED

Four major tasks were completed by Geo-Marine, Inc. under this contract with the U.S. Army Corps of Engineers, Fort Worth District and the Texas Water Development Board. These tasks were: (1) a literature review on aquatic ecological effects from the introduction of aquatic organisms; (2) a qualitative analysis of potential aquatic ecological impacts of a proposed West-Central to South-Central Texas interbasin water transfer; (3) a general qualitative analysis of potential aquatic ecological impacts from proposed interbasin water transfers in Southeast, West-Central, and South-Central Texas; and (4) a review of potential economic/environmental costs associated with past and present impacts from introduced aquatic organisms.

INTRODUCTION

Interbasin water transfers are one method currently being evaluated by the Texas Water Development Board under the State Water Plan/Trans-Texas Water Program to meet projected late 20th- to mid 21st-century domestic and municipal water supply deficits/needs in the San Antonio, Corpus Christi, Austin, and Houston metropolitan areas. Ecological assessments of interbasin water transfers are needed since historic and current evidence from worldwide environmental studies suggests that interbasin water transfers may result in significant changes in ecosystems as a result of alterations in flow (Stanford and Ward 1979; O'Keeffe and de Moor 1988; Petitjean and Davies 1988); changes in water quality (Thomas and Box 1969; Roy and Messier 1989, Schorr 1995), habitat alterations (Mooney and Drake 1986; Moyle et al. 1987; Meador and Matthews 1992); and the introduction of nonindigenous aquatic organisms (Guiver 1976; Laurenson and Hocutt 1986; Laurenson et al. 1989; Ross 1991; Scoppettone 1993). In addition, interbasin water transfers could directly or indirectly result in violation of federal/state legislation. Federal laws which may be applicable to interbasin water transfers include the Fish and Wildlife Act, Public Law 89-298, Endangered Species Act, Clean Water Act, Executive Order 11987 (Exotic Organisms), Executive Order 11990 (Protection of Wetlands), Safe Drinking Water Act, Lacey Act, Federal Noxious Weed Act, and the Nonindigenous Aquatic Nuisance Prevention and Control Act. Texas legislation includes the Texas Administrative Code, Texas Parks and Wildlife Code, Texas Water Code, Texas Health and Safety Code, Texas Water Commission Watershed Protection Rule, and the Texas Clean Rivers Act. Based on these environmental concerns, an analysis of the potential aquatic ecological impacts which could result from the proposed interbasin water transfers in Southeast, West-Central, and South-Central Texas was conducted.

EXECUTIVE SUMMARY

LITERATURE SYNTHESIS

The literature review documents the magnitude and seriousness of potential problems which can arise from the transfer and/or introduction of aquatic organisms by identifying and characterizing past problems associated with water transfers. Representative examples of native/exotic species which caused direct/indirect problems as a result of introduction through a variety of transfer mechanisms are discussed in this section of the report. The literature review synthesizes information on introduced species; date/location of the introduction and geographical extent of the problem; transport mechanisms; native species which were affected or extirpated; the suspected or known mechanisms by which the nonindigenous species caused harm, reduction, or elimination of endemic species; as well as success of any mitigation techniques.

WEST CENTRAL TO SOUTH-CENTRAL INTERBASIN WATER TRANSFER

Colorado River to Sandy Creek

Moderate potential impacts could occur to threatened, candidate, and sensitive benthic and fish species if they are present at the site or in the vicinity of the proposed low head dam/new channel reservoir. Potential impacts to these aquatic components of the Colorado River would be significantly less if the species are not present. Direct and indirect impacts could potentially occur to several aquatic communities in Sandy Creek due habitat alterations associated with the increase in current flow in Sandy Creek and the potential transfer of several adaptive native fish species from the Colorado River (Table 1). In addition, federal/state and Texas Organization of Endangered Species (TOES) threatened, candidate, and "watch list" species occur in the Colorado River and could be affected by the proposed interbasin water transfer (Table 2). One exotic species could be transferred, become established, and affect the aquatic ecosystem of recipient waters (see Table 2). Several components of the aquatic environment could not be assessed due to the lack of current data on composition and abundance. An environmental assessment is needed to accurately assess the potential impacts on the aquatic environment in the Colorado River and Sandy Creek. The potential environmental impacts of the proposed Colorado River to Sandy Creek interbasin water transfer are summarized in Table 3.

Table 1

List of Fish Species with the Potential to be Introduced by the Proposed Interbasin Water Transfer from the Colorado River to the Lavaca-Navidad River Basin

Taxa	Colorado	Lavaca-Navidad*	Transfer
BOWFINS			
Bowfin	N		No
HERRINGS			
Skipjack herring	N		No
Gizzard shad	N[0]	N[1]	Yes[2]
CARPS/MINNOWS			
Grass carp		I[+1]	No
Ribbon shiner	N		No
Silverband shiner	N		No
Suckermouth minnow	N[0]		Yes[2]
SUCKERS			
Blue sucker	N[0]	N	Yes[3]
SUNFISHES			
Guadalupe bass	N[0]	N	Yes[3]
PERCHES			
Logperch	N[0]		Yes[4]
CICHLIDS			
Rio Grande cichlid	I	I	NA[5]
Blue tilapia	I	I	NA[5]

[+] Triploid
*Includes species in Sandy Creek and Lake Texana
[0] Fishes collected in the Egypt Study reach (intake area) of the Colorado River
[1] Lake Texana
[2] Low to moderate potential for establishment
[3] Unlikely to become established; maybe affected by construction/transfer
[4] Moderate to high potential for establishment
[5] Occurs only below proposed intake area

Legend: N = Native
I = Introduced
NA = Not Applicable

Source: USDI 1974; Conner and Suttkus 1986; Hubbs et al. 1991; Robbins et al. 1991; Morales 1991; Bayer et al. 1992; Mosier and Ray 1992; Patek 1994; Chilton 1995; Jons 1995

Table 2

List of Aquatic Federal/State/TOES Threatened, Candidate, and Watch List and Exotic Species Potentially Occurring in the Colorado/Lavaca-Navidad River Basins

Common/Scientific Name	Colorado	Lavaca-Navidad Sandy Creek	 Lake Texana
REPTILES			
American alligator *Alligator mississippiensis*	TWL		
FISH			
Blue sucker[1] *Cycleptus elongatus*	C2,ST,TWL		
Guadalupe bass[1] *Micropterus treculi*	C2,TWL		
EXOTIC SHELLFISH			
Asiatic clam[1] *Corbicula fluminea*	X		
EXOTIC FISH			
Blue tilapia *Tilapia aurea*	X		
Rio Grande cichlid *Cichlasoma cyanoguttatum*	X		

[1]Known to occur in the reach where the intake site is proposed to be constructed

Legend: C2 = Candidate Category 2
TWL = TOES Watch List
ST = State Threatened
X = Exotic

Source: McMahon 1983; Hubbs et al. 1991; TOES 1995; TPWD 1995a, 1995b; USFWS 1995b, 1995c

Table 3

Qualitative Rank of Potential Environmental Impacts
Colorado River to Sandy Creek

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	No significant increase in density	Low
Other Microbes	Unknown	No presence/absence or density data	High
Phytoplankton	Low	Continuous pumping and increase in flow would disperse potential algal blooms	Low
Periphyton	Low/Moderate	Little difference in species composition between Colorado River and Sandy Creek; in the long-term, potentially could cause abrasion and corrosion problems in pumps and/or pipeline	Moderate
Aquatic Plants	No Effect	Noxious species not present in the Colorado River; habitat in Sandy Creek not suitable for Colorado River macrophytes	Low
Zooplankton	Unknown	Composition/density data not available	Not Applicable
Benthic Invertebrate			
Mollusks	Moderate	Potential impacts on native mollusks; potential clogging/fouling problems from Asiatic clam	Moderate
Others	Unknown	Potential habitat alteration and subsequent change in benthic community of Sandy Creek due to an increase in flow (intermittent to permanent)	Not Applicable
Amphibians/Reptiles	Low	Potential local construction effects on Colorado River, increase in flow and change of status from intermittent to permanent in Sandy Creek; low chance of surviving transfer	Moderate
Fish	Moderate	Potential presence of federal C2/state-listed threatened/TOES fish species in Colorado River; potential introduction and/or establishment of non-native fish species and fish pathogens; potential alterations in the Sandy Creek fish community due to an increase in current flow	Moderate

Sandy Creek to Lake Texana

Two components of the aquatic environment could potentially be affected by the interbasin transfer of water from the Colorado River/Sandy Creek to Lake Texana. Low to moderate potential impacts could occur to benthic communities in Lake Texana from the potential introduction of the Asiatic clam (see Table 2). Moderate long-term impacts could occur to the fish community if adaptive fish species present in the Colorado River basin are transferred to Sandy Creek and subsequently become established in Sandy Creek and Lake Texana (see Table 1). Other components of the aquatic environment would experience unknown or no significant effects from the proposed interbasin water transfer. Potential environmental impacts of the Colorado River/Sandy Creek to Lake Texana interbasin water transfer are summarized in Table 4.

Lake Texana to the O.N. Stevens Terminal Water Storage Reservoir

Four components of the aquatic environment could potentially be affected by and/or could subsequently impact Lake Texana, the conduit system and/or operations at O.N. Stevens Water Treatment Plant due to the proposed interbasin transfer of water from Lake Texana to the terminal storage water reservoir. Low to moderate impacts would potentially occur from the transfer of microbes, phytoplankton, aquatic plants, and fish. The transfer of microbes could introduce a protozoan parasite (*Cryptosporidium parvum*) into water which would be used for human consumption. Taste/odor problems could result from the water transfer during blue-green algal blooms. Two noxious plants present in Lake Texana could become established in the terminal water storage reservoir and result in clogging problems (see Table 2). Pelagic fish populations could be impinged and/or entrained, potentially reducing survival, recruitment and the size of the populations. In addition, the death of entrained aquatic organisms would potentially increase Biological Oxygen Demand levels at the treatment plant. The impacts on the other aquatic components are either unknown, have no effect or have low potential impacts. The potential impacts of the proposed Lake Texana to O.N. Stevens Terminal Water Storage Reservoir are summarized in Table 5.

SOUTHEAST STUDY AREA

Potential impacts to and from aquatic communities for the proposed interbasin water transfers are difficult to assess due to the lack of recent aquatic biological data on rivers and some of the reservoirs in the

Table 4

Qualitative Rank of Potential Environmental Impacts
Sandy Creek to Lake Texana

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	No significant increase in density	Low
Other Microbes	Unknown	No presence/absence data	High
Phytoplankton	Low	Potential for bloom after flood; slight increase in BOD due to bloom die-off after transfer from new channel reservoir on the Colorado River	Moderate
Periphyton	No Effect	Periphyton has low potential for transfer and/or survival if successfully transferred due to differences in habitat between Sandy Creek and Lake Texana	Low
Aquatic Plants	No Effect	Noxious aquatic plants not present in Colorado River/Sandy Creek	Low
Zooplankton	No Effect	Potential for survival is low due to differences in habitat between the Colorado River/Sandy Creek and Lake Texana	Low
Benthic Invertebrates			
Mollusks	Low	Potential introduciton of the Asiatic clam	Moderate
Other	Moderate	No site-specific data	High
Amphibians/Reptiles	No Effect	No transfer, survival, or establishment expected	Low
Fish	Moderate	Potential establishment of two fish species; unknown effects from fish pathogens	Moderate

Table 5

Qualitative Rank of Potential Environmental Impacts
Lake Texana to O.N. Stevens Terminal Water Storage Reservoir

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	Coliform densities below criteria level in Lake Texana	Low
Other Microbes	Low-Moderate	Potential presence of a protozoan parasite, *Cryptosporidium parvum*	High
Phytoplankton	Low-Moderate	Potential taste/odor problems from algal blooms; potential long-term structural damage to pumps/pipeline	Moderate
Periphyton	Unknown	Absense of site-specific data	Not Applicable
Aquatic Plants	Moderate	Potential establishment of two state-listed noxious plant species (water hyacinth and hydrilla) at the terminal water storage reservoir; potential clogging of water intake at the treatment plant	Moderate
Zooplankton	Unknown	Absense of site-specific data	Not Applicable
Benthic Invertebrates	Low	Transfer potential low if intake is located at surface or mid-depth	Moderate
Amphibians/Reptiles	No Effect	Habitat does not exist at intake site	Low
Fish	Moderate	Impingement/entrainment at intake and potential reduction in survival/recruitment of pelagic species; increase in BOD due to impingement	Moderate

Southeast Study Area. However, some general qualitative impacts to aquatic communities can be postulated. Native and introduced fish species could be transferred, become established, and subsequently affect the aquatic environment (Table 6). Several federal/state/TOES endangered, threatened, candidate, "watch list", and special concern species could be affected by transfer operations or construction of the proposed interbasin transfers (Table 7). In addition, exotic organisms could be transferred and have significant environmental effects (Table 8). Depending on the location and design of the proposed transfer (i.e., river-to-river, reservoir-to-reservoir, reservoir-to-river) impacts would potentially vary from low to high (Table 9). However, the uncertainty of analysis for most aquatic components is moderate to high. Therefore, site-specific environmental assessments are needed to determine potential impacts for each proposed transfer.

WEST-CENTRAL/SOUTH-CENTRAL STUDY AREA

Potential impacts to and from aquatic communities for the proposed interbasin water transfers are difficult to assess due to the lack of recent aquatic biotic data for the West-Central and South-Central study areas. However, some general qualitative impacts to aquatic communities can be postulated. Several native and introduced fish species could be transferred, become established, and thereby affect the aquatic environment of the recipient water body (Table 10). Several federal/state/TOES endangered, threatened, candidate, and "watch list" species are present and could be affected by the proposed interbasin water transfers (Table 11). Significant effects could also occur due to the introduction of several exotic organisms (Table 12). Overall, impacts would potentially vary from low to moderate (Table 13). However, the uncertainty of analysis for most aquatic components is moderate to high. Therefore, site-specific environmental assessments are needed to determine potential impacts for each proposed transfer.

Summary of Proposed Interbasin Water Transfers

In general, open transfer systems (e.g., canals, reservoirs, rivers) have a higher potential for significant impacts because of the lack of controls to prevent potential introduction, dispersal, and establishment of introduced native and exotic organisms. Although closed systems (pipelines, tunnels) can result in significant environmental impacts, closed systems generally have lower impact potential since engineering and environmental controls can often be designed to lessen or mitigate impacts.

Table 6

List of Fish Species With the Potential for Transfer in the Various River Basins and Man-Made Impoundments/Southeast Study Area

Taxa	Sabine/Neches/Angelina	Trinity/San Jacinto	Brazos	Transfer
LAMPREYS				
Chestnut lamprey	N			Yes
Southern Brook lamprey	N	N		No
PADDLEFISHES				
Paddlefish	N[1]	N[1]		No
CARPS/MINNOWS				
Grass carp	I	I[2]		Yes
Cypress minnow	N			No
Redfin shiner	N	N		No
Speckled chub	N		N	No
Emerald shiner	N	N		No
Ironcolor shiner	N			No
Taillight shiner	N			No
Sabine shiner	N	N		No
Suckermouth minnow	N	N		No
Creek chub	N	N		No
Rudd			I	No
SUCKERS				
Bigmouth buffalo	N			Yes
Black buffalo	N		NI	Yes
Blacktail redhorse	N	N		No
BULLHEADS/CATFISHES				
Freckled madtom	N	N		No
PIKES				
Chain pickerel	N			Yes
SILVERSIDES				
Brook silversides	N	N		No
TEMPERATE BASSES				
Yellow bass	N	N		No
PERCHES				
Western sand darter	N			No
Scaly sand darter	N	N		No
Mud darter	N			Yes
Harlequin darter	N	N		No
Cypress darter	N	N		No
River darter	N			No
CICHLIDS				
Blue tilapia		I		Yes
Rio Grande Cichlid			I	No

[1]Found only in riverine systems below most downstream dams
[2]Reproducing population in the Trinity River and Galveston Bay

Legend: N = Native I = Introduced NI = Considered native but possibly introduced

Source: Conner and Suttkus 1986; Trimm et al. 1989; Hubbs et al. 1991; Pitman 1991; Robbins et al. 1991; Whiteside and Berkhouse 1992; Webb 1995

Table 7

List of Federal/State/TOES Endangered, Threatened, Candidate, Watch List, and Special Concern Aquatic Species Potentially Occurring in River Basins of the Southeast Study Area

Common/Scientific Name	Sabine			Neches			Trinity			San Jacinto			Brazos		
	F	S	TO	F	S	TO	F	S	TO	F	S	TO	F	S	TO
PLANTS															
Tissue sedge															
Carex hyalina							C2		W						
Neches River rosemallow															
Hisbiscus dasycalyx				C2	E										
Grass-of-Parnassus															
Parnassia asarifolia					T										
INVERTEBRATES															
Big Thicket emerald dragonfly															
Somatochlora margarita	C2														
MOLLUSKS															
Texas heelsplitter															
Potamilus amphichaenus	C2		SC	C2		SC	C2		SC	C2		SC			
REPTILES															
Alligator snapping turtle															
Macroclemys temmincki	C2	T	T	C2	T	T	C2	T	T	C2	T	T			
American alligator															
Alligator mississippiensis			WL			WL			WL			WL			
FISH															
Paddlefish															
Polyodon spathula	C2	E	T	C2	E	T	C2	E	T	C2	E	T			
Ironcolor shiner															
Notropis chalybaeus			WL			WL									
Sharpnose shiner															
Notropis oxyrhyncus													C2		T
Blue sucker															
Cycleptus elongatus	C2	T	WL	C2	T	WL	C2	T	WL	C2	T	WL			
Creek chubsucker															
Erimyzon oblongatus		T			T			T			T				
Western sand darter															
Ammocrypta clara			T												
Blackside darter															
Percina maculata		T	T												

Legend:
F = Federal; S = State; TO = TOES; WL = Watch List
E = Endangered; T = Threatened; C2 = Candidate Category 2; SC = Special Concern

Source: TOES 1993, 1995; TPWD 1995c; USFWS 1994, 1995b

Table 8

Known Occurrence of Exotic Organisms by River Basin/Man-Made Impoundment
(Southeast Study Area)

Common/Scientific Name	River Basin				
	Sabine	Neches	Trinity	San Jacinto	Brazos
EXOTIC PLANTS					
Giant duckweed/*Spirodela oligorhiza*		X[2]			
Salvinia/*Salvinia* spp.	X	X[2]			
Water hyacinth/*Eichhornia crassipes*	X	X	X	X[5]	X
Water lettuce/*Pistia stratiotes*					X
Hydrilla/*Hydrilla verticillata*	X[1]	X[3]	X[4]	X[6]	X[7]
Egeria/*Egeria densa*	X	X[3]			
Alligatorweed/*Alternanthera philoxeroides*	X	X	X	X[5]	
Water Fern/*Azolla* spp.	X	X[3]			
EXOTIC SHELLFISH					
Asiatic clam/*Corbicula fluminea*	X	X	X	X	X
EXOTIC FISH					
Grass carp/*Ctenopharyngodon idella*	X	X	X	X	
Rudd/*Scardinius erythrophthalmus*					X
Blue tilapia/*Tilapia aurea*			X	X	
Rio Grande cichlid/*Cichlasoma cyanoguttatum*					X

[1]Only Toledo Bend Reservoir
[2]Only B.A. Steinhagen Lake
[3]Only Sam Rayburn Reservoir and B.A. Steinhagen Lake
[4]Only Livingston Reservoir
[5]Only Lake Conroe and Lake Houston
[6]Only Lake Conroe
[7]Only Gibbons Creek Reservoir and Somerville Lake

Legend: spp. = species

Source: McMahon 1983; Howells et al. 1991; Hubbs et al. 1991; Bushek and Cameron 1992; Howells 1992; Helton and Harmon 1995

Table 9

Qualitative Rank of Potential Environmental Impacts
Southeast Study Area

Environmental Component	Rank Impact	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	Unknown	Future municipal use of conduit and/or recipient systems unknown; lack of site-specific data	Not Applicable
Other Microbes	Unknown		
Algae	Low-Moderate	Potential taste-odor problems from algal blooms; potential long-term damage to pumps/pipelines	Moderate
Aquatic Plants	Low-High	Potential transfer of water hyacinth and hydrilla, clogging of intakes	Low
Zooplankton	Low-Moderate	Construction/operation of intake structures may result in local impacts to zooplankton populations and subsequently consumer (fish) populations	High
Benthic Invertebrates			
Mollusks	Low-High	Potential clogging of intake structure by the Asiatic clam and potential impacts of construction/operational activities on native mollusk populations in rivers	Moderate
Other	Unknown	No site specific data	Not Applicable
Amphibians/Reptiles	Low-Moderate	Potential local construction impacts on habitat; alteration/destruction of semi-aquatic and riparian habitat from increases in current flow (river to stream/creek)	High
Fish	Low-High	Potential impacts on threatened, endangered, and indigenous species from construction/operational activities (impingement, entrainment, etc.) and introduction of non-indigenous/native forms	High

Table 10

List of Fish Species with the Potential for Transfer in the Various River Basins and Man-Made Impoundments West-Central to South-Central Study Areas

Taxa	West-Central Guadalupe/San Antonio	South-Central Nueces	Transfer
CARPS/MINNOWS			
Grass carp	I[1]		Yes
Nueces roundnose minnow	E		No
Ribbon shiner	N		No
Pallid shiner	N		Yes
Sand shiner	N		No
Rudd	I		Yes
SUCKERS			
Lake chubsucker	N		No
BULLHEADS/CATFISHES			
Widemouth blindcat	E		NA[2]
Toothless blindcat	E		NA[2]
SUCKERMOUTH CATFISHES			
Suckermouth catfish	I		Yes
KILLIFISHES			
Golden topminnow	N		No
Blackstripe topminnow	N		No
LIVEBEARERS			
Largespring gambusia	E		No
San Marcos gambusia	E		No
Guppy	I		Yes
SUNFISHES			
Rock bass	I		Yes
Smallmouth bass	I		No
Spotted bass	NI		Yes
PERCHES			
Bluntnose darter	N		No
Fountain darter	E		No
Bigscale logperch	N		Yes
Dusky darter	N		No
CICHLIDS			
African lake cichlid	I		Yes
Convict cichlid	I		Yes
Blue tilapia	I		Yes
Mozambique tilapia	I		Yes
Redbelly tilapia	I		Yes

[1]Introduced radio-tracked specimens in Guadalupe River below the City of Sequin
[2]Subterranean fishes

Legend:
N = Native
I = Introduced
NI = Considered native but possibly introduced
E = Endemic
NA = Not Applicable

Source: Conner and Suttkus 1986; Howells et al. 1991; Hubbs et al. 1991; Robbins et al. 1991; Whiteside and Berkhouse 1992; SARA 1994b

Table 11

List of Federal/State/TOES Endangered, Threatened, Candidate, and Watch List Aquatic Species Potentially Occurring in River Basins of the West-Central/South-Central Study Areas

	West-Central						South-Central		
	Guadalupe			San Antonio			Nueces		
Common/Scientific Name	F	S	TO	F	S	TO	F	S	TO
PLANTS									
Texas wild-rice									
Zizania texana	E	E	E						
AMPHIBIANS									
San Marcos salamander									
Eurycea nana	T	T	T						
Texas salamander									
Eurycea neotenes	C2			C2					
Texas blind salamander									
Typhlomoge rathbuni	E	E	T						
REPTILES									
Cagle's map turtle									
Graptemys caglei	C1								
American alligator									
Alligator mississippiensis			WL			WL			WL
FISH									
Blue sucker									
Cycleptus elongatus	C2	T	WL	C2	T	WL	C2	T	WL
Toothless blindcat									
Trogloglanis pattersoni	C2	T	E						
Widemouth blindcat									
Satan evrystomus	C2	T	E						
San Marcos gambusia									
Gambusia georgei	E	E	X						
Guadalupe bass									
Micropterus treculi	C2		WL	C2		WL	C2		WL
Fountain darter									
Etheostoma fonticola	E	E	E						

Legend: F = Federal; S = State; TO = TOES; WL = Watch List; T = Threatened; C1 = Candidate Category 1; C2 = Candidate Category 2; X = Extinct; E = Endangered

Source: TOES 1993, 1995; TPWD 1995a, 1995b; USFWS 1995c, 1995d

Table 12

Known Occurrence of Exotic Organisms by River Basin/Man-Made Impoundment
(West-Central and South-Central Study Areas)

Common/Scientific Name	West-Central		South-Central
	Guadalupe	San Antonio	Nueces
EXOTIC PLANTS			
Water hyacinth/*Eichhornia crassipes*	X[1]		X[4]
Water lettuce/*Pistia stratiotes*	X[2]		
Hydrilla/*Hydrilla verticillata*	X[3]		X[5]
Eurasian watermilfoil/*Myriophyllum spicatum**			
Alligatorweed/*Alternanthera philoxeroides*	X[2]		
EXOTIC SHELLFISH			
Giant Ram's-horn snail/*Marisa cornuarietis*	X		
Asiatic clam/*Corbicula fluminea*	X	X	X
EXOTIC FISH			
Grass carp/*Ctenopharyngodon idella*	X		
Rudd/*Scardinius erythrophthalmus*	X		
Africa lake cichlid/*Pseudotropheus* sp.	X	X	
Convict cichlid/*Cichlasoma nigrofasciatum*	X	X	
Rio Grande cichlid/*Cichlasoma cyanoguttatum*	X	X	X
Blue tilapia/*Tilapia aurea*	X	X	
Mozambigue tilapia/*Tilapia mossambica*	X	X	
Redbelly tilapia/*Tilapia zilli*		X	

*Occurs in Lake Travis
[1]Only Lake Dunlap and Guadalupe River
[2]Only Lake Dunlap
[3]Only Coleto Creek Reservior, Lake Dunlap, and San Marcos River
[4]Only Lake Corpus Christi
[5]Only Choke Canyon Reservior

Legend: sp. = species (singular)

Source: McMahon 1983; Howells et al. 1991; Hubbs et al. 1991; Horne et al. 1992; Howells 1992; Helton and Harmon 1995

Table 13

Qualitative Rank of Potential Environmental Impacts
West-Central/South-Central Study Areas

Environmental Component	Rank Impact	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	Low	Low levels of fecal coliforms in most of the river basins	Moderate
Other Microbes	Low-Moderate	Potential presence of a human protozoan parasite (*Cryptosporidium parvum*); potential increases in Biological Oxygen Demand levels could cause taste and odor problems	High
Algae	Low-Moderate	Potential taste/odor, human health, and toxic effects to fish from algal blooms; potential long-term wear problems on pipelines and pumps from algae	High
Aquatic Plants	Low-Moderate	Potential transfer of noxious aquatic plants	Moderate
Zooplankton	Unknown	Lack of historic/recent zooplankton data	Not Applicable
Benthic Invertebrates			
Mollusks	Low-Moderate	Potential construction/operational activities impact on native mollusks; potential clogging of intakes by an exotic mollusk (Asiatic clam)	High
Other	Unknown	No site-specific data	Not Applicable
Amphibians/Reptiles	Low-Moderate	Local construction impacts on breeding and nursery habitat (littoral zone, river back-waters); alteration of small river/creek habitat due to potential increase in flow	High
Fish	Low-Moderate	Potential transfer of exotic fish species, introduction of non-indigenous/native forms, and impacts from construction/operational activities (impingement, entrainment, etc.) on threatened, endangered, and indigenous species	Moderate

Specific ecological impacts are difficult to identify in many sections of the study areas due to the lack of recent and or site-specific abiotic/biotic data for the donor, conduit corridor, and recipient basin. Therefore, only general qualitative assessments were made regarding the proposed transfers.

RECOMMENDATIONS/MITIGATIONS

During the site selection process, several alternative locations and alternative intake sites at each location should be proposed. An environmental assessment should be conducted at each location and proposed intake site to ensure that the best alternative for the environment (i.e., the least affected site for native mollusks/fishes, threatened/endangered species, exotic/nuisance organisms) and the proposed project can ultimately be selected. Comprehensive water quality studies should be conducted for the assessment to determine if the overall water quality at the proposed intake site(s) is suitable for its designated uses (i.e., contact recreation, high quality aquatic habitat, and public water supply). Multi-year environmental studies are recommended due to the current lack of abiotic/biotic aquatic data from river/reservoir ecosystems in the study areas and the variability in the population due to fluctuations in the abiotic environment (e.g., droughts, floods). Recommendations for pre-operational and post-operational environmental assessments are illustrated in Figure 1.

Engineering and environmental mitigations which can be utilized during the engineering design and operational phases of the project to alleviate or lessen impacts to or from aquatic components of the ecosystem can be categorized by the type of transfer (i.e., open or closed). Open transfers utilize existing rivers, reservoirs, or canals to complete the transfer. Closed transfers use new or existing conveyance facilities (e.g., pipelines, tunnels) which terminate into another body of water or a terminal water storage reservoir adjacent to a water treatment facility. General mitigations for each of these transfer types and associated facilities are listed below:

(1) open transfers from reservoirs/rivers:

- the intake site should be located in the middle (transitional zone) or (lower lacustrine zone) section of the reservoir to reduce impacts on aquatic biological communities (e.g., aquatic plants, fishes, amphibians, reptiles);

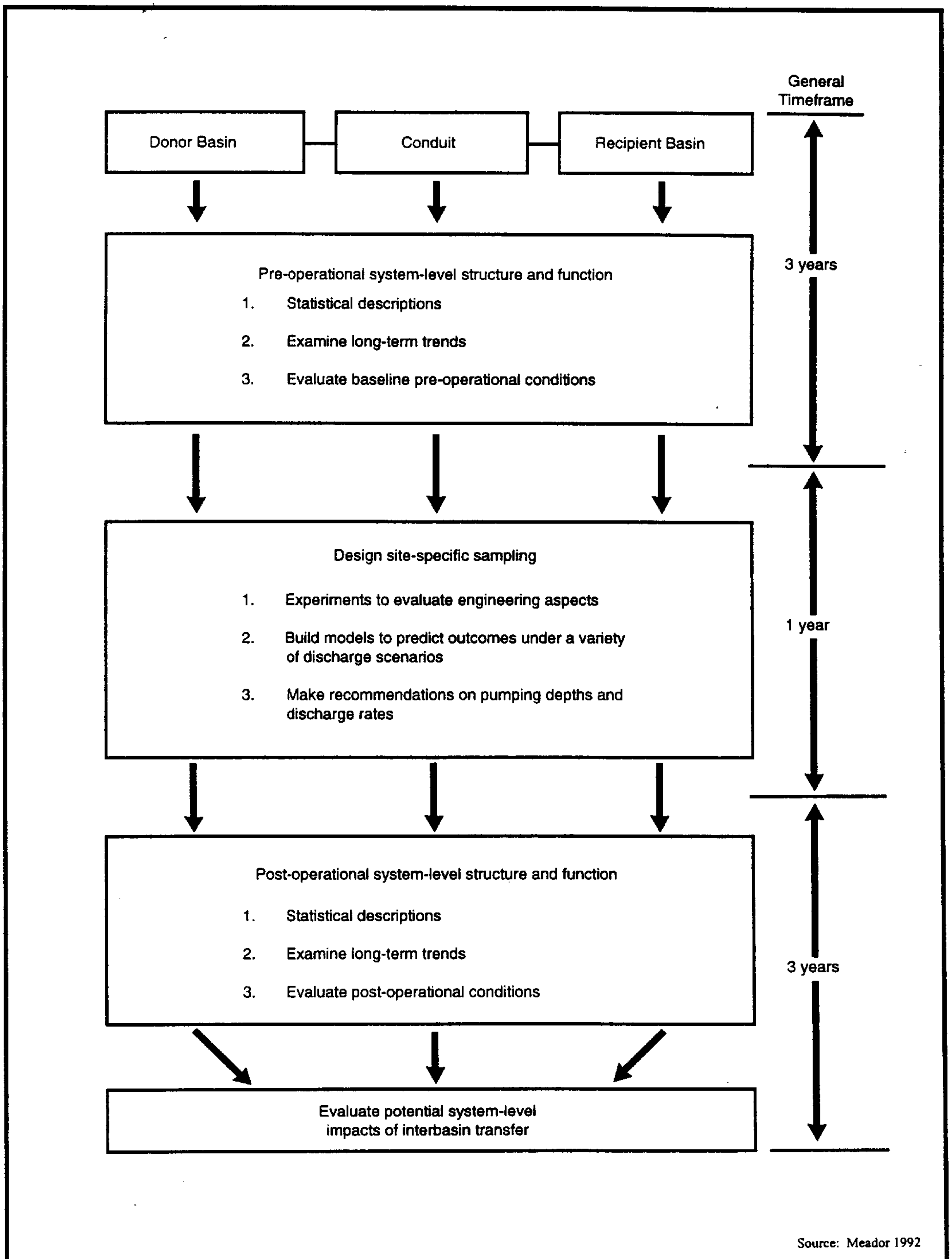


Figure 1. Recommendations for Pre-operational/Post-operational Environmental Assessments for Interbasin Water Transfers.

(1) open transfers from reservoirs/rivers (continued):

- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).

(2) new channel reservoirs (open/closed transfers):

- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).
- if necessary, treat the intake area with algicides prior or during pumping to alleviate potential long-term pump damage;
- design the reservoir with steep sides or schedule periodic 30-day water level drawdowns (initial design must allow this to occur concurrently with operation) to limit the establishment of the Asiatic clam.

(3) conveyance structures in closed transfers:

- design or plan to use horizontal screens in intake structures to reduce the impact of fish impingement;
- utilize screens with mesh size of less than 0.08 centimeters, remove shells manually, or use mechanical clam traps at appropriate points in the system, and/or conduct periodic chlorination at the intake site to control the Asiatic clam in the system;
- use materials in pipelines (i.e., mortar lining) that will resist damage from transferred aquatic organisms (e.g., algae, bacteria);
- use bar screens (one inch diameter) to prevent the entrainment of fish;
- use aeration devices along the conveyance route to reduce Biological Oxygen Demand from decaying aquatic organisms.

(4) terminal water storage reservoirs;

- design the terminal water storage reservoir to hold maximum long-term water storage capacity and/or design an overflow system to ensure that noxious/exotic organisms which may survive the transfer do not escape into nearby water bodies;
- design the terminal water storage reservoir to prevent establishment of noxious aquatic plants;
- utilize aeration devices during operation if odor/taste problems result from algal blooms and/or high BOD levels.

(5) water treatment facilities:

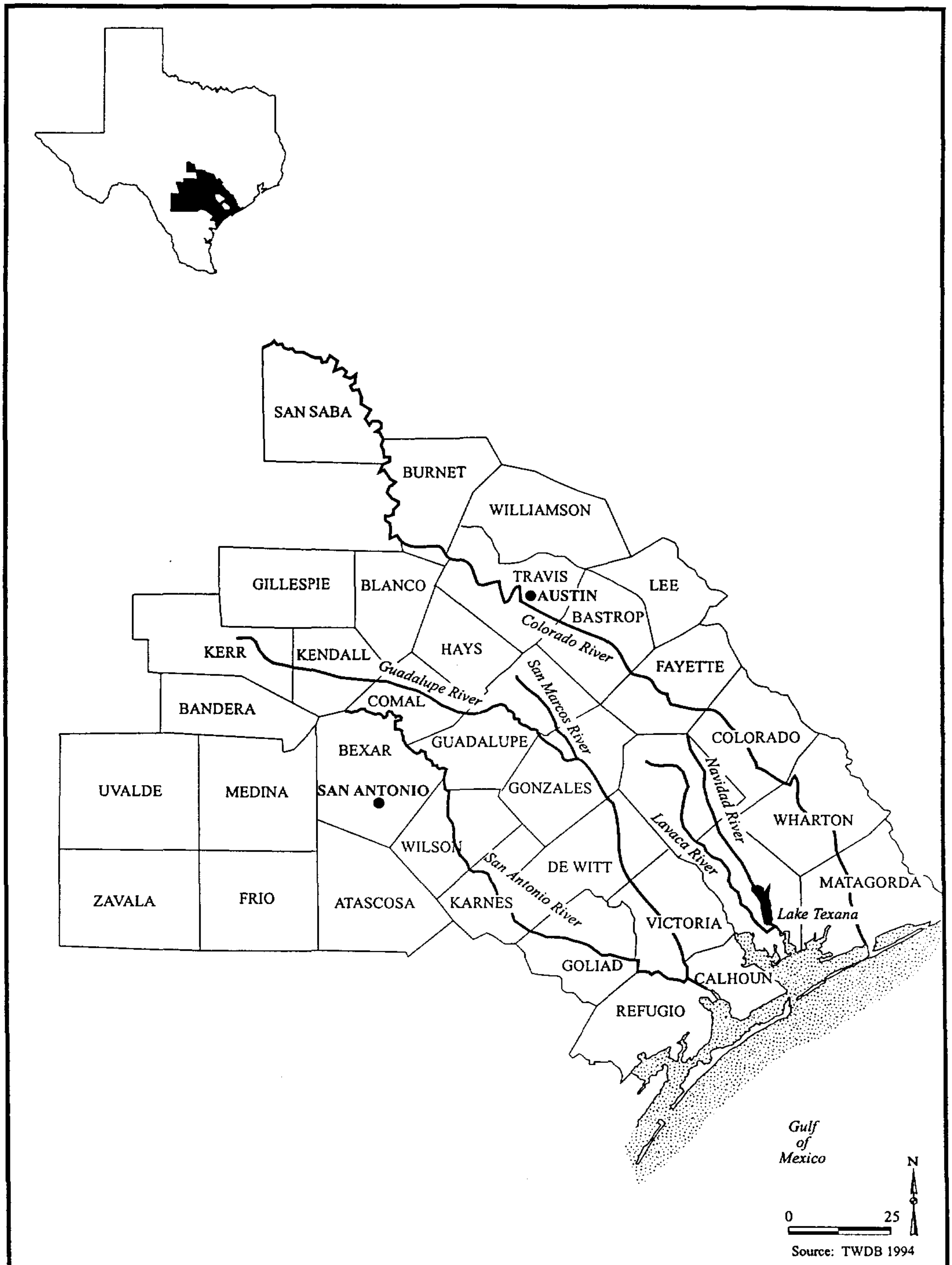
- conduct pre-construction and/or pre-treatment surveys to determine the presence or absence of pathogenic organisms (i.e., *Cryptosporidium parvum*, *Giardia*, *Escheri coli*, enterovirsuses, total/fecal coliforms) in the recipient system, as specified by the U.S. Environmental Protection Agency's (1994) Information Collection Rule, Disinfectants/Disinfection Byproducts Rule, Enhanced Surface Water Treatment Rule, and if necessary, add additional water devices (e.g., micron porosity pressure filters, ozone) in the treatment plant to ensure a safe water supply.

ENVIRONMENTAL/MITIGATION COSTS

Environmental/mitigation costs cannot be accurately quantified since site-specific preliminary engineering designs have not been completed for the proposed interbasin water transfers. In order to reduce costs associated with control and eradication, more emphasis is needed on the prevention of problems associated with interbasin water transfers. Ecologists, biologists, and engineers need to work together during the site selection and preliminary engineering design phases for the proposed interbasin water transfers to identify alternative site locations and engineering designs to prevent the transfer of nonindigenous/native aquatic organisms and the potential problems they may create. Environmental assessments and long-term pre-project plans are needed to identify potential impacts and subsequently alternative engineering designs to lessen long-term environmental costs associated with control and eradication of nonindigenous/native aquatic organisms.

MAPS OF THE STUDY AREA

Southeast Study Area : Trans-Texas Water Program



West-Central Study Area: Trans-Texas Water Program

South-Central Study Area : Trans-Texas Water Program

SECTION I

INTRODUCTION

1.0 INTRODUCTION

1.1 Purpose and Need

Interbasin water transfers are one method currently being evaluated by the Texas Water Development Board (TWDB) under the State Water Plan/Trans-Texas Water Program (TTWP) to meet projected late 20th- to mid 21st-century domestic and municipal water supply deficits/needs in the San Antonio, Corpus Christi, Austin, and Houston metropolitan areas. The purposes of this report are to:

- Conduct a literature review that demonstrates an understanding of the magnitude and seriousness of potential problems which can arise from the transfer and/or introduction of aquatic organisms by identifying and characterizing past problems associated with various transfer mechanisms;

- Provide a qualitative impact assessment of the potential aquatic ecological effects of one proposed interbasin water transfer between the West-Central Study Area and the South-Central Study Area;

- Conduct a general qualitative impact assessment of aquatic ecological effects from potential interbasin water transfers in the Southeast Texas Study Area;

- Conduct a general qualitative impact assessment of aquatic ecological effects from potential interbasin water transfers in the West-Central/South-Central study areas;

- Propose mitigations to reduce potentially significant adverse aquatic ecological impacts associated with the proposed transfers;

- Recommend additional environmental assessments to determine if the effects of a proposed transfer(s) would significantly impact the aquatic environment;

- Discuss economic/environmental costs associated with past and potential current impacts from introduced aquatic organisms.

These assessments are needed since historical and current evidence from worldwide environmental studies suggests that interbasin water transfers may result in significant changes in ecosystems as a result of alterations in flow (Stanford and Ward 1979; O'Keeffe and de Moor 1988; Petitjean and Davies 1988); changes in water quality (Thomas and Box 1969; Roy and Messier 1989; Schorr 1995); habitat alterations (Mooney and Drake 1986; Moyle et al. 1987; Meador and Matthews 1992); and the introduction of nonindigenous aquatic organisms (Guiver 1976; Laurenson and Hocutt 1986; Laurenson et al. 1989; Ross 1991; Scoppettone 1993).

1.2 Trans-Texas Water Program

The TTWP is a comprehensive water resources planning program which evaluates the full range of management strategies for three study areas (Southeast, West-Central, and South-Central) in Texas. The key components of the TTWP include: (1) water conservation, (2) innovative water management, (3) environmental water needs, and (4) public participation.

Measures to enhance water conservation and/or generate additional water savings are thoroughly evaluated and, if cost-effective, included in program recommendations. A full range of innovative water management strategies is investigated including expanded water reuse, desalinization, groundwater recharge enhancement, conjunctive management of surface and groundwater, and demand management during drought conditions. In addition to examining local water supply options, the option of sharing water among river basins (e.g., water "wheeling" arrangements involving either water rights exchanges or physical transfers of water between basins) is also evaluated. Water needed for preservation of environmentally and economically important aquatic ecosystems (e.g., instream flows, bay and estuary inflows) is addressed early in the planning process as a priority equal to the projected water demands for other purposes. The State of Texas cooperates with virtually all major local and regional water resource agencies in the study areas to determine solutions to water supply deficits (TWDB 1994).

The TTWP is comprised of five distinct phases: (I) Program Initiation and Conceptual Planning; (II) Feasibility Studies; (III) Preliminary Project Design/State and Federal Permitting; (IV) Property Acquisition/Final Design; and (V) Project Construction, Start-up, and Operation (TWDB 1994). Each phase is discussed briefly below.

Phase I involves a preliminary screening of all potential water management strategies (e.g., desalination, groundwater recharge) for the study area. Each of the alternatives is assessed for technical feasibility, cost, legal and institutional issues, and any other applicable factors. Additional alternatives are identified and evaluated. A major goal of Phase I is the screening of alternatives in relation to preliminary environmental criteria for instream flows, bay and estuarine inflows, water quality, and operation of reservoirs. After evaluation of these factors, a conceptual water management plan is developed. This plan identifies the alternatives recommended for further investigation in Phase II.

An in-depth screening of the alternatives recommended for additional study in Phase I is presented in Phase II. Analyses concentrate on developing a concise definition for each alternative; additional refined estimates of capital, operation, and maintenance costs; financing and pricing alternatives; and legal/institutional arrangements for implementation of recommended alternatives. Environmental assessments are completed in sufficient detail to support permitting activities in Phase III.

During Phase III, the preferred water management plan for each study area is developed. This includes compilation of all information required for federal and/or state permits and a detailed schedule for program implementation. Phase IV involves property acquisition and final design for each of the recommended projects. Phase V includes bidding, construction, initial start-up, and operational support.

In summary, the TTWP examines both short- and long-term water needs and evaluates strategies for reducing demands through conservation and reuse, increasing water supplies, and transferring water from areas of abundance to areas of potential shortage. Each potential alternative identified by the program is subsequently evaluated in terms of technical feasibility, cost, and environmental acceptability. The overall goal of the program is to identify the most cost-effective and environmentally sensitive strategies for meeting the current and future water needs of the study areas. Overall guidance for the program is provided by the TWDB (1994).

1.3 Description of Study Areas

The TTWP is organized into three study areas: (1) Southeast Study Area, (2) West-Central Study Area, and (3) South-Central Study Area. The Southeast Study Area extends along the Texas Gulf Coast from the Louisiana border in the east to the Brazos River in the west and includes the major cities of Houston, Galveston, Beaumont, Port Arthur, and Orange. This area consists of 32 counties within the Sabine, Neches, Trinity, San Jacinto, and Brazos river basins (Figure I-1). The West-Central Study Area encompasses the region west of the Brazos River and includes the City of San Antonio and all other cities (e.g., San Marcos, Sequin, New Braunfels) that rely upon the Edwards Aquifer for their water supply. Thirty-three counties including parts of the Colorado and Lavaca-Navidad river drainages and all of the Guadalupe and San Antonio river basins form this study area (Figure I-2). The South-Central Study Area encompasses the region west of the Brazos River, including the City of Corpus Christi. This area consists of 12 counties and the Nueces River Basin (Figure I-3) (TWDB 1994).

1.4 Regulatory Compliance

Interbasin water transfers could directly or indirectly result in violation of federal/state legislation. Federal laws which may be applicable to interbasin water transfers include the Fish and Wildlife Act, Public Law (P.L.) 89-298, Endangered Species Act (ESA), Clean Water Act (CWA), Executive Order 11987 (Exotic Organisms), Executive Order 11990 (Protection of Wetlands), Safe Drinking Water Act (SDWA), Lacey Act, Federal Noxious Weed Act, and the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA). Texas legislation includes the Texas Administrative Code (TAC), Texas Parks and Wildlife Code, Texas Water Code, Texas Health and Safety Code, Texas Water Commission (TWC) Watershed Protection Rule, and the Texas Clean Rivers Act. Each of these is discussed briefly in the following subsections.

1.4.1 Federal Laws

1.4.1.1 Fish and Wildlife Act

The Fish and Wildlife Act of 1956 (16 United States Code [U.S.C.] 742a-742j) authorized the Secretary of Interior to take steps "required for the ... conservation and protection of fisheries resources."

1.4.1.2 Public Law 89-298

Section 302 of P.L. 89-298 of 1965 authorizes the Aquatic Plant Control (APC) to provide for control and progressive eradication of water hyacinth (*Eichornia crassipes*), alligatorweed (*Alternanthera*

Figure I-1. Southeast Study Area : Trans-Texas Water Program

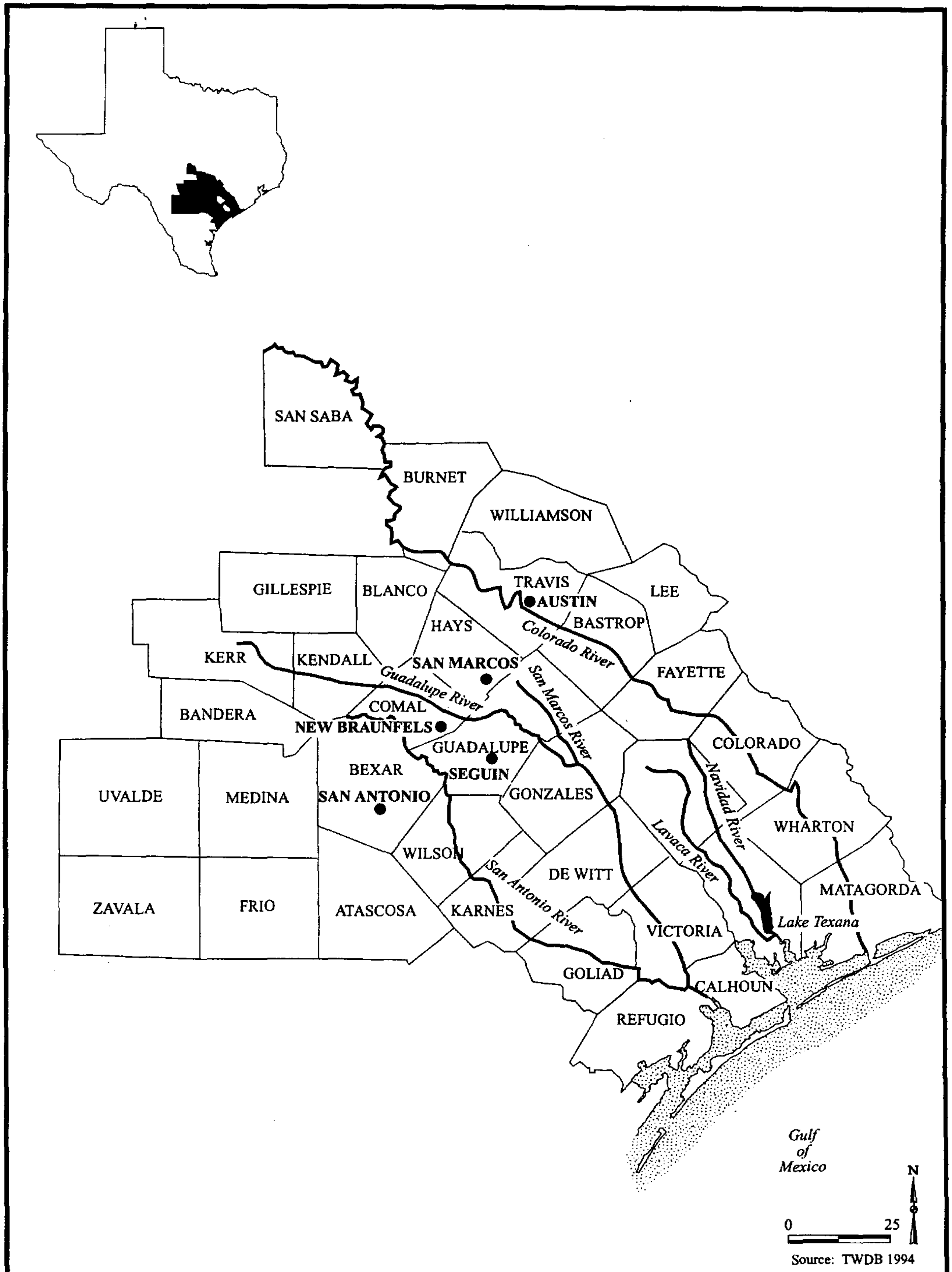


Figure I-2. West-Central Study Area: Trans-Texas Water Program

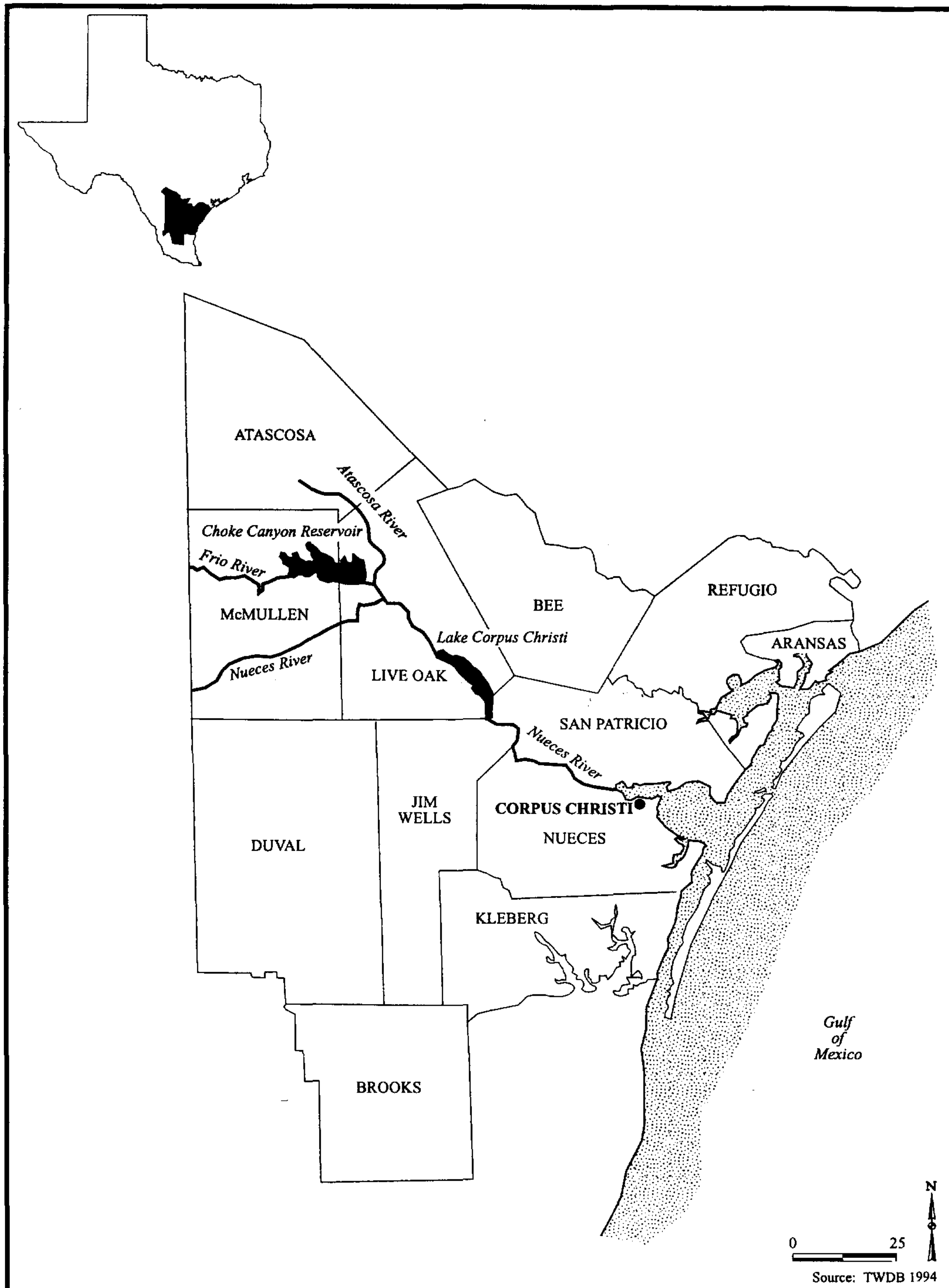


Figure I-3. South-Central Study Area : Trans-Texas Water Program *philoxeriodes*), Eurasian water milfoil (*Myriophyllum spicatum*), and other noxious aquatic vegetation from navigable waters, tributary streams, connecting channels, and other allied waters of the United States in the combined interest of navigation, and for flood control, drainage, agriculture, fish and wildlife conservation, recreation, public health and related purposes, including continued research for development of the most effective and economical control measures.

1.4.1.3 Endangered Species Act

The ESA (P.L. 92-205; 16 U.S.C. 1513 et seq.) of 1973, as amended, was enacted to provide a program for the conservation of endangered and threatened species and to conserve the ecosystems upon which they depend for survival. The ESA defines "conserve" as the use of "all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary..." The United States Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) are the primary agencies responsible for implementing the ESA.

Sections 7 and 10 of the ESA might also provide a vehicle for prohibiting the introduction of aquatic organisms if it can be determined *a priori* that the introduction is likely to jeopardize a listed species. For instance, consistent with the requirements of Section 7, the USFWS in the past has conditioned its fishery activities, especially fish stocking, to avoid any real or potential conflicts with threatened or endangered species.

1.4.1.4 Clean Water Act

The CWA (P.L. 95-217; 33 U.S.C. 1288) of 1977 authorized the USFWS to provide technical assistance to states in developing "best management practices" as part of water pollution control programs. Section 303(d) requires each state to rank designated segments by water quality and priority for corrective action.

1.4.1.5 Executive Order 11987

Executive Order 11987 (Exotic Organisms) of 1977 directs federal agencies to restrict the introduction of exotic species into natural ecosystems under their jurisdiction and to encourage states to do the same.

It also directs the Secretaries of Interior and Agriculture to restrict the introduction into any natural system of animal or plants designated as injurious or noxious under the Lacey Act Amendments and Federal Noxious Weed Act.

1.4.1.6 Executive Order 11990

Executive Order 11990 (Protection of Wetlands) of 1977 directs federal agencies "to avoid short and long term adverse impacts associated with the destruction or modifications of wetlands."

1.4.1.7 Safe Drinking Water Act Amendments

The SDWA (P.L. 99-339; 42 U.S.C. 300g-l) Amendments of 1986 proposed national primary drinking water regulations specifying maximum contaminant levels (MCLs) and the criteria under which filtration (including coagulation and sedimentation) and disinfection are required as a treatment technique for all public water systems supplied by surface water sources. In addition to the Total Coliform Rule (54 Federal Register [FR] 27544) and the Surface Water Treatment Requirements (SWTR) (54 FR 27486), the U.S. Environmental Protection Agency (USEPA) proposed three new national regulations that will provide greater safety for consumers of public drinking water (USEPA 1994a). These new rules include Information Collection Rule (ICR) - proposed 2/94 (59 FR 6332) and promulgation 10/94 and Disinfectants/Disinfection Byproducts Rule (D/DBPR) and Enhanced Surface Water Treatment Rule (ESWTR) - proposed 6/94 and promulgation 12/96.

1.4.1.8 Lacey Act Amendments

The Lacey Act (18 U.S.C. 42) Amendments of 1990 authorizes the Secretary of Interior to prohibit the importation of mongooses, fruit bats, zebra mussel, and other birds, mammals, reptiles, amphibians, fish, mollusks, and crustacea which are declared to be "injurious" to agriculture, horticulture, forestry, and wildlife resources (including aquatic and terrestrial vegetation upon which wildlife depends).

1.4.1.9 Federal Noxious Weed Act

The 1990 amendment (7 U.S.C. 2814[e][7]) to the Federal Noxious Weed Act of 1975 (P.L. 93-269) requires each federal land-managing agency to establish and fund a program to manage "undesirable" plants found on lands under its jurisdiction. "Undesirable" is defined as plants "classified as undesirable, noxious, harmful, exotic, injurious, or poisonous, pursuant to State or Federal law."

1.4.1.10 Nonindigenous Aquatic Nuisance Prevention and Control Act

The NANPCA (P.L. 101-646) of 1990 was passed primarily in response to unintentional introductions of aquatic organisms (Lassuy 1994). The Act defines "nonindigenous species" as any species or other viable biological material that enters an ecosystem beyond its historic range, including any such organism transferred from one country to another. An "aquatic nuisance species" is defined as a nonindigenous species that threatens the diversity or abundance of native species; or the ecological stability of infested waters; or commercial, agricultural, aquacultural, or recreational activities dependent on such waters.

The purposes of the Act which are relevant to potential introduction of aquatic organisms from interbasin water transfers are: (1) to coordinate federally conducted, funded, or authorized research, prevention control, information dissemination, and other activities regarding the zebra mussel and other aquatic nuisance species; (2) to develop and carry out environmentally sound control methods to prevent, monitor, and control unintentional introduction of nonindigenous species from other pathways (i.e., other than ballast water); (3) to understand and minimize economic and ecological impacts of nonindigenous aquatic nuisance species that become established, including the zebra mussel; and (4) to establish a program of research and technology development and assistance to states in the management and removal of zebra mussels (P.L. 101-646, Section 1002).

Subtitle C of the NANPCA provides and implements an Aquatic Nuisance Species Program for waters of the United States: (1) to prevent introduction and dispersal of aquatic nuisance species; (2) to monitor, control, and study such species; (3) to disseminate related information; and (4) to implement measures to carry out cooperative, environmentally sound efforts with regional, state, and local entities to minimize the risk of an introduction for which there are substantial adverse consequences.

1.4.1.11 Executive Order 12962

Executive Order 12962 (Recreational Fisheries) of 1995 directs federal agencies in cooperation with the state to conserve, restore, and enhance aquatic systems that support recreational fisheries.

1.4.2 State Laws

1.4.2.1 Texas Administrative Code

Title 30 of the TAC discusses environmental quality. Chapter 307.2 provides surface water quality standards in order to maintain the quality of water consistent with public health and protection of aquatic life. Sections 65.171-65.184 review threatened and endangered wildlife/fish species. Title 31 of the TAC discusses natural resources and conservation. Chapter 57.111 et seq. lists harmful or potentially harmful exotic fish, shellfish, and aquatic plants. Chapter 57.251 et seq. discusses the introduction of fish (native/nongame), shellfish (crustaceans and mollusks), and aquatic plants to native communities. Sections 69.01-69.14 review resource protection, endangered, threatened, and protected native plants.

1.4.2.2 Texas Parks and Wildlife Code

The Texas Parks and Wildlife Code (Section 12.015) regulates the introduction and stocking of fish, shellfish, and aquatic plants into the public waters of the state. Chapters 67/68 and 88 discuss threatened and endangered wildlife/fish species and endangered, threatened, or protected native plants.

1.4.2.3 Texas Water Code

The Texas Water Code (Sections 16.051 and 16.055) directs the Executive Administrator of the TWDB to prepare and maintain a comprehensive State Water Plan as a flexible guide for the orderly development and management of the state's water resources so sufficient water will be available at a reasonable cost to further the economic development of the entire state. The TWDB is also directed to amend and modify the plan in response to changing conditions (TWDB 1994).

1.4.2.4 Texas Health and Safety Code

Chapter 341 of the Texas Health and Safety Code gives authority for regulating public water systems and adopts rules to implement the necessary programs. The "Rules and Regulations for Public Water Systems" sets standards for construction, operation, and maintenance of water systems. The "Drinking Water Standards Governing Drinking Water Quality and Reporting Requirements for Public Water Supply Systems" sets standards for chemical and microbiological quality and is the state equivalent of the National Primary Drinking Water Regulations.

1.4.2.5 Texas Water Commission Watershed Protection Rule

Chapter 311 subchapter D: §§ 311.31-311.36 of the TWC Watershed Protection Rule requires all domestic and industrial permittees in the entire Lake Houston Watershed to meet effluent limitations equal to or commensurate to 10 milligrams/per liter (mg/ℓ) Biological Oxygen Demand (BOD_5), 15 mg/ℓ Total Suspended Solids (TSS), and 3 mg/ℓ Ammonia Nitrogen (NH_3-N) as a 30-day average.

1.4.2.6 Texas Clean Rivers Act

The Texas Clean Rivers Act (Senate Bill [SB] 818) of 1991 requires each river basin in the State of Texas be assessed individually for nonpoint source pollution, intrusion of toxic materials and overloading of nutrients, impacts of water quality (i.e., increased sedimentation, depressed/dissolved oxygen levels) and water supply, or the cumulative water quality impacts on human health (e.g., high fecal coliform levels), regional ecosystems, aquatic life (e.g., loss or degradation of habitat), and excessive aquatic vegetation. Assessments conducted under the SB 818 program form the basis for a comprehensive approach to water resource management that will enable the "Texas Natural Resource Conservation Commission [TNRCC] (formerly the TWC)" to establish risk-based priorities under Chapter 26 of the Texas Water Code and under the federal CWA.

1.5 Project Funding/Contracting

This project is funded under the Federal Planning Assistance to States Program (Water Resource Development Act of 1974, Section 22, P.L. 93-251). This legislation provides authority for cooperating with any state in preparation of comprehensive plans for the development, utilization, and conservation of water and related resources of basins located within the boundaries of such state. The State of Texas through the TWDB is the principal sponsor for work under this program. The Texas Parks and Wildlife Department (TPWD) and the TNRCC are cooperating agencies. The U.S. Army Corps of Engineers (USACE)/Fort Worth District is responsible for administering the project and has contracted Geo-Marine,

Inc., of Plano, Texas, to complete an analysis on the potential aquatic ecological impacts which could result from proposed interbasin water transfers in Southeast, West-Central, and South-Central Texas.

1.6 Report Organization

This report consists of six major sections including this introductory section. Section II provides the results of a literature review conducted by Geo-Marine, Inc. regarding known and potential aquatic ecological impacts due to the introduction of nonindigenous organisms including interbasin water transfers. This section synthesizes information on introduced species; transport mechanism; date/location of introduction and the geographical extent of the problem; native species which were affected or extirpated; the suspected or known mechanisms by which the nonindigenous species caused harm, reduction, or elimination of endemic species; as well as success of any mitigation techniques. Section III provides a qualitative impact analysis of potential aquatic ecological impacts which could occur as a result of a proposed interbasin water transfer between the West-Central and the South-Central study areas. A general qualitative impact assessment of proposed interbasin water transfers in the Southeast and West-Central/South-Central study areas is provided in Sections IV and V, respectively. Recommendations and mitigations to alleviate or lessen potential environmental impacts identified during the impact analyses are discussed in each of these sections. Section VI reviews the potential economic and environmental (i.e., mitigation) costs associated with past and potential impacts from introduced aquatic organisms.

SECTION II

LITERATURE REVIEW

1.0 METHODOLOGY

The literature review on aquatic ecological effects of interbasin water transfers and introduced aquatic organisms was completed by:

- Utilizing the on-line computer facilities at the University of Texas at Dallas (UTD) to search the following databases: Online Computer Library Center (OCLC), DIALOG (i.e., Water Resources Abstracts, Aquatic Science and Fisheries Abstracts, Enviroline, Zoological Record Online, National Technical Information Service (NTIS), WaterNet, Dissertation Abstracts, and Conference Paper Index); FirstSearch (i.e., Article First, BiolAgrIndex, BioDigest, BIOSIS/FS, and Government Printing Office [GPO]); INTERNET (e.g., GOPHER - universities: University of Texas at Austin, Texas A&M University, University of Houston, Lamar University, Southwest Texas State University, Stephen F. Austin State University; biodiversity/biological); U.S. Environmental Protection Agency (USEPA) Online Library System (OLS); Texas Natural Resource Conservation Commission (TNRCC) Information Data Center; and Texas State Library Index;

- Visiting area libraries (Southern Methodist University, University of North Texas, UTD, and Texas Parks and Wildlife Department (TPWD)/TNRCC in Austin) and reviewing abstracts (Fisheries Review), periodicals (American Midland Naturalist, Aquatic Botany, BioScience, Canadian Journal of Aquatic Fisheries and Sciences, Copeia, Ecology, Environmental Biology of Fishes, Fisheries, Freshwater Biology, Hydrobiologia, Limnology and Oceanography, North American Journal of Fisheries Management, Southwestern Naturalist, Texas Journal of Science, Transactions of the American Fisheries Society), federal/state reports, thesis, dissertations, and recent publications (e.g., books, reports) in aquatic sciences;

- Contacting private organizations (HDR Engineering, Inc., American Water Resources Association), public utilities (Texas Municipal Power Authority, Central Power and Light), universities (Southwest Texas State, University of Texas at Austin Center for Research in Water Resources), state agencies (Texas Department of Health, Texas Water Department Board [TWDB], TNRCC, TPWD), river authorities (Lower Colorado River, Sabine River, Angelina and Neches River, Lower Neches Valley, Brazos River, San Antonio River, and Navidad-Lavaca

River), and federal agencies (U.S. Army Corp of Engineers [USACE], U.S. Fish and Wildlife Service [USFWS], U.S. Geological Survey [USGS]), and analyzing published/unpublished information from aquatic ecological surveys conducted on the various river basins within the study areas;

- Attending conferences on interbasin water transfers sponsored by the Southern Division of the American Fisheries Society and the American Society of Civil Engineers (TEXAS WATER '95, a Component Conference of the First International Conference on Water Resources Engineering).

2.0 INTERBASIN WATER TRANSFERS

2.1 Introduction

An interbasin water transfer is an artificial withdrawal of water from one drainage basin (i.e., donor) to another drainage basin (i.e., recipient) for beneficial use. Generally, water is diverted from a river, lake, or reservoir and delivered by conveyance facilities (e.g., canals, channels, aqueducts, conduits, tunnels, and pipelines) over long distances for irrigation, municipal and industrial water supply, and navigation (Biswas 1983; Shiklomanov 1985). A reasonable definition should also include the scale of the diversion and its impact on the ecological, hydrological, social, and economic systems in the scheme (Warnick 1969; Micklin 1985). Interbasin water transfers may be considered in terms of three geographical scales: local, regional, and global. Local transfers occur when diverted water returns to the same river or watershed. Global interbasin water transfers divert waters to substantially different ecoregions and cross major watershed and continental divides. Regional transfers are on a continuum between local and global interbasin water transfers. The following subsections briefly review the history of interbasin water transfer projects and examine known and potential ecological impacts associated with these transfers.

2.2 Historical Background

The practice of diverting water from one river basin to another has been in existence for hundreds, even thousands, of years. Many ancient civilizations used water transfers for irrigation and the development of their civilization. Archaeological evidence indicates that the first interbasin water transfer was developed in the Mesopotamian Valley as early as the Babylonian times. In 2500 B.C., a water resource development (i.e., Shatt-el-Hai Canal) was constructed to connect the Tigris and Euphrates rivers. Based on hieroglyphics by the Pharaohs of the Twelfth Dynasty, extensive irrigation (i.e., Bohr-Housef Canal) was also practiced in Egypt at the same time. Interbasin transfers in China were also in existence before the Qing Dynasty (221-201 B.C.), concluding during the period from 1271-1368 A.D. with the 932-mile-long Yun Ho (Grand Canal) which crosses the Great Plain from Beijing to Hangzhou. In 1000 A.D., the City of Baghdad possessed the greatest system of irrigation canals that had ever been constructed with a length of over 3,000 miles (mi), the largest being the Chosroes Canal. Extensive aqueducts were also constructed at Segovia, Tejada, and Sajunto in Spain between 53 and 138 A.D. and in southern France during the 1680s. More than a century ago (ca. 1750-1900), water transfer systems were implemented for navigation in Europe. The construction of middle-size to large-scale systems of interbasin water transfers in the Soviet Union began in the first half of the 20th century.

In the Western Hemisphere, ruins in Peru suggest the existence of a canal that carried water 125 miles from the Andes Mountains to the capital city. From 300 B.C. to 1450 A.D., Native Americans (i.e., Hohokam, Pima) in the Salt River Valley of central Arizona constructed at least 311 mi of major canals and 994 mi of smaller laterals for irrigation in what is now the Phoenix metropolitan area. These canals as well as acequias designed by the Spaniards in the southwestern United States during the 1600s and 1700s (e.g., San Antonio, Texas in 1718) cannot be attributed to regional water transfers, but may have served an important role in the development of large-scale transfer projects that followed in the Southwest (Warnick 1969).

California was the first state in the United States to develop an interbasin transfer of water to meet regional water supply and irrigation demands. Projects were proposed for transfer of water from the Sacramento Valley to the San Joaquin Valley as early as 1873. The Los Angeles Aqueduct (the first California project constructed) was completed in 1913 to carry approximately 150,000 acre-feet (ac-ft) of water from the Owens Valley on the eastern slopes of the Sierra Nevadas to the City of Los Angeles. In 1928, a 250-mi aqueduct was constructed to transfer water (in excess of 1.2 million ac-ft) from the Colorado River to the Los Angeles and San Diego metropolitan areas. One of the most complex and expensive interbasin transfer projects was the construction of the California State Water Project in 1972. Designated to carry 4.2 million ac-ft of water from northern California's Sacramento and Feather rivers, through the deltas of the Sacramento and San Joaquin rivers, to the Central Valley and southern

California; this project included 21 dams and reservoirs, 22 pumping plants, and 684 mi of canals, tunnels, and pipelines. Other noteworthy interbasin water transfers in the west include the Truckee-Carson basins transfers in western Nevada and the Yakima River Basin in Washington State (Micklin 1985; Shiklomanov 1985; National Research Council, Water Science and Technology Board, and Committee on Western Water Management 1992).

In the late 19th century, it was realized that in order for agriculture to expand in the Great Plains, water from the western slope of the Rocky Mountains had to be diverted to the drier eastern plains. An ingenious series of tunnels (i.e., Moffet, Vasquez, Gumlick, and Roberts) was designed and constructed to transfer water through the Rocky Mountains. These transfers included the Big Thompson Project in north-central Colorado, which transferred water from the Colorado River to the Platte River Basin, and the Frying Pan-Arkansas Project, which diverted water from the Colorado River Basin into the Arkansas River Basin. Another major interbasin water transfer from the Colorado River Basin was the Central Arizona Project (CAP) in southern Arizona. Water has also been diverted from the Rio Grande Basin via the San Juan-Chama rivers in northern New Mexico. Petsch (1985) reported a total of 111 conveyances which export water between water resources subregions in the western conterminous United States.

Texas has also been active in interbasin water transfers. Proposals were made to divert water to the Texas High Plains from the Mississippi River as well as the Arkansas and White rivers in Arkansas. However, recent evaluations of cost and water demands in the basin of origin appear to make interbasin transfer of water to the Texas High Plains unlikely for the near future (Lacewell and Lee 1988). A smaller scale interbasin transfer was completed to provide water to the metropolitan Dallas area. Water was pumped from Lake Texoma (Oklahoma-Texas, Red River Basin) to Lake Lavon (Texas, Trinity River Basin) via a combination of pipeline and stream channels (Schorr 1995). In 1992, the Trans-Texas Water Program (TTWP) began to address water supply concerns for major growth centers in the Southeast, West-Central, and South-Central areas of Texas. A total of 76 trans-basin diversions have been listed for the State of Texas (Gooch 1994).

Interbasin water transfers in the United States have not been limited to the West. To support the population of metropolitan New York, water (e.g., 2 million ac-ft per year [ac-ft/yr]) has been diverted from the Croton River (1842 to 1904), the Catskill reservoirs (1915 to 1924), and finally from the

Delaware River Basin system (1936 to the present). Interbasin transfers have also been proposed for Florida, Connecticut, and Virginia. Other noteworthy projects include the Santee-Cooper Diversion/Rediversion Project in South Carolina and the proposed Tri-State Comprehensive Study involving the Apalachicola-Chattahoochee-Flint and the Alabama-Coosa-Tallapoosa river basins. Although distances covered by interbasin transfer in the eastern United States are not as great as those in the West, interbasin transfer has played a role in urban growth and development along the Atlantic Coast. Mooty and Jeffcoat (1986) reported a total of 145 conveyances which export water between water resources subregions in the eastern United States.

Interbasin transfers across international boundaries have also been considered. The Grand Replenishment and Northern Development (GRAND) Canal concept involves the collection and diversion of runoff from James Bay watershed into the Great Lakes for water level control and hydropower production. The Garrison Diversion Unit (GDU) is proposed to transfer water via transboundary streams from the Missouri River Basin to the Hudson Bay drainage basin for the purpose of irrigation, municipal and industrial water supply, and recreational and fish/wildlife opportunities in North Dakota. Perhaps the largest interbasin transfer scheme ever devised is the North American Water and Power Alliance (NAWAPA), which would provide water to seven Canadian provinces, 33 states, and three states in Mexico. The complexities of such projects have so far prevented construction. Sewell (1985) and Quinn (1987) reported a total of 60 Canadian interbasin water transfers (i.e., Churchill River Diversion, the Churchill Falls Project, and the McGregor Diversion). The majority of these diversions would be used to facilitate generation of hydroelectric power.

Globally, interbasin water transfers are assuming increased importance. Both the Soviet Union and China have active interbasin transfer programs (Golubev and Biswas 1985). Presently, a total of 16 major water transfer systems (e.g., Karakum Canal, world's largest operating transfer system) is in operation or design in the Soviet Union. China has also constructed or planned numerous interbasin water transfers (e.g., LuanHe-Tianjin, Three Gorges Project, and South-to-North Diversions) (Shiklomanov 1985; Ganging 1987). An increase in interbasin transfer projects has been proposed in Great Britain to meet rapid growth in water demand. In South Africa, nearly nine percent of the total mean annual runoff will soon be diverted from one river basin to another (Petitjean and Davies 1988). O'Keeffe and de Moor

(1988) reported a total of 12 completed, under design, or proposed water transfers in South Africa, including the Orange/Great Fish River Tunnel, the Eastern National Water Carrier, the Tugela-Vaal Scheme, and the Lesotho Highlands Water Project.

2.3 Ecological Impacts

The impact of interbasin water transfers on the environment may be considered in terms of three different geographic regions: the water exporting region (donor), the transfer region (conveyance), and the importing region (recipient). Padmanabhan et al. (1990) and Jensen (1991) reported that diversions and transfers can negatively impact these regions through changes in channel morphology, flow regime, water quality/quantity, undesirable aquatic biota, diseases, ecosystems, and aesthetics. Historical and current evidence from worldwide environmental studies suggest that in general interbasin water transfers may result in significant changes in ecosystems (Thomas and Box 1969). However, major impacts are rarely isolated and typically comprise several ecological effects of lesser magnitude. Although many potential ecological impacts may result from water transfers, four basic classifications of specific impacts can be identified: (1) alterations in flow, (2) changes in water quality, (3) habitat alteration, and (4) introduction of nonindigenous aquatic organisms (Meador 1992). These impacts are described in the following subsections.

2.3.1 Alterations in Flow

Hydrologic regime alteration is an important problem in interbasin water transfers. In a transfer of water from the Orange River to the Great Fish River in South Africa, the upper Great Fish River received a 500-800 percent increase in flow (Petitjean and Davies 1988). Transfer of water from the Colorado River to the North Fork of the South Platte River via Roberts Tunnel increased mean flow by as much as 60 percent (Stanford and Ward 1979). In South Carolina, the Santee River was diverted into the Cooper River in 1942 for hydroelectric power production, decreasing flow 88 percent in the Santee River and increasing flow over 220 percent in the Cooper River (Meador et al. 1984).

O'Keeffe and de Moor (1988) reported that shifts in the benthic invertebrate community of the Great Fish River were primarily the result of changes in flow regime due to interbasin transfer. Only 33 percent of the invertebrate taxa were common to both the pre- and post-transfer surveys. Though overall densities were not altered, changes occurred in dominant chironomid (midge fly), hydropsychid (caddisfly), and simuliid (black fly) species. Of particular concern was the replacement of pre-transfer dominant simuliids *Simulium adersi* and *S. nigritarse* by *S. chutteri*, a blood-feeding pest of livestock which inflicted biological and economic damage in the area. Snaddon and Davies (1995) also reported a decrease in benthic macroinvertebrate species richness below the transfer outlet on the Great Berg River in the Western Cape of South Africa. Sensitive families such as the heptagenid ephemeropterans (mayflies) and leptocerid trichopterans (caddisfly) were not observed below the outlet, while hydropsychid trichopterans increased due to the introduction of zooplankton from the source reservoir. Drastically reduced winter flows led to a major reduction in macroinvertebrate densities below the water transfer site on the River Glomma in Scandinavia. Most noticeable was the elimination of the winter growing Capniidae (plecopteran-stoneflies) and the severe reduction in the winter generation of *Baetis rhodani* (ephemeroptera-mayfly). In contrast, densities of filter-feeding trichoptera (caddisflies) increased, and *Diura nanseni* became an even more dominant member of the plecopteran (stonefly) community (Brittian et al. 1984).

2.3.2 Changes in Water Quality

The movement of water from one river/lake to another may result in physicochemical changes in the recipient basin. In arid lands particularly, problems often result from changes in conductivity. For example, the conductivity of Lake Texoma (Texas/Oklahoma border) is generally about 1,300-1,500 microsiemens per centimeter (μS/cm) due to the relatively saline Red River. This water is intermittently pumped into the comparatively freshwater Lake Lavon via Sister Grove Creek (Texas), where conductivity rarely exceeds 300 μS/cm (Meador, USGS, unpublished data). Transfer of water from the Santee River to the Cooper River in South Carolina resulted in saltwater intrusion in the Santee River and a subsequently larger silt load in the Cooper River which necessitated silt removal from Charleston Harbor. The increase in flow (72 cubic feet per second [cfs] to 15,600 cfs) in the Cooper River changed Charleston Harbor from a vertically well-mixed estuary to a stratified estuary which caused shoaling to increase from 110,000 to 10 million cubic yards per year in the navigational channels (Cooke 1995).

Transfer of water from the Snowy and Eucumbene rivers in eastern Australia's Snowy Mountains to the arid western Murray and Murrumbidgee rivers resulted in lower water temperature for considerable distance downstream in the recipient drainage (Thomas and Box 1969). In addition, turbidity, alkalinity, and pH were also lowered. These changes in water quality appear to have affected the spawning of native fish species in the Murray and Murrumbidgee rivers (Thomas and Box 1969). Other transfers have also noted changes in water quality: the Great Berg River saw an increase in turbidity, pH, and temperature, and increased sulfate, nitrate, sodium, and chloride concentrations; and the Great Fish River showed a reduction in concentrations of sodium, magnesium, chloride, and sulfate (O'Keeffe and de Moor 1988; Snaddon and Davies 1995).

Water quality in the Eastmain and Opinaca rivers of the La Grande Complex in Canada changed significantly after flow diversion, mainly because of the water quality from the tributaries of the residual drainage basin, the erosion generated by the drop in water level, and the increase in flow-through time. Along the Eastmain River, parameters which vary mainly in relation to flow of tributaries draining the neighboring bogs (color, organic carbon, etc.) increased from 60 percent to 300 percent, and those parameters associated with erosion (turbidity, suspended matter, and total phosphorous) increased from 200 percent to more than 700 percent while transparency dropped to 25 percent of its prediversion level. Five years after the diversion of flow, the water of both the Eastmain and Opinaca rivers was more turbid, more mineralized, and richer in nutrients and organic matter (Roy and Messier 1989).

2.3.3 Habitat Alterations

Alteration of flow volume and discharge timing can seriously impact aquatic habitats. In many recipient basins, former seasonally intermittent waters have become perennial as a result of water transfer. Prior to interbasin water transfer, the Great Fish River in South Africa consisted of a series of isolated pools (Laurenson and Hocutt 1986). Today, the Great Fish River has been transformed into a permanently flowing water body. It is not clear what impact such habitat alterations will have on temporal patterns of stream fishes that evolved in seasonal low-flow and high-flow periods (Meador and Matthews 1992). However, habitat alterations may favor introduced species that may then eliminate native fauna through predation, competition, and higher reproductive success (Mooney and Drake 1986; Moyle et al. 1986).

Transfer of water from Lake Texoma to Lake Lavon in Texas has raised the concern over the future of the important striped bass (*Morone saxatilis)* fishery in Lake Texoma. Lake Texoma provides one of the few self-sustaining populations of land-locked striped bass in the United States. Coutant (1985) suggested that summer mortality of reservoir populations of striped bass was a result of a decrease in suitable habitat, since water temperatures in the epilimnion exceeded 25 degrees Celsius (°C) and dissolved oxygen levels in the hypolimnion decreased below 2 milligrams per liter (mg/ℓ). The depth of the water intake for transfer is a critical factor in maintaining summer physicochemical habitat requirements of striped bass in Lake Texoma.

Roy and Messier (1989) reported that fishing yields in the Eastmain and Opinaca rivers of the La Grande Complex in Canada were five times greater after flow diversion, due to the concentration of fish after flow reduction. Once the world's fourth largest freshwater lake, the Aral Sea of central Asia has been steadily shrinking due to diversions for irrigation. Since 1960, the lake level has dropped 49 feet (ft), its surface area has shrunk by 40 percent and its volume by 60 percent, and the salinity has tripled. The fish yield from the Aral Sea was 44,000 metric tons in the 1950s, but its fishery has since collapsed and all 24 native fish species have disappeared. Salinization of the lake and desertification of catchment is underway, with serious consequences for the human and economic health of the region (Micklin 1988; Postel 1992). Similar patterns in the decline of fish catches, up to 90 percent following construction of diversion projects on major rivers, have been recorded for the shallow coastal zones of the Black Sea, Sea of Azoz, and Caspian Sea (Rozengurt et al. 1987).

Cross and Moss (1987) reported that aquatic habitats and fish assemblages of plains streams of Kansas (i.e., Arkansas River) changed due to a variety of human influences (e.g., diversions for irrigation of cropland). In the Kansas high plains, the distinctive local fish fauna had adapted to shallow streams subject to fluctuating flows and shifting sand beds. By eliminating the extreme annual fluctuation in discharge, diversions have caused channels to become narrower, more uniform in depth, and firmer in substrate. The absence of flood peaks has elevated plankton populations and reduced or eliminated predominant turbid-river fishes dependent on floods to trigger spawning, while increased water clarity has favored a different fish species assemblage including sight-feeding planktivores and piscivores.

Between 1970 and 1980, Los Angeles diverted an average of 100,000 ac-ft/yr, or five-sixths of the average flows of principal tributaries (Rush, Lee Vining, Walker, and Parker creeks), from Mono Lake via the Mono Craters Tunnel. As a result of these diversions, Mono Lake shrunk by 40 vertical ft causing increased salinity levels which endangered the lake's suitability as a nesting and feeding area for migratory waterfowl and shorebirds. These diversions also periodically dried up the tributaries and caused catastrophic damage to the trout fisheries and associated riparian vegetation, channel forms, wetlands, and springs (Roos-Collins 1993).

2.3.4 Introduction of Nonindigenous Aquatic Organisms

The obvious potential impact of interbasin water transfers is the breakdown of biogeographic barriers between water basins by the introduction of nonindigenous aquatic organisms. These impacts include disease vectors (water-borne and water-based viruses and bacteria), aquatic plants, phytoplankton, periphyton, zooplankton, aquatic invertebrates (insects, mollusks), and fish and fish pathogens. Problems from diseases and sanitary conditions have been reported as a result of water withdrawal and interbasin transfer in the Soviet Union (Gurvich et al. 1975). The diatom *Stephanodiscus* sp. and the zander (*Stizostedion lucioperca*) have altered the ecology of the River Stour as a result of the Great Ouse interbasin transfer in Great Britain (Guiver 1976). Transfer of non-toxic, malodorous geosmin (a cyanobacterial exudate) from the Theewaterskloof, an impoundment on the Riversonderend system in South Africa, has been reported as affecting rainbow trout (*Oncorhynchus mykiss*) farmed in the Great Berg catchment (Snaddon and Davies 1995).

Reduction of current speed and turbulence, nutrient enrichment, and increase of flow-through time were beneficial for both phytoplankton and zooplankton in the Eastmain River of the La Grande Complex in Canada. Concentrations of chlorophyll A almost doubled from 1.5 mg/ℓ to 2.3 mg/ℓ, while zooplankton density/biomass (i.e., copepods, rotifers, and cladocerans) increased from less than 1,000 individuals per cubic meter (ind/m^3) to 25,000 ind/m^3 and from 800 milligrams per cubic meter (mg/m^3) to more than 20,000 mg/m^3, respectively (Roy and Messier 1989).

Fish transfers in interbasin water transfers are often difficult to evaluate. Part of the problem may stem from how exotic and introduced species are defined. Exotic (non-native) species can cause problems through rapid population growth, colonizing ability, parasite introduction, predation, and possible deleterious interactions with native fish by competing with indigenous fish for food and space (Owen and Elsen 1976; Loch et al. 1979). Introduced fish are harmful because of hybridization and predatory/competitive effects on native fish and their value as game fish. This is a long-term complex set of events rather than an instantaneous occurrence (Clambey et al. 1983). Introduction of piscivorous

Sacramento squawfish (*Ptychocheilus grandis*) into California's Eel River induced major shifts in the spatial partitioning of habitat and microhabitat use within the resident fish assemblage (i.e., Sacramento sucker [*Catostomus occidentalis*], rainbow trout [*Oncorhynchus mykiss*], California roach [*Hesperoleucus symmetricus*], and threespine stickleback [*Gasterosteus*]) (Brown and Moyle 1991). The introduced non-native shortfin molly (*Poecilia mexicana*) caused the decline of the Moapa dace (*Moapa coriacea*) in the Upper Muddy River, Nevada through competition and predation on the larvae (Scoppettone 1993). Introduced non-native salmonids: brown (*Salmo trutta*), brook (*Salvelinus fontinalis*), and rainbow trout have displaced the golden trout (*Oncorhynchus aguabonita*) possibly through competitive mechanisms in the Kern River watershed of the Eastern Sierra Nevada Mountains of California (Schreck and Behnke 1971). Wilcove et al. (1992) reported that 29 endangered fish species are threatened by species introduced in connection with sport fisheries. These include both the deliberate introduction of game fish by fisheries managers and the accidental or deliberate release of bait fish by fisherman.

Introduced organisms may harbor parasites or diseases that can decimate native species (Elton 1958). Transfer of parasites to native fishes by introduced fish vectors has been documented in some instances. The fish louse, *Argulus* (Williams 1980) and the anchor worm, *Lernaea cyprinacea* (Roberts 1978) are now common in several indigenous Australian fishes. Moyle (1986) noted that indigenous California fishes seemed to be more heavily parasitized by exotic parasites, such as *L. cyprinacea*, than exotic fishes. Stocking of Atlantic salmon (*Salmo salar*) smolts from Sweden in 1975 likely caused the introduction of a parasitic fluke (*Gyrodactylus salaris*) to wild salmon populations in Norway (Johnsen and Jensen 1986; Sattaur 1988). Parasites associated with an introduced sturgeon (*Acipenser stellaturs*) devastated populations of a native species (*A. nudiventris*) in the Aral Sea (Bauer and Hoffman 1976).

Courtenay and Moyle (1994) suggested that hybridization is rare with introductions but fairly common with transplants. Hybridization may be very gradual and the effects hard to detect, but it can sometimes be rapid. Importantly, evidence suggest that hybridization can result in reduced fitness of native species. In the 1980s, the sheepshead minnow (*Cyprinodon variegatus*) was released into the Pecos River, where it began to hybridize with the endemic Pecos pupfish (*Cyprinodon pecosensis*). Five years later hybrids could be found along more than 250 miles of stream, while the pure Pecos pupfish no longer existed. Introduced or transplanted fish can also have a substantial impact on other taxa. Kaiser (1991) and Orchard (1992) reported a correlation between the introduction of game fishes in Canadian lakes and subsequent declines in native amphibian populations.

Investigations into effects of water transfer from the Orange/Great Fish River Tunnel in South Africa indicate that five Orange River species (smallmouth yellowfish [*Barbus aeneus*], Orange River mudfish [*Labeo capensis*], mud mullet [*L. umbratus*], sharptooth catfish [*Clarias pariepinus*], and rock barbel [*Gephyroglanis scalteri*]) now have a man-made access to the Great Fish River (Laurenson and Hocutt 1986). Since two of these species (smallmouth yellowfish and Orange River mudfish) occur in both drainages, there is speculation as to whether these species were indigenous stock or introduced exotics (Laurenson et al. 1989). Studies conducted independently on the sharptooth catfish showed that this omnivorous predator on fish and invertebrate prey reduced insect species diversity in coleoptera (beetles) by 78 percent and in hemiptera (true bugs) by 66 percent (Weir 1972; Bruton 1979).

Development of water resources for irrigation via numerous canal systems in the Phoenix metropolitan area of central Arizona have changed the Salt River from a desert river with a high groundwater table to a dry river bed with a depressed water table. In addition, the historic assemblage of 15 native fish species has declined to four. Twenty-nine introduced fish species, luxuriant grows of the green algae, *Cladorpha glomerata* and various blue-greens, and burrowing invertebrates like the introduced Asiatic clam (*Corbicula fluminea*) and introduced crayfish (*Procambarus clarki*) are now present. The physical uniformity of the canals and routine dewatering for maintenance are probable causes of the loss of native species and the almost continual change in the composition of the exotic species in this major lotic habitat (Marsh and Minckley 1982).

The decline of indigenous fishes (e.g., United States, Australia) has most often occurred in disturbed and polluted habitats which introduced species such as poeciliids (livebearers), cyprinids, and cichlids are able to exploit because of their broad environmental tolerances, flexible habitat requirements, and trophic opportunism (Arthington et al. 1983; Courtenay and Stauffer 1984; Moyle et al. 1986). In California, 50-95 percent of introduced fishes have negatively affected native species (Herbold and Moyle 1986).

3.0 REVIEW OF EFFECTS FROM THE INTRODUCED AQUATIC ORGANISMS

3.1 Introduction

One of the most pervasive and damaging anthropogenic impacts on the world's ecosystems is the introduction of nonindigenous species (Elton 1958; Drake et al. 1989). In the United States, at least

4,542 nonindigenous species including several thousand plant and insect species and several hundred non-native vertebrate, mollusk, fish, and plant pathogen species have established free-living populations (Office of Technology and Assessment [OTA] 1993). Approximately 15 percent of these nonindigenous species have caused severe harm affecting agriculture, industry, human health, and the natural environment (OTA 1993). Introduction of species may also lead to extensive ecological changes through a variety of processes including interspecific competition, disturbance, and predation.

The success of introduced organisms depends on many factors, including survivability in unfavorable conditions, adaptability to new environments, high reproductive capability, and ability to disperse rapidly (Baker and Stebbins 1965). Understanding the effects of introduced species on different ecosystems is critical because successful exotics may render previously stable systems unbalanced and unpredictable. Such global mixing of organisms has contributed to the worldwide loss of diversity in aquatic (Baker and Stebbins 1965) and terrestrial (Heywood 1989) communities. Although the number of species, dispersal rates, and the factors controlling movement and establishment has received much attention recently (Groves and Burton 1986; Mooney and Drake 1989), the ecological effects of introduced species worldwide are still poorly known (Vitousek 1986; Pimm 1991).

Since the early 1800s, some of the greatest ecological disasters in the Great Lakes of North America, the world's largest freshwater resource, have resulted from biological invasions. Exotic species have contributed significantly to the biological artificiality of the Great Lakes ecosystem and have had impacts on virtually every ecological niche. For this large freshwater ecosystem, almost 10 percent of established exotic species have had serious impacts, with fish having important long-term ecological and/or economic consequences, especially the earliest introductions. The Great Lakes currently host at least 139 nonindigenous aquatic species. Mills et al. (1993) discusses the introductions of these exotic species, which are represented by aquatic plants (purple loosestripe, *Lythrum salicaria*), fishes (round goby, *Neogobius melanostomus* and tubenose goby, *Proterorhinus marmoratus*), algae (*Stephanodiscus binderanus*), mollusks (guagga mussel, *Driessena bugensis*), crustaceans, oligochaetes, disease pathogens (*Glugea hertwigi*), bryozoans, cnidarians, and flatworms. Major transport vectors through which exotic organisms entered the Great Lakes include: (a) shipping - ballast water, solid ballast, and fouling; (b) deliberate release - stocking of fish; (c) unintentional release - cultivation and aquaculture, bait, aquarium, and accidental; (d) canals; and (e) construction of railroads and highways. Unintentional releases (29 percent) and releases associated with ships (29 percent) are the two most commonly utilized entry vectors of Great Lakes exotic species of which most have come from Eurasia (55 percent) and the Atlantic Coast (13 percent) (Mills et al. 1993, 1994).

Since the Great Lakes has the greatest amount of available data, some representative species from some of the various aquatic components will be used to define the known ecological effects from introductions of aquatic organisms. Potential ecological effects will be summarized from preliminary studies conducted on proposed interbasin water transfers. Both areas will be discussed in the following subsections.

3.2 Known Ecological Effects

Information on the transfer of potentially invasive fish species has been well documented compared to other aquatic organisms, excluding some aquatic plants and mollusks. Welcomme (1981) cites three periods of transfer of invasive fishes: (1) European Middle Ages - Asia to Europe; (2) middle of the 19th century to the beginning of World War II - Europe to Western Hemisphere, Africa, and parts of Asia via immigrants and the early development of international trade; and (3) after World War II, mostly during the 1950s, the early 1970s, and continuing today - Africa and South/Central America to the United States and Asia following the advent of commercial ornamental fish industry/hobby and transcontinental jet air cargo aircraft.

Introduction of fish species has ranged from great success, such as the Pacific salmons (chinook, *Oncorhynchus tshawytscha*; coho, *O. kisutch*; and kokanee, *O. nerka*) in the Great Lakes (Kohler and Courtenay 1986) and the clupied, *Limnothrissa miodon* in lakes Kivu and Kariba, East Africa (Ogutu-Ohwayo and Hecky 1991) to disasters like the brown trout introduced into New Zealand and Australia, the large piscivorous Nile perch (*Lates niloticus*) in Lake Victoria, East Africa, and the predatory centrarchids in Clear Lake, California. Colonization by brown trout was responsible for the extinction of the New Zealand grayling (*Protroctes oxyrhynchus*), the decline/fragmentation of galaxiid (*Galaxis* spp.) fishes, and the elimination/reduction of several plecoptera (stonefly) and trichoptera (caddisfly) along with the decline of the Tasmanian mountain shrimp in Victorian streams (Fletcher 1979; Arthington 1991; Allan and Flecker 1993). The well-intended introduction of Nile perch possibly caused the largest single reduction of vertebrate diversity in the history of ecosystem management and the disruption of a traditional fishing-based society resulting in the loss of 300 species of endemic haplochromine (Cichlidae-*Oreochromis* spp.) (Barbel et al. 1985; Miller 1989; Kaufman 1992). Over many decades (1880-1980), 16 alien fish species were introduced successfully into one of the oldest, largest natural lakes in North America. Although total species richness doubled from 11 native species to 21, six native species were extirpated, two of them becoming globally extinct (Courtenay and Moyle 1992; Courtenay 1993).

In contrast, San Luis Valley, Colorado, illustrates both the problems and the benefits of non-native fish introductions. The impacts of the wide range of introductions (28 out of 52 species) are represented by new competitors (food and space), predators, hybrid combinations, crowding, and stunting that resulted in modification of native fish behavior, environmental modifiers (turbidity, nutrient levels, aquatic vegetation structure), and non-native parasites and diseases. Beneficial effects included providing new food and sport fish for man's use and valuable prey for piscivorous birds (Zuckerman and Behnke 1986). Examples of known ecological impacts from other fish species and aquatic organisms (e.g., microbes, aquatic plants, phyto/zooplankton, macroinvertebrates [benthos, mollusks], amphibians/reptiles, fish pathogens, aquatic mammals) that have been introduced by various mechanisms are listed in Table II-1.

3.3 Potential Ecological Effects

One of the major environmental concerns associated with large-scale water transfers is the potential ecological effects associated with the biota transfer of fish and pathogens (fish- and human-related). Recent construction of the CAP Canal, from the lower Colorado River into the south-central interior of Arizona, was recognized as a potential vector for introduction of non-native fishes (tilapias [*Tilapia* spp.], striped bass, and white bass [*Morone chyrops*]) from the Colorado River into inland Arizona drainages (Grabowski et al. 1984). The CAP Canal could also provide a route for invasion of rainbow smelt (*Osmerus mordax*) into these same drainages if Utah carries out a proposed introduction into a major reservoir upstream in the Colorado system (Courtenay and Robins 1989). Two proposed interbasin water transfers in China, the South-to-North Diversion and the Three Gorges Project, could potentially spread schistosomiasis (human disease) via host snails with the transfer of water (Ganqing 1987).

The possibility of transfer of Missouri River fish species to the Hudson Bay drainage has been cited as one of the major potentially negative consequences of the GDU Project. Transfer of fish may impact the Hudson Bay drainage from: direct interactions between resident and transferred fish species (rainbow smelt; gizzard shad [*Dorosoma cepedianum*]; Utah chub [*Gila atraria*]; zander) and/or transfer of parasites (*Polypodium hydriforme* on sturgeons [*Acipenser* spp.] and paddlefish [*Polyodon spathula*]) or

Table II-1

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
MICROBES						
Cryptosporidium parvum	Fecal waste from young animals (cattle, sheep, swine, deer, racoon, foxes, etc.) via groundwater and surface water runoff	1984/Braun Station, Texas and 1987/Carrollton, Georgia/ widespread (found in 95 percent of all surface waters) including Texas	Affects *Homo sapiens* and other vertebrates (e.g., fish, reptiles)	Cryptosporidiosis - Chronic gastroenteritis/ immunosuppressed individuals and infants	Effective water treatment: coagulation and filtration - one micron porosity pressure filter, ozone/yes	Lederberg et al. 1992; Fox 1994; Moore et al. 1994; Du Pont et al. 1995
Giardia lamblia	Fecal waste from animals (nutria, beaver) via surface runoff	1971/California/potentially nationwide including Texas	Affects *Homo sapiens*	Giardiasis - Chronic gastroenteritis/ immunosuppressed persons and infants	Effective water treatment: conventional rapid sand filters and pretreating by coagulation, flocculation, and settling/yes	Ampy and Gupta 1987; Lederberg et al. 1992; Moore et al. 1994
PHYTOPLANKTON						
Stephanodiscus sp.	Cut-off channel	1976/River Stour/ United Kingdom	Affected diatom species	*Melosira* sp., predominant diatom decreased in abundance	Chlorination and sedimentation/no	Guiver 1976
Various marine diatom species: *Biddulphia* *Chaetoceros* *Skeletonema* *Thalassiosira*	Ballast water exchange	1930s/Great Lakes	*	Shifts in native algal community	Great Lakes Ballast Water control guidelines/no - slight reduction	Stoermer et al. 1985; Sheath 1987; Locke et al. 1993; Mills et al. 1993
AQUATIC PLANTS						
Hydrilla *Hydrilla verticillata*	Vegetative reproduction: tubers and turions via waterways	1940s/Florida/Georgia, Louisiana, Texas, Iowa, California	Affects more desirable aquatic plants	Outcompetes other native species/ impedes navigation, clogs drainage and irrigation canals, reduces recreational activity, and disrupts wildlife habitat	Mechanical (cutting and harvesting) drawdown, chemical (herbicides), sterile triploid grass carp (*Ctenopharyngodon idella*), insects, and plant pathogens/yes - variable	Sculthorpe 1967; Balciunas and Minno 1985; Pieterse and Murphy 1990; Joye and Cofrancesco 1991; Gangstad 1992
Water hyacinth *Eichhornia crassipes*	Seed or vegetative reproduction via waterways	1884/Louisiana/ Virginia south to Florida, west to Missouri and Texas and California	Affects more desirable aquatic plants	Shading and competing with native species/impedes navigation; limits water access and recreation; provides microhabitat for agents of several human diseases: malaria, encephalitis, and schistosomiasis; increases water loss through transpiration; and clogs pipes of hydroelectric systems	Mechanical, chemical (herbicides), arthropods, microbial herbicides, grass carp/yes - variable	Sculthorpe 1967; Correll and Correll 1972; Barrett 1989; Pieterse and Murphy 1990

Table II-1 (Continued)

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
AQUATIC PLANTS (Cont.)						
Eurasion watermilfoil *Myriophyllum spicatum*	Vegetative reproduction (stolens) via waterways	1942/Washington, D.C./ Continental U.S. - 39 states	Affects native plants	Shading and crowding of native plants/affects sportfishes by obstructing predation, sheltering panfish, and covering spawning areas; impairs recreational boating; limits phytoplankton growth and herbivorous zooplankton by assimilating nitrogen and phosphorus; impairs planktivores by restricting open water inhibiting vertical migrations of zooplankters including *Chaoborus* sp.; depletes oxygen levels; stimulates algal blooms by releasing phosphorus	Mechanical, chemical (herbicides), drawdown, phenological plant control, microbial herbicides, phytophagous fish, arthropods, native transplants/yes - variable	Sculthorpe 1967; Hinkle 1986; Madsen et al. 1991; Pieterse and Murphy 1990; Smith and Barko 1990; Engel 1995
Alligatorweed *Alternanthera philoxeroides*	Ship ballast, vegetative reproduction	1894/Southeast U.S./ Coastal Plain: North Carolina to Florida, and west to Louisiana and Texas; and California	Affects native plants	Crowds out native plants/clogs waterways, provides microhabitat for various species of mosquitoes	Chemical (herbicides), biological control (insects: Klamathweed beetle (*Agasicles hygrophila*), moth (*Vogtia malloi*), and fungi)/yes - variable	Correll and Correll 1972; Gangstad et al. 1975; USACE 1984; Pieterse and Murphy 1990
ZOOPLANKTON						
Spiny water flea *Bythotraephes cederstroemii*	Ballast water	1984/Lake Huron/ Great Lakes	Affected native cladocerans	Caused decline in number of grazing zooplankton species (small-bodied cladocerans and rotifers)/decrease in water clarity and changes in abundance of plankton - feeding fishes (decrease in yellow perch [*Perca flavescens*])	Unknown/unknown	Evans 1988; Scavia et al. 1988; Sprules et al. 1990; Garton et al. 1993; Lehman and Caceres 1993; Mills et al. 1993
Water flea *Eubosminia coregoni*	Ballast water	1966/Lake Michigan/ Great Lakes	Affected native zooplankters	Became one of the dominant zooplankters	Unknown/unknown	Deevey and Deevey 1971; Mills et al. 1993
Calanoid copepod *Sinocalanus doerrii*	Ballast water	1978/Sacramento - San Joaquin Estuary	Affected native copepods	Became most abundant copepod/avoids predation by larval fishes more effectively than native copepods	Unknown/unknown	Orsi et al. 1983; Moyle 1991
BENTHIC INVERTEBRATES						
Opposum shrimp *Mysis relicta*	Deliberate release - stocking	1968-1975/Flathead River - Lake ecosystem	Affected and extirpated zooplankton population	Copepod and cladoceran zooplankton populations declined dramatically/ contributed to collapse of planktivorous fish population (e.g., kokanee salmon [*Oncorhynchus nerka*]) and displacement of birds (i.e., bald eagle [*Haliaeetus leucocephalus*]) and mammals (i.e., grizzly bears [*Ursus arctos*]) feeding on spawning kokanee	Reduce opposum shrimp abundance/variable	Beattie and Clancey 1991; Spencer et al. 1991

Table II-1 (Continued)

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
BENTHIC INVERTEBRATES (Cont.)						
Crayfish *Orconectes rusticus*	Deliberate release - bait buckets	1960s/Northern Wisconsin Lakes	Extirpated native and introduced crayfish	Congener extinction of native (*O. virilis*) and introduced (*O. propinquus*) species/ reductions in littoral zone macrophytes and invertebrates; changes in nutrient cycling	Unknown/unknown	Carpenter and Lodge 1986; Olson et al. 1991; Lodge 1993
Blackfly *Simulium chutteri*	Interbasin water transfer	1977/Great Fish River/ South Africa	Affected dominant blackflies	Replaced dominant simuliids (*S. adensi* and *S. nigritarse*)/inflicted biological and economic damage by feeding on blood of livestock	Stop flow of river in winter for one or two months to stimulate effects of periodic droughts in natural regime/unknown	O'Keeffe and de Moor 1988
Mayfly/caddisfly	Interbasin water transfer	1977/Great Fish River/ South Africa	Affected abundant mayflies/ caddisflies	Mayflies: *Baetis harrisoni* increased in abundance along with nonindigenous *B. glaucus* due to an increase in erosional habitat; while the nonindigenous caddisfly, *Cheumatopsyche afra*, also increased in abundance when lower quantities of silt and sand were carried in the water column	Unknown/unknown	O'Keeffe and de Moor 1988
Asiatic clam *Corbicula fluminea*	Birds, sand or gravel, bait or aquarium specimen, free-swimming veliger larva	1938/Columbia River, Washington/Continental U.S. - 35 states	Affects indigenous clam species	Outcompetes and displaces indigenous North American unionid and sphaeriid species by high reproductive capacity and growth rate/invades freshwater transmission systems clogging valves, meters, and condensor tubes in rawwater transport systems; infest water intake areas, damage centrifugal pumps, clog straining screens, and contribute to taste and odor that remain after chemical treatment in municipal water treatment facilities	Drawdowns, chlorination, periodic flushing of static lines, manual shell removal, use of mechanical clam traps, screening intake water; increase or decrease in temperatures (27°C or -15°C), molluscicides/ variable	Britton 1982; McMahon 1983; Counts 1986; Bushek and Cameron 1992; Williams et al. 1993
Zebra mussel *Dreissena polymorpha*	Ballast water, natural (current, birds, animals) and human-related mechanisms (waterways [canals], vessels, navigation, fishery activities, and a wide variety of miscellaneous vectors - aquarium release, scientific research), planktonic eggs/larvae and sedentary juveniles/adults	1988/Lake St. Clair/Great Lakes Drainage Basin, Hudson, Upper/ Lower Mississippi and Susquehanna Drainage Basins	Affects native populations	Alters ecology of aquatic ecosystems: causes major shifts in food-web interactions and in the movement of the nutrients and toxic materials, reduces diversity of species (native unionid clams, phytoplankton, benthos) by their ability to establish large populations/ biofouling of water intake (loss in hydraulic capacity, clogging of strainers/filters, obstruction of valves) and nautical/littoral structures	Monitoring, mechanical, chemical oxidants (chlorination), molluscicides, surface coatings, heat treatment, desiccation, suppressed water velocities, and microsieves; use of fishes - freshwater drum (*Aploditinus grunniens*) and California roach (*Hesperoleucus symmetricus*)/ variable	Strayer 1991; Mills et al. 1993, 1994; Nalepa and Schloesser 1993; Schloesser and Nalepa 1994
AMPHIBIANS						
Bullfrog *Rana catesbeiana*	Unknown	New Mexico and Arizona/ Continental U.S. except western mountainous states and far northern plains	Native species affected	Predation and competition on lowland leopard frog (*Rana yavapaiensis*)/unknown	Unknown/unknown	Stebbins 1985; AGFD 1988; NMDGF 1990

Table II-1 (Continued)

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
REPTILES**						
FISH						
Sea Lamprey *Petromyzon marinus*	Migration through Erie or St. Lawrence Canal systems or attached to boats	1830s/Lake Ontario/Labrador to Florida, Great Lakes, and several New York lakes	Extirpated native fishes	Predation led to decline of native lake trout (*Salvelinus namaycush*), burbot (*Lota lota*), and lake whitefish (*Coregonus clupeaformis*)/ commercial fisheries	Lampricides: TFM and Bayer 73; TFM compound selectively killed lamprey larvae reducing populations to about five percent of their previous levels/variable - neither chemical is registered under Federal Insecticide, Fungicide, and Rodenticide Act Amendment of 1988, thus limiting their availability	Lee et al. 1980; Mooney and Drake 1986; Yount 1990; Mills et al. 1993, 1994; OTA 1993
Ruffle *Gymnocephalus cernuus*	Ballast water	1987/St. Louis River/Lake Superior and Ontonagon River, Michigan, Lake Huron	Affects native fish populations	Competes with native fish species (i.e., preys on eggs of whitefish)/unknown	Stocking predatory fish (northern pike [*Esox lucius*] and walleye [*Stizostedion vitreum*]) to control populations/ unknown	Yount 1990; Mills et al. 1993, 1994; OTA 1993
Blue tilapia *Tilapia aurea*	Deliberate release: research, algal/aquatic vegetation control, bait; multiple spawns	Early 1960's/ Alabama/Florida, Alabama, Texas, Georgia, North Carolina, California, Oklahoma, and Arizona	Affects native fish populations	Ratio of game versus non-game species declined; reproduction of many species (largemouth bass [*Micropterus salmoides*], clupeids [*Dorosoma* spp.], carp [*Cyprinus carpio*], crappie [*Pomoxis* spp.], gar [*Lepisosteus*]) were suppressed by high tilapia abundance	Predatory control (striped bass *[Morone saxatilis*] x white bass [*Morone chrysops*] hybrid, largemouth bass stocking), harvest and water temperature regulation (below 10°C)/yes	Courtenay et al. 1984; Noble and Germany 1986; Muoneke 1988
Large mouth bass/small mouth bass *Micropterus salmoides/ M. dolomieu*	Deliberate release - sport fishing	1928 and 1937/South Africa	Extirpated rare or endangered species/unknown	Reduction or local extinction of eight minnows (*Barbus* and *Oreodaimon* spp.) and one kneria by competing for food and space, disrupting breedng patterns, and parental care of offspring	Unknown/unknown	Skelton 1977; Gaigher et al. 1980; Kleynhans 1985; Bruton and van As 1986
Rainbow/brown trout *Oncorhynchus mykiss/ Salmo trutta*		1890 and 1897/South Africa				
Chinook/coho salmon- *Oncorhynchus tshawytscha/ O. kisutch*	Deliberate release- sport fishing and unintentional release - accidental	1873 and 1933/Great Lakes	Native populations affected	Ecologically and genetically by competition, predation, and introducion of parasites and diseases/ selective forces and/or reduction of effective population size, genetic drift, and inbreeding	Valuable sport fish/yes - not applicable	Krueger and May 1991; Mills et al. 1993, 1994
Brown darter *Etheostoma edwini*	Deliberate release - bait	1960s/Eglin Air Force Base/Alabama, Florida, and Georgia	Affected native fish	Reduced population of endangered okaloosa darter (*Etheostoma okaloosae*) by ecological competition and habitat degradation	Eradication of introduced darter/unknown	Burkhead and Williams 1990; Page and Burr 1991

Table II-1 (Continued)

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
FISH (Cont.)						
Grass carp *Ctenopharyngodon idella*	Deliberate release - research	1963/Alabama and Arkansas/ Continental U.S. - 34 states	Affects native populations	Altered food chain and trophic structure of aquatic systems by inducing changes in vegetation (plant reductions caused increased nutrient concentrations and algal densities, reduced water clarity and zooplankters, decrease in waterfowl population, changes in dissolved oxygen), vertebrates (reduces density and species of phytophilous species with benthic forms increasing), and fish (planktivorus forms increase whereas littoral species decrease, transmit diseases to other species)	Conservation incremental stocking and monitoring of vegetation/yes	Ivasik et al. 1969; Lee et al. 1980; Leslie and Kobylinski 1985; Wiley et al. 1987; Maceina et al. 1992; Bain 1993; Bettoli et al. 1993
Green sunfish *Lepomis cyanellus*	Deliberate release - research	1950s and 1970s/North Carolina and California/U.S. except Northwest and Florida	Extirpated native fish species	Eliminated minnows (redlip shiner [*Notropis chiliticus*], highback chub [*Hybopsis hypsinotus*], and California roach in headwater streams through predation pressure, habitat displacement, and food competition	Long-term species removal/yes	Moyle 1973; Moyle and Nichols 1973, 1974; Pianka 1981; Garman and Nielsen 1982; Lemly 1985
Mosquitofish *Gambusia affinis*	Deliberate release to control mosquito reproduction	1922/California/Southwest: Arizona, California, New Mexico, Texas	Affects native fish population	Competitor reducing populations of killifishes (Cyprinodontidae) and livebearers (Poeciliidae) by predation on fry and niche partitioning by aggression, altering trophic relationships (e.g., invertebrates)	Conduct monitoring and limit introduction of piscivorous fishes/unknown	Lee et al. 1980; Schoenberr 1981; Meffe 1985; Courtenay and Meffe 1989
Red shiner *Cyprinella lutrensis*	Deliberate release - bait	1948/Lower Colorado River/ Colorado River Basin	Affects/expirates native fish species	Demise of Colorado squawfish (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) larvae (Yampa and Green rivers) by predation, caused decline of wound fin (*Plagopterus argentissimus*) (Virgin River) by competitive superiority and tapeworm infestation (red shiner carrier of Asia tapeworm [*Bothriocephalus acheilognathi*]) introduced by grass carp	Unknown/unknown	Heckmann et al. 1986; Deacon 1988; Ruppert et al. 1993; Swift et al. 1993
FISH PARASITES						
Ciliophoran *Trichodina acuta*	Carp (*Cyprinus carpio*)	Unknown/South Africa/ Widespread	Extirpated native fish species	Mass mortalities of Mozambique tilapia (*Oreochromis mossambicus*) and carp fry in Transvaal	Monitoring and fish management, chemicals (chloramine-B, potassium permanganate, quick lime, sodium chloride)/variable	Hoffman 1967; Hoffman and Meyer 1974; van As et al. 1984; Bruton and van As 1986

Table II-1 (Continued)

Known Effects of Native/Non-Native Aquatic Organisms Introduced by Various Mechanisms

Introduced Species	Transport Mechanism	Date Introduced/Location/ Geographic Extent	Native Species Affected or Extirpated	Direct/Indirect Problems	Mitigation Techniques/Successful	References
FISH PARASITES (Cont.)						
Cestotode *Bothriocephalus acheilognathi*	Grass carp (*Ctenopharyngodon idella*)	1975/Eastern Transvaal, South Africa/ Transvaal and Cape, South Africa	Extirpated native fish species	Infect a wide range of cyprinid fishes (mortalities of carp and largemouth yellowfish [*Barbus kimberleyensis*])	Monitoring and fish management, chemicals (calcium chloride, fenasal)/ variable	Hoffman 1967; Hoffman and Meyer 1974; Boomker et al. 1980; Brandt et al. 1981; Bruton and van As 1986
Protozoan *Ichthyophthirius multifilis*, "Ich"	Freshwater fish	Unknown/Transvaal, South Africa/Unknown	Extirpated native fish species	Mortalities of various cultured and aquarium fish, also affects species in wild	Monitoring and fish management, various chemicals (malachite green, formalin, chloramine-T), species dependent/variable	Hoffman 1967; Hoffman and Meyer 1967; van As and Basson 1984; Bruton and van As 1986
Ectoparasitic crustacean *Argulus japonicus*	Carp (*Cyprinus carpio*)	Unknown/Western Transvaal, South Africa/Unknown	Extirpated native species	Mortalities of various indigenous fish species and rainbow trout	Monitoring and fish management, chemicals - lindane/yes	Hoffman 1967; Hoffman and Meyer 1974; Kruger et al. 1983; Bruton and van As 1986; van As and Basson 1988
MAMMALS						
Nutria *Myocastor coypu*	Deliberate release - vegetation control, fur-bearer	1930s/Louisiana/Southeast and Northwest U.S.	Native species affected	Overpopulation: grazing damage to the endangered Texas wild rice (*Zizania texana*)/loss of riparian habitat in San Marcos River	Eradication of species/variable	Whitaker 1980; Nabhan 1988; Davis and Schmidly 1994

* Difficult to determine which species are introductions and which are uncommon native forms that only appeared in abundance after favorable environmental conditions (i.e., salinity) arose, allowing these forms normally found in marine and brackish environments to more readily adapt to freshwater habitats.

** Case et al. (1992) found no documented case in which a native reptile species was reduced to extinction by the introduction of a reptilian competitor.

Legend:

e.g. = exempli gratia (for example)	spp. = species (plural)	AGFD = Arizona Game and Fish Department	USACE = U.S. Army Corps of Engineer	°C = degrees Celsius
i.e. = id est (that is)	et al. = et alii (and others)	OTA = Office of Technology Assessment	NMDFG = New Mexico Department of Fish and Game	
sp. = species (singular)	etc. = et cetera (and so forth)			

pathogens (*Yersinia ruckeri*, a bacterium causing Enteric Redmouth [ERM] and Infectious Hematopoietic Necrosis Virus [IHNV]) to resident fish (trout and salmon) from transferred species (Clambey et al. 1983; Sayler 1990). Seagle (1987) reported that three pathogens (internal protozoan [*Ceratomyxa shasta*], external protozoan [*Cryptobia salmositica*], and *Haemogregarina irkalukpiki*) not currently found in the Parsnip drainage could pose the greatest threat to the valued Pacific salmon fisheries resources. The latter two forms are considered to be of lesser importance, primarily because they both require intermediate hosts and are reported to be less pathogenic. *Ceratomyxa shasta* appears most problematic since it has a direct life cycle, is highly pathogenic, affects economically important species of fish, and could affect a very large geographic area (i.e., the entire Peace-Athabasca-Mackenzie river systems of the McGregor Diversion Project).

3.4 Summary

Proponents of large-scale water development plans commonly insist that the environmental consequences of known/potential ecological effects are minimal (Ray and Messier 1989). When in fact, adverse effects are well-documented in some cases (Hecky et al. 1984). Perhaps most important, case studies establish that some of the most serious issues emerge only after years to decades have elapsed, and they often are unanticipated (i.e., largemouth bass, *Micropterus salmoides* and black crappie, Pomoxis *nigromaculatus* in Lake Atitlan, Guatemula and peacock bass, *Cichla ocellaris* in Gatun Lake, Panama Canal Zone) (Zaret and Paine 1973). As Rosenberg et al. (1987) argues, damage can be assessed after the fact, however, predictive capabilities still are rudimentary. As a consequence, much uncertainty surrounds the outcome of any large-scale disruption of ecological systems (e.g., African tilapia, *Oreochromis* spp. in Lake Nicaragua and an exotic cladocern, *Daphnia lumholtzi*, in North American reservoirs via nonindigenous fishes: Lake Fairfield and Joe Poole Lake, Texas and Lake Texoma, Oklahoma/Texas) (Havel and Hebert 1993; Havel et al. 1995; Lienesch and Gophen 1995; McKaye et al. 1995).

SECTION III

PROPOSED WEST-CENTRAL TO SOUTH-CENTRAL INTERBASIN WATER TRANSFER

1.0 PROJECT DESCRIPTION

The proposed project involves one of the potential water supply alternatives identified during Phase I for the South-Central Texas Study Area. This includes proposed interbasin water transfers via buried pipelines from: (1) an intake structure on a new channel reservoir adjoining the Colorado River to Sandy Creek, an intermittent stream, in Wharton County, Texas; and (2) an intake structure on the Palmetto Bend Dam at Lake Texana in Jackson County, Texas, to the O.N. Stevens Terminal Water Storage Reservoir near Calallen in Nueces County, Texas (Figure III-1). Water from the Colorado River Basin would be introduced into the Lavaca-Navidad River Basin via Sandy Creek and would subsequently flow into Lake Texana. Water from both of these basins would subsequently be transferred to a terminal water storage reservoir at the O.N. Stevens Water Treatment Plant in the Nueces River Basin. Therefore, the Colorado River Basin would potentially serve as a donor basin. The Lavaca-Navidad River Basin would potentially serve as both a donor and recipient basin, while the Nueces River Basin would be a recipient basin.

Water from the Colorado River would be withdrawn approximately 17 river miles (mi) below the City of Garwood (HDR Engineering, Inc. 1993). A 3-to-4 foot (ft) low head dam would be constructed across the river. A new channel reservoir (5 to 10 ft deep) would be constructed along the western shore of the Colorado River. Water from all depths of the river would be diverted into the new channel reservoir. The water would then be pumped through a buried 48- or 60-inch (in) diameter pipeline approximately 16 mi to Sandy Creek (i.e., at the intersection of Highway 1300 and Sandy Creek) in Wharton County. The pipe would be either a steel pipe with mortar lining, a concrete pipe with steel reinforcing, or a ductile iron pipe with mortar lining. Pumping rates would range from a low of 60 cubic feet per second (cfs) to a high of 105 cfs. The most likely water diversion plan would be to pump at a rate of 60 cfs for 294 days per year or 80 percent of the year (Choffel 1995a). A maximum of 35,000 acre-feet (ac-ft) of water would be diverted during the year. The water discharged into Sandy Creek would flow approximately 12 mi downstream to Lake Texana (HDR Engineering, Inc. 1995). Sandy Creek would therefore serve as a conduit system during the water transfer.

Water would be withdrawn from the western outlet of the Palmetto Bend Dam at Lake Texana and transferred via a 104-mi pipeline to the O.N. Stevens Terminal Water Storage Reservoir. The buried 60- or 72-in diameter pipeline, constructed of either a steel pipe with mortar lining, a concrete pipe with steel

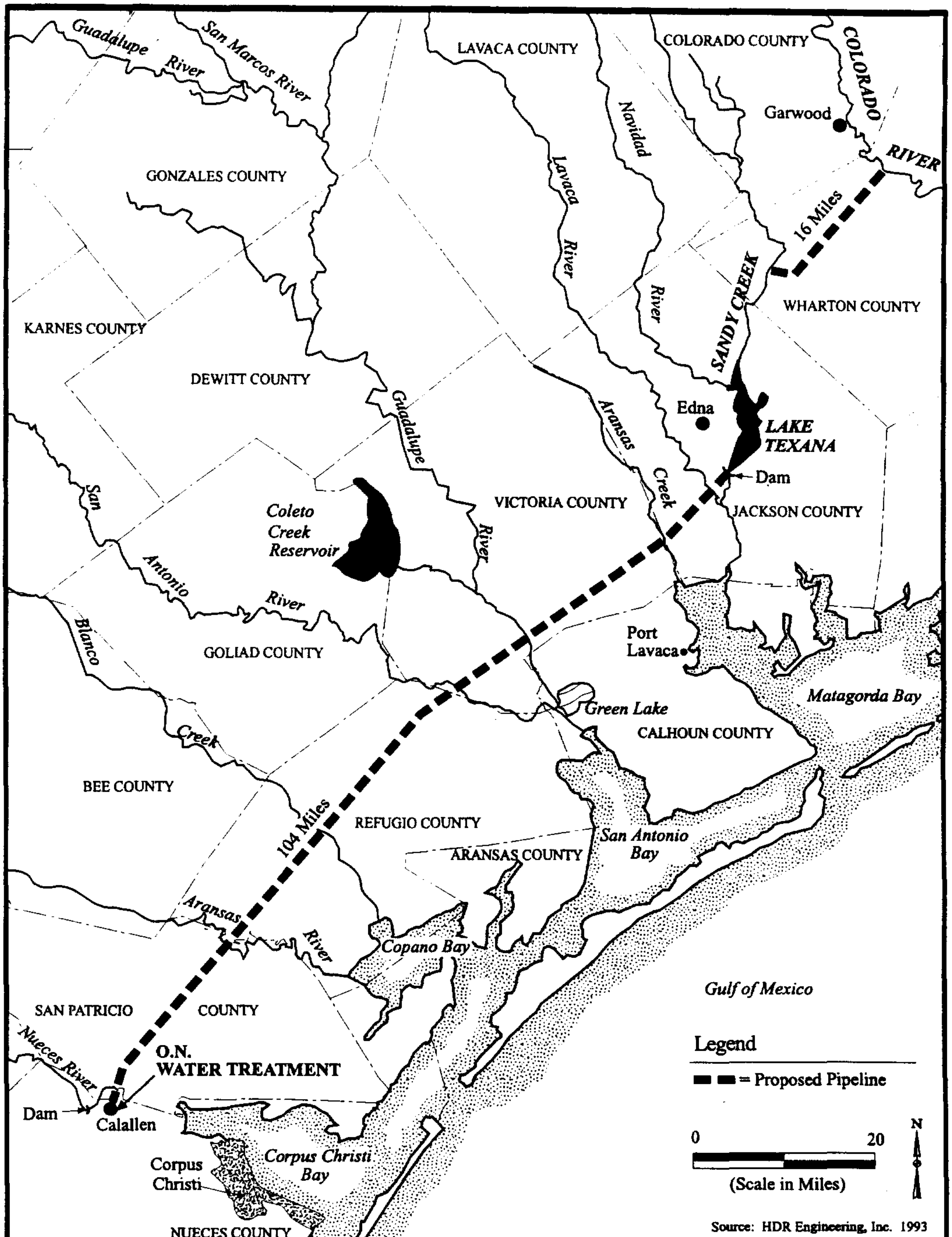


Figure III-1. Location of Proposed Interbasin Water Transfer for the South-Central Study Area.

reinforcing, or a ductile iron pipe with mortar lining, would be used for the Lake Texana to O.N. Stevens Terminal Water Storage Reservoir transfer. The water would be stored in two 3,000-to-4,000 gallon (gal) metal water storage tanks along the proposed route for an undetermined amount of time before being pumped to the terminal water storage reservoir near Calallen. Pumping rates would range from a low of 93 cfs to a high of 132 cfs. Water flow would be continuous. The maximum allowable water transfer from Lake Texana would be 41,840 ac-ft of water per year (HDR Engineering, Inc. 1993, 1995; Choffel 1995a, 1995b).

The terminal water storage reservoir at the O. N. Stevens Water Treatment Plant currently covers 17 acres (ac) in the northwest corner of the plant site. The reservoir has 2-in thick soil cement slopes and a compacted 12-in clay liner on the bottom. The total storage capacity of the reservoir is approximately 120 million gal. At maximum storage capacity the water is 22 ft deep (Bridges 1995; Garana 1995).

Raw water is pumped from the reservoir behind the Calallen Dam on the Nueces River into the terminal water storage reservoir at the plant. Water from the terminal water storage reservoir is subsequently pumped into the treatment train at the facility. Chlorine dioxide and potassium permanganate are injected at the raw water intakes and raw water reservoir, respectively, before entering the treatment train to control taste and odor. The treatment train utilizes a coagulation, sedimentation, and filtration process and is able to process a maximum of 144 million gal of water daily. All of the water transferred into the terminal water storage reservoir would be processed and subsequently utilized for municipal and manufacturing uses in the city of Corpus Christi. Water in the terminal water storage reservoir has never been directly discharged from the reservoir to another surface water source on or outside the plant boundary (Garana 1995).

2.0 METHODOLOGY

A general qualitative impact assessment methodology was developed to analyze the proposed interbasin water transfer for the South-Central Texas Study Area. The four basic components of the assessment methodology are: (1) a literature search to obtain historic/current abiotic and biotic information on the aquatic environment of the donor/recipient basins and the conduit corridor; (2) the preparation of descriptions of the existing abiotic/biotic aquatic environment of the donor/recipient basins and the conduit corridor; (3) a comparison of species composition between the donor/recipient basins and the conduit corridor utilizing historic and/or current data to determine which species would potentially be transferred; and (4) an evaluation and assessment of the environmental impacts from the potential introduction of aquatic organisms between basins based on distribution and known habitat requirements of the potential transfer species.

As discussed in Section II, descriptions of the existing environment were based on information collected during the literature search. Abiotic components discussed include physiographic location, physical characteristics, hydrology, and physicochemical characteristics. Aquatic abiotic effects are discussed first to provide a basis for the analysis of potential interactions with aquatic biotic communities. Aquatic biotic communities discussed include microbes, phytoplankton, periphyton, aquatic plants, zooplankton, benthic macroinvertebrates, amphibians/reptiles, and fish. When recent baseline ecological data on the composition of biotic communities in the donor/recipient basins and the conduit corridor were not available, historic and or representative data from similar or nearby habitats were used to describe the existing environment.

Species lists for each biotic community were subsequently prepared. The preferred habitat for each transfer species was subsequently researched and compared to the habitat and species composition of the conduit/recipient system to determine if the species would potentially survive the transfer and become established in the conduit system and/or the recipient basin. The potential risk for adverse environmental impacts were subsequently assessed and ranked as low, moderate, high, unknown or no effect for each major aquatic biological community. The uncertainty of each analysis was also rated based on the quality of information available for each major biological component at or in the vicinity of the proposed transfer sites. Three rating categories, low, medium, or high, were used for the uncertainty analysis. A "low rating" indicates that the accuracy of the analysis was generally good, while a "high rating" indicates that the accuracy of the analysis was questionable due to the scarcity of historic/current general and/or site-specific data.

3.0 DESCRIPTION OF THE EXISTING ENVIRONMENT

The existing abiotic/biotic environment of the donor (Colorado River)/recipient (Lake Texana) basins and the conduit corridor (Sandy Creek) are described below based on historic and/or current data available in the literature. The existing environment at the O.N. Stevens Terminal Water Storage Reservoir in the

Nueces River Basin is not considered since water and/or organisms from the terminal water storage reservoir are not currently and would not be directly discharged at any time to nearby surface water sources (Garana 1995).

3.1 Colorado River

3.1.1 Abiotic Environment

3.1.1.1 Physiographic Location

The Colorado River originates in eastern New Mexico and follows a meandering 9,000-mi course southeast to the Gulf of Mexico (Figure III-2). The Brazos River and Guadalupe/Pecos River Basins border the Colorado River Basin to the southeast and southwest, respectively. The major tributaries include Beall's Creek and the Concho, San Saba, Llano, and Pedernales rivers. Most of its tributaries and associated drainage basins are upstream of Austin, Texas. In the study area, the Colorado River traverses the Gulf Coastal Plain, an area of elevated sea bottom with low topography (Mosier and Ray 1992). Below Austin the Colorado River flows through blackland prairie, post oak, and coastal prairie habitats (Hatch et al. 1990).

3.1.1.2 Physical Characteristics

The Colorado River below Austin is a bedload-dominated fluvial river system with a coarse sand and gravel streambed (Mosier and Ray 1992). Previous researchers have divided the segment of the Colorado River below Austin into distinct river reaches based on geology and channel morphology. The proposed intake structure for the Colorado River to Sandy Creek interbasin water transfer would be located in the Egypt Reach approximately 17 river miles below the city of Garwood (Figure III-3). Although this reach contains some gravel and cobble riffles, it is generally characterized by extensive sand reaches with a braided channel pattern typical of rivers with fine bed materials (Mosier and Ray 1992; Patek 1994). Occasional outcrops of resistant clay, limestone, and sandstone are present in the Egypt Reach (Mosier and Ray 1992).

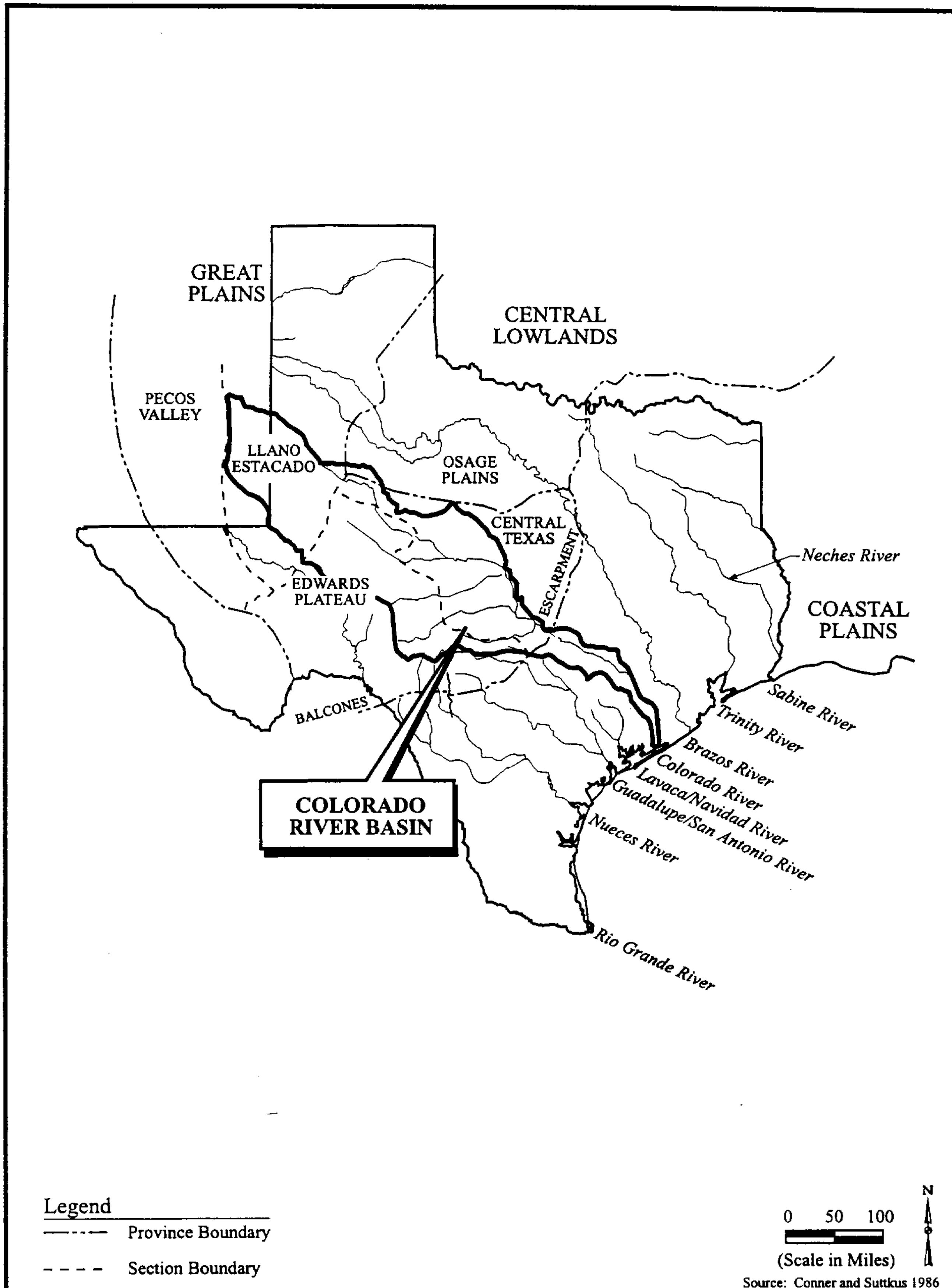


Figure III-2. Physiographic Provinces and Major Drainage Basins of the Western Gulf Slope.

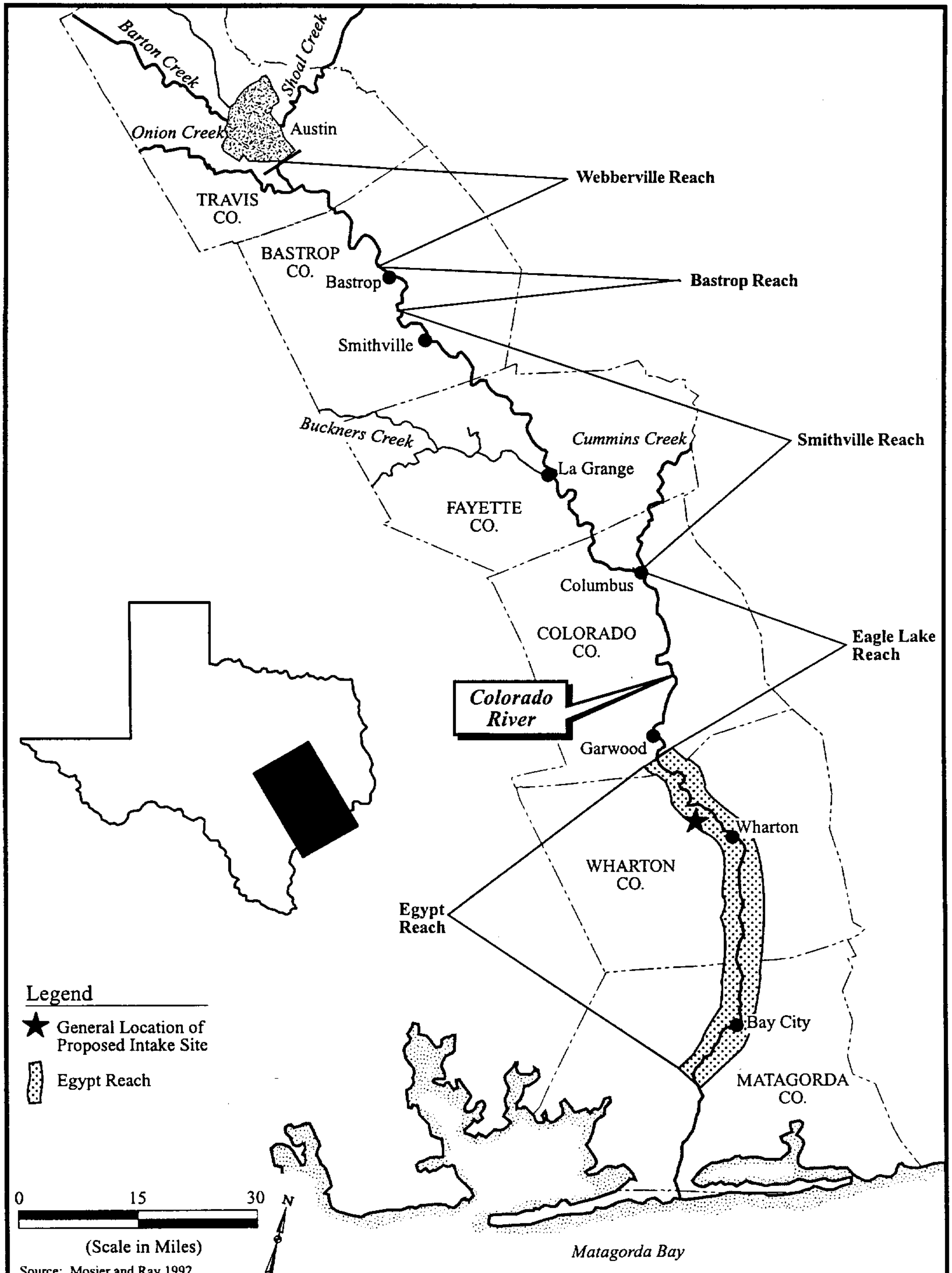


Figure III-3. Colorado River Study Reaches below Austin.

Geologic characteristics of a drainage basin strongly influence the physical characteristics of a stream. The attributes of channel morphology (stream length, meander patterns, pool and riffle sequence, substrate distribution, slope, cross sectional characteristics, and chemical characteristics) are responsible for the relatively large habitat diversity in rivers and streams. Riverine habitats in the Colorado River include riffles, rapids, chutes, runs, pools, and backwaters (Mosier and Ray 1992). These habitats are described below:

- RIFFLES - Riffles are shallow reaches with fast water causing some surface disturbance. The size of the substrate is generally larger in riffles due to the evacuation of larger materials from pools and subsequent deposition on riffles during high flow periods. The substrate provides instream cover in the form of velocity shelters.

- RAPIDS - Rapids are fast, shallow or deep water with substantial whitewater. Rapids often develop at rock outcrops or other areas where the substrate is highly resistant to transport and a substantial drop in elevation occurs. The substrate is commonly a bedrock sheet overlain with gravel to boulder-sized bed material.

- CHUTES - Chutes are areas of deep, fast water with little or no surface disturbance. Chutes are caused by constrictions in the channel or between objects such as large boulders.

- RUNS - Runs are shallow reaches with moderate to fast water and little or no visible surface disturbance. Runs may also be wide, shallow areas in a pool. The substrate is usually sand, gravel, or rubble.

- POOLS - Pools are deep reaches along the main channel with relatively slow current. The substrate is normally sand or silt. Pools frequently have a deep steeply sloped bank on the outside of a bend and a shallow area on the inside curve of the bend. The deep side may form undercut banks or expose roots thereby providing instream cover for fish. Additional instream cover is provided by fallen trees which tend to accumulate to accumulate in pools

- BACKWATERS - Backwaters are quiescent, normally shallow areas contiguous to the main channel with little or no current. Typical backwaters are sloughs and the mouths of smaller streams. The substrate is typically silt and detritus.

3.1.1.3 Hydrology

Prior to 1937, the flow of the Colorado River was not regulated. Since that time, human needs (i.e., water for commercial, residential, and recreational use) have resulted in the construction of 10 reservoirs on the Colorado mainstem. These reservoirs include: J.B. Thomas, E.O. Spence and Owen Ivy in Central and West-Central Texas, and the Highland lakes (Buchanan, Inks, Lyndon B. Johnson, Marble Falls, Travis, Austin Reservoir, and Town Lake). In addition, four low-water dams are located on the Colorado south of Austin (Mosier and Ray 1992). Depending on design, low-water dams may create lentic conditions upstream, however, they usually do not significantly alter downstream river flow regimes.

Flows prior to impoundment of the Colorado River generally followed rainfall patterns, resulting in high spring flows, substantially lower flows during the summer, a slight increase in flow during the hurricane season, and lower flows during the winter months. Other than the period from 1941 to 1965 when the Lower Colorado River Authority (LCRA) hydroelectric generation resulted in median winter flows equal or greater than pre-impoundment flows, the Colorado River has been characterized by low flows. The median flow rates for the Colorado River at Columbus from 1966-1990 vary from a low of 700 cfs in late summer (August) to 900 cfs in winter (December) to a high of 2,800 cfs in late spring (May). Based on measurements made in 1990, normal flow rates in the vicinity of the proposed intake would potentially range from 100 to 1,500 cfs (Mosier and Ray 1992).

The LCRA entered into a memorandum of agreement with Texas Parks and Wildlife Department (TPWD) in 1988 to perform a study designed to determine flow levels appropriate to maintain a healthy, native aquatic community in the Colorado River. The recommended flows for the Colorado River downstream from Austin are listed in Table III-1.

Table III-1

Recommended Target Flow (cfs) Schedule for the Colorado River Downstream of Austin

	Study Reach				
Month	Webberville	Bastrop	Smithville	Eagle Lake	Egypt
January	214	369	457	295	240
February	247	426	529	341	277
March	322	555	688	444	361
April	351	605	750	484	393
May	596	1028	1275	822	668
June	480	827	1026	662	538
July	214	369	457	295	240
August	141	244	302	195	158
September	233	402	498	321	261
October	274	473	586	378	307
November	213	366	454	293	238
December	195	337	417	269	219

Legend: cfs = cubic feet per second

Source: Mosier and Ray 1992

Instream/estuarine flow rates to protect aquatic life in the Colorado River have been adopted by the State of Texas (Texas Natural Resource Conservation Commission [TNRCC] 1994a).

3.1.1.4 Physicochemical Characteristics

The TNRCC recognizes the geologic and hydrologic diversity of the state by dividing major river basins, reservoirs, bays, and estuaries into defined segments (referred to as classified segments). Waters are classified as supporting, partially supporting, or not supporting their individual uses based on rating criteria developed by the TNRCC or established by the U.S. Environmental Protection Agency (USEPA) in guidance for the State of Texas Water Quality Report prepared pursuant to Section 305b of the Clean Water Act (USEPA 1993). The Texas Surface Water Quality Standards (TSWQS) (30 Texas Administrative Code [TAC] § 307.2-307.10) include: (1) general standards which apply to all surface waters in the state and (2) segment-specific standards which identify appropriate uses (aquatic life, contact recreation, drinking water, etc.) and designate limits for common indicators (criteria) of water quality (such as dissolved oxygen, temperature, pH, chloride, sulfate, and total dissolved solids) (Table III-2). Screening levels were developed to identify areas where elevated levels of various parameters are a cause for concern (fecal coliforms, specific nutrients, and chlorophyll A). Standards were also established for specific toxic substances and total toxicity. Specific numerical criteria for the protection of aquatic life from 35 toxic materials (e.g., metals, organic chemicals) and protection of human health from 61 toxic materials in drinking water and freshwater fish are listed in the standards (Table III-3 and Table III-4). An exceptionally high, intermediate, or limited aquatic life classification is assigned to each waterbody in the TSWQS based on physical, chemical, and biological characteristics (see Table III-2). The TNRCC is designated by state law as the agency responsible for monitoring water quality through the Surface Water Quality Monitoring (SWQM) Program. Stations within the classified segments are sampled by the TNRCC several times each year (TNRCC 1994b).

Water quality in the Colorado River changes with location due to the man-made uses (impoundment, diversions, recycling, etc.). Water quality has improved in the Colorado River Basin over the past years. Although local violations of water quality standards do occur due to human influences, the water quality in the Colorado River Basin is suitable for its designated uses (i.e., contact recreation, high quality aquatic habitat, public water supply). Dramatic improvements have occurred below Austin due to the upgrade of wastewater treatment plants. Although improvements have been made at the largest point sources in Austin, there is still considerable concern with regard to nutrient enrichment/pollution. Non-point pollution and toxic chemicals are sources of concern (TWC 1992a).

The TNRCC, LCRA, and U.S. Geological Survey (USGS) have conducted numerous physicochemical analyses in the Colorado River Basin. The TNRCC conducts water quality assessments in designated segments of the Colorado River several times each year. Water quality assessments of the Colorado River Basin have also been conducted by the LCRA with assistance from the Upper Colorado River Authority and the Colorado River Municipal Water Authority. The LCRA established a Reservoir and Stream (RSS) monitoring program in 1982 to serve as a general surveillance and trend assessment tool for monitoring water quality in the Colorado River Basin. The goal of this program is to determine the general levels of water quality over a broad area and to serve as an early warning system for extreme pollution problems. Monitoring of the Colorado River was conducted by the LCRA on a monthly basis from 1982 until the spring of 1990 when bimonthly monitoring was initiated (Patek 1994). The USGS

Table III-2

Texas Surface Water Quality Criteria and Screening Levels

Parameters	Criteria[1]	Screening Levels[2]
Dissolved Oxygen (mg/ℓ)	Segment Specific	
Temperature (°C)	Segment Specific	
pH	Segment Specific	
Chloride (mg/ℓ)	Segment Specific	
Sulfate (mg/ℓ)	Segment Specific	
Total Dissolved Solids (mg/ℓ)	Segment Specific	
Fecal Coliforms (# colonies/100 mℓ):		
Contact Recreation		400 colonies/100 mℓ
Criteria for Freshwater Streams and Reservoirs		
Ammonia Nitrogen		1.0 mg/ℓ
Nitrite + Nitrate Nitrogen		1.0 mg/ℓ
Orthophosphate Phosphorus		0.1 mg/ℓ
Total Phosphorus		0.4 mg/ℓ
Chlorophyll A		30 μg/ℓ

[1]An area for which specific parameters are set for aquatic life use designations

[2]Screening levels are developed to identify areas where elevated concentrations of various parameters are a cause for concern

Legend:
mg/ℓ = milligrams per liter
°C = degrees Celsius
pH = hydrogen-ion
ml = milliliter
μg/ℓ = micrograms per liter

Source: TNRCC 1994b

Table III-3

Toxicants with Criteria to Protect Freshwater Aquatic Life

Parameter	Acute Criteria	Chronic Criteria
Aldrin	3.0	-
Aluminum[a]	991	-
Arsenic[a]	360	190
Cadmium[a]	$_e$(1.128[In(hardness)]-1.6774)	$_e$(0.7825[In(hardness)]-3.490)
Carbaryl	2.0	-
Chlordane	2.4	0.0043
Chlorpyrifos	0.083	0.041
Chromium (Tri)[a]	$_e$(0.8190[In(hardness)]+3.688)	$_e$(0.8190[In(hardness)]+1.561)
Chromium (Hex)[a]	16	11
Copper[a]	$_e$(0.9422[In(hardness)]-1.3844)	$_e$(0.8545[In(hardness)]-1.386)
Cyanide*	45.78	10.69
DDT (Dichloro diphenyl trichloroethane)	1.1	0.0010
Demeton	-	0.1
Dieldrin	2.5	0.0019
Endosulfan I&II	0.22	0.056
Endrin	0.18	0.0023
Lindane (Gamahexachlorocyclohexane)	2.0	0.08
Guthion	-	0.01
Heptachlor	0.52	0.0038
Lead[a]	$_e$(1.273[In(hardness)]-1.460)	$_e$(1.273[In(hardness)]-4.705)
Malathion	-	0.01
Mercury[a]	2.4	1.3
Methoxychlor	-	0.03
Mirex	-	0.001
Nickel[a]	$_e$(0.8460[In(hardness)]+3.3612)	$_e$(0.8460[In(hardness)]+1.1645)
Total PCBs (Polychlorinated Biphenyls)	2.0	0.014
Parathion	0.065	0.013
Phenanthrene	30	30
PCP (Pentachlorolphenol)	$_e$(1.005(pH)-4.830)	$_e$(1.005(pH)-5.290)
Selenium[a]	20	5
Silver, as free ion[a]	0.92	0.49
Toxaphene	0.78	0.0002
Tributlytin	0.13	0.024
2, 4, 5-Trichlorolphenol	136	64
Zinc[a]	$_e$(0.8473[In(hardness)]+0.8604)	$_e$(0.8473[In(hardness)]+0.7614)

[a]Criteria for a specific parameter are for the dissolved portion in water.
All other criteria are for total recoverable concentrations.
*Amenable to chlorination
$_e$log scale

Note: All values are listed or calculated in micrograms per liter ($\mu g/\ell$).
Hardness concentrations are milligrams per liter (mg/ℓ).

Legend: pH = hydrogen-ion

Source: 30 TAC § 307

Table III-4

Toxicants with Human Health Criteria to Protect Human Consumption of Drinking Water and Freshwater Fish

Compound	Water and Fish ($\mu g/\ell$)	Fish Only ($\mu g/\ell$)
Aldrin	0.0312	0.0327
Alpha-hexachlorocyclohexane	0.645	0.997
Arsenic[a]	50*	-
Barium[a]	1000*	-
Benzene	5*	312
Benzidine**	0.0011	0.0035
Beta-hexachlorocyclohexane	2.26	3.49
Bis (chloromethyl) ether	0.0207	1.59
Cadmium[a]	10*	-
Carbon Tetrachloride	5*	182
Chlordane***	0.0210	0.0213
Chlorobenzene	1305	4947
Chloroform	100*	12130
Chromium[a]	50*	-
Cresols	4049	46667
DDD (Dichloro diphenyl dichloroethane)	0.297	0.299
DDE (Dichloro diphenyl ethylene)	0.0544	0.0545
DDT (Dichloro diphenyl trichloroethane)	0.0527	0.0528
2, 4-D (Dichlorophenoxyacaetic Acid-herbicide)100*	-	
Danitol	0.709	0.721
Dibromochloromethane	1590	15354
1, 2-Dibromoethane	0.0518	1.15
Dieldrin**	0.0012	0.0012
p-Dichlorobenzene, (1, 4-Dichlorobenzene)	75*	-
1, 2-Dichloroethane	5*	1794
1, 1-Dichloroethylene	7*	87.4
Dicofol	0.215	0.217
Dioxins/Furans (TCDD Equivalents)**	0.0000010	0.0000010

Compound	Equivalency Factors
2, 3, 7, 8-TCDD	1
2, 3, 7, 8-PeCDD	0.5
2, 3, 7, 8-HxCDD	0.1
2, 3, 7, 8-TCDF	0.1
1, 2, 3, 7, 8-PeCDF	0.05
2, 3, 4, 7, 8-PeCDF	0.5
2, 3, 7, 8-HxCDF	0.1

Endrine	.2*	-
Fluoride	4000*	-
Gamma Hexachlorocyclohexane (Lindane)	4*	16.0
Heptachlor	0.0177	0.0181
Heptachlor Epoxide	1.08	7.39
Hexachlorobenzene	0.0129	0.0129
Hexachlorobutadiene	9.34	11.2
Hexachloroethane	84.4	94.1
Hexachlorophene	0.0531	0.0532
Lead[a]	5.00	25.0

Table III-4 (Continued)

Toxicants with Human Health Criteria to Protect Human Consumption of Drinking Water and Freshwater Fish

Compound	Water and Fish ($\mu g/\ell$)	Fish Only ($\mu g/\ell$)
Mercury***	0.0122	0.0122
Methoxychlor	100*	-
Methyl Ethyl Ketone	4411	886667
Mirex	0.0171	0.0189
Nitrate-N	10000*	-
Nitrobenzene	41.8	721
n-Nitrosodiethylamine	0.0382	7.68
N-Nitroso-di-n-Butylamine	1.84	13.5
PCBs (Polychlorinated Biphenyls)	0.0013	0.0013
Pentachlorobenzene	1.09	1.11
Pentachlorolphenol	129	136
Pyridine	88.1	13333
Selenium[a]	10*	-
Silver[a]	50*	-
1, 2, 4, 5-D Tetrachlorobenzene	1.43	1.52
Tetrachloroethylene	597	1832
Toxaphene**	0.0440	0.0445
2, 4, 5-TP (Silvex)	10*	-
2, 4, 5-Trichlorophenol	2767	4021
Trichloroethylene	5*	-
1, 1, 1-Trichloroethane	200*	-
TTHM (Total Trihalemethanes)	100*	-
Vinyl Chloride	2*	94.5

*Based on maximum contaminant levels specified by the Texas Department of Health in 25 TAC § 337 (relating to Drinking Water Standards)

**Calculations based on measured bioconcentration factors; no lipid content correction factor was applied

***Calculations based on U.S. Food and Drug Administration Action Levels for fish tissue concentrations

[a]Indicates that the criteria for a specific parameter are for the dissolved portion in water. All other criteria are for total recoverable concentrations.

Legend: $\mu g/\ell$ = micrograms per liter

Source: 30 TAC § 307

also conducts water quality assessments at various locations along the Colorado River. Monitoring is generally bimonthly and includes a wider range of parameters.

The proposed intake site is located within TNRCC Segment 1402 (Figure III-4). A summary of water quality data from this segment, which covers the area from below Smithville to below Bay City, is listed in Table III-5. This segment occasionally experiences compliance problems due to elevated levels of chloride, sulfate, total dissolved solids (TDS), nitrates, orthophosporus, and total phosphorus (TNRCC 1994b). The LCRA water quality summary statistics above (Station 1402.0200) and below (Station 1402.0100) the proposed intake site for the water transfer are listed in Table III-6. Both stations have similar mean values for most physicochemical parameters. However, there are noticeable differences in mean values for ammonia, TDS, and total suspended solids (TSS). The nearest USGS water quality sampling station to the proposed intake site on the Colorado River is at Wharton (Table III-7). Water quality parameters at Wharton are within TSWQS standards. The TNRCC has recently started to monitor toxic substances in sediments and water. Only one exceedance (i.e., arsenic in sediment) was reported in the Colorado River in 1993 (Tables III-8 and III-9).

3.1.2 Biotic Environment

3.1.2.1 Microbes

- Community Composition

Specific investigations concerning microbial communities, with the exception of fecal coliforms, have not been conducted in the Colorado River below Austin. A general characterization of the microbial community expected to occur in the Colorado River is presented below based on a review of pertinent riverine literature.

The bacterial flora of riverine surface waters is quite diverse. Its overall composition depends, above all, on the supply of nutrients in the water and on other terrestrial influences. In flowing waters, which are poor in nutrients, gram-negative non-sporing rods still predominate. In addition, there are often various stalked bacteria like *Hyphomicrobium*, *Caulobacter* and *Gallionella*, and pseudomonads. The genera *Flavobacterium* and *Acinetobacter* are dominant in relatively clean streams; however, with

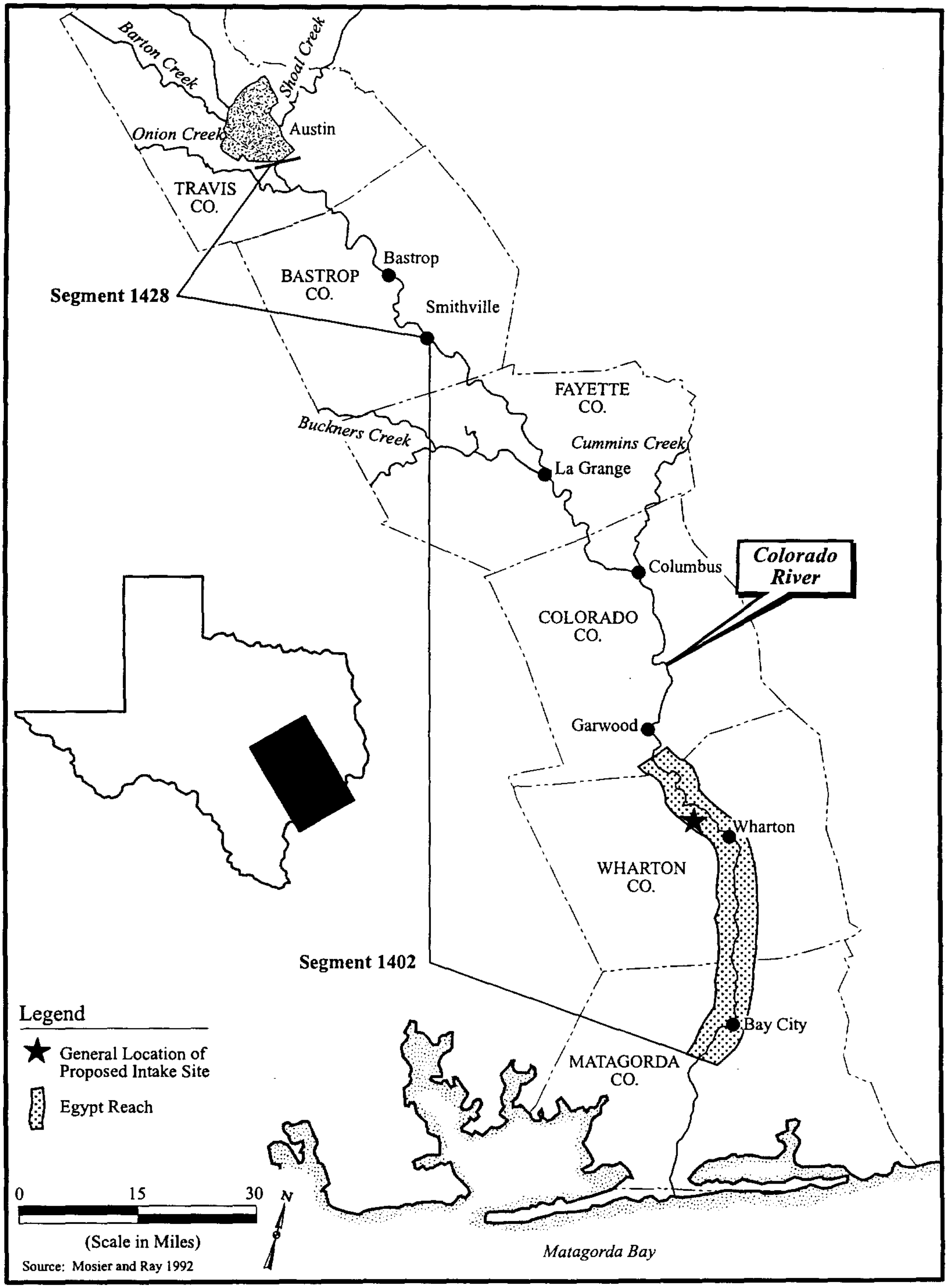


Figure III-4. TNRCC Designated Segments 1428 and 1402, Colorado River.

Table III-5

Field Measurements and Water Chemistry for Colorado River Below Smithville (Segment 1402)

Parameters	Standards Criteria	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Values Outside Criteria or Screening Levels	
							Number	Mean
Water Temperature[1]	35.00		41	10.00	32.00	22.94	0	0.0
Dissolved Oxygen[2]	5.00		41	5.20	10.80	8.16	0	0.0
pH[3]	6.50-9.00		35	7.40	8.90	8.19	0	0.0
Chloride[2]	90.00		39	4.00	141.00	77.95	15	113.0
Sulfate[2]	60.00		40	1.00	110.00	65.01	24	80.7
Conductivity Field[4]			13	300.00	912.00	729.69	0	0.0
Total Dissolved Solids[2]	450.0		35	195.70	592.58	403.72	13	515.8
Ammonia[2]		1.00	40	0.01	0.56	0.07	0	0.0
Nitrates + Nitrites[2]		1.00	40	0.10	3.59	1.01	14	1.8
Orthophosphorus[2]		0.10	40	0.01	1.03	0.32	33	0.4
Total Phosphorus[2]		0.20	40	0.06	1.76	0.41	31	0.5
Chlorophyll A[5]		30.00	16	1.00	25.40	5.47	0	0.0

[1]°C (degrees Celsius)
[2]mg/ℓ (milligrams per liter)
[3]pH (hydrogen-ion)
[4]µmhos (micromhos)
[5]µg/ℓ (micrograms per liter)

Source: TNRCC 1994b

Table III-6

Summary of Water Quality Statistics for Stations 1402.0100 and 1402.0200 on the Colorado River

Parameter	Number of Records (1)	(2)	Mean (1)	(2)	Median (1)	(2)	Minimum (1)	(2)	Maximum (1)	(2)	Range (1)	(2)
Chlorophyll A[1]	90	90	0.0055	0.0045	0.003	0.003	0.0	0.0	0.046	0.028	0.046	0.028
Chloride[2]	90	90	62.7822	62.1533	57.0	55.0	12.0	16.0	141.4	143.4	129.4	127.4
Specific Conductivity[3]	90	90	602.0778	597.0889	608.5	584.5	266.0	288.0	899.0	901.0	633.0	613.0
Dissolved Oxygen[2]	90	90	8.4878	8.4067	8.3	8.2	5.9	6.4	12.4	14.1	6.5	7.7
Ammonia Nitrogen[2]	90	90	0.0552	0.055	0.03	0.04	0.01	0.01	0.54	0.25	0.53	0.24
Nitrate + Nitrite Nitrogen[2]	90	90	0.7941	0.8347	0.72	0.725	0.02	0.07	2.92	3.27	2.9	3.2
Orthophosphorus[2]	90	90	0.276	0.2825	0.235	0.25	0.01	0.003	0.86	0.86	0.85	0.857
pH[4]	90	90	8.1433	8.0867	8.15	8.1	7.0	7.3	9.4	8.8	2.4	1.5
Secchi Depth[5]	90	90	1.2422	1.6928	1.0	1.15	0.0	0.2	4.5	8.0	4.5	7.8
Sulfate[2]	90	90	47.68	48.0911	44.0	43.0	12.0	17.0	100.0	106.0	88.0	89.0
Total Dissolved Solids[2]	90	90	354.5444	339.615	343.0	331.0	120.0	0.35	850.0	532.0	730.0	531.65
Temperature[6]	90	90	21.5856	21.7811	22.3	23.05	7.2	5.4	31.6	31.6	24.4	26.2
Total Kjeldahl Nitrogen[2]	90	90	0.9601	0.9198	0.775	0.825	0.02	0.25	5.63	4.11	5.61	3.86
Total Organic Carbon[2]	90	90	4.6667	4.4011	4.0	4.0	2.0	1.0	16.0	11.0	14.0	10.0
Total Phosphorus[2]	90	90	0.4136	0.3876	0.35	0.34	0.07	0.002	1.61	1.49	1.54	1.488
Total Suspended Solids[2]	90	90	104.3356	69.4333	59.5	41.0	0.2	2.0	1140.0	618.0	1139.8	616.0

1 = Sampling Station 1402.0100 - Colorado River at Business 59 (State Highway [SH] Loop 183), Wharton County (river mile [R.M.] 66.6) - Downstream from intake point

2 = Sampling Station 1042.0200 - Colorado River at Farm Market (FM) 950 (R.M. 100.5) - Upstream from intake point

[1] μg/ℓ (micrograms/liter)
[2] mg/ℓ (milligrams/liter)
[3] μmhos (micromhos)
[4] pH (hydrogen-ion)
[5] ft (feet)
[6] °C (degrees Celsius)

Source: Patek 1994

Table III-7

Water Quality Parameters - Colorado River at Wharton in 1994

Parameters	Jan 19	Mar 28	May 25	Jul 12	Sep 06	Water Quality Standards
Regulated						
pH[1]	8.0	8.2	7.6	7.6	8.3	6.5-9.0
Temperature[2]	10.0	14.0	25.5	30.0	26.0	35
Dissolved Oxygen[3]	11.0	10.0	7.5	8.0	7.7	5.0
Dissolved Sulfate[3]	49.0	46.0	36.0	41.0	41.0	60
Dissolved Chloride[3]	63.0	62.0	41.0	60.0	61.0	90
Dissolved Flouride[3]	0.3	0.3	0.3	0.3	0.3	4000
Total Dissolved Solids[3]	397.0	371.0	260.0	328.0	333.0	450
Suspended Sediment[3]	9.0	25.0	72.0	95.0	53.0	-
Dissolved Aluminum[4]	< 10	-	20.0	-	< 10	991
Dissolved Barium[4]	120.0	-	97.0	-	93.0	1000
Dissolved Selenium[4]	< 1.0	-	< 1.0	-	< 1.0	20/5*
Dissolved Silver[4]	< 1.0	-	< 1.0	-	< 1.0	0.92/0.49*
Non-Regulated						
Specific Conductance[5]	707.0	655.0	480.0	580.0	606.0	NA
Turbidity (NTU)	1.1	6.0	23.0	46.0	1.2	NA
Total Hardness[3]	260.0	240.0	180.0	220.0	220.0	NA
Alkalinity[3]	221.0	199.0	123.0	161.0	167.0	NA
Dissolved Silica[3]	4.6	9.6	13.0	11.0	10.0	NA
Total Nitrogen - Nitrate[3]	1.67	0.94	0.95	0.66	0.69	NA
Dissolved Phosphorus[3]	0.15	0.24	0.18	0.17	0.18	NA
Dissolved Orthophosphorus[3]	0.17	0.23	0.19	0.12	0.17	NA
Dissolved Orthophosphate[3]	0.52	0.71	0.58	0.37	0.52	NA

*Acute/chronic criteria
[1]pH (hydrogen-ion)
[2]°C (degrees Celsius)
[3]mg/ℓ (milligrams per liter)
[4]μg/ℓ (micrograms per liter)
[5]μS/cm (microsiemens per centimeter)

Legend: NTU = Nephelometric Turbidity Units
NA = Not Applicable

Source: Gandara et al. 1995; 30 TAC § 307

Table III-8

Toxic Substances in Sediment for Colorado River Below Smithville (Segment 1402)

Parameters	Units	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Number of Values Outside Criterion or Screening Levels
Arsenic	mg/kg	6.700	3	1.700	7.200	4.867	1
Barium	mg/kg	190.000	3	37.000	150.000	90.000	0
Cadmium	mg/kg	2.000	3	0.100	0.250	0.167	0
Chromium	mg/kg	26.000	3	7.800	17.000	11.600	0
Copper	mg/kg	21.000	3	2.900	11.000	6.300	0
Lead	mg/kg	50.000	3	0.500	32.000	17.500	0
Manganese	mg/kg	481.000	3	110.000	460.000	255.000	0
Mercury	mg/kg	0.090	3	0.005	0.030	0.015	0
Nickel	mg/kg	18.000	3	1.000	11.000	5.033	0
Selenium	mg/kg	0.960	2	0.100	0.200	0.150	0
Silver	mg/kg	1.600	3	0.100	0.250	0.167	0
Zinc	mg/kg	93.000	3	24.000	53.000	34.000	0
Aldrin	μg/kg	0.500	2	0.250	0.500	0.375	0
Alpha-Hexachlorocyclohexane	μg/kg	0.500	0	NAV	NAV	NAV	0
Gama-Hexachlorocyclohexane	μg/kg	0.500	2	0.500	0.500	0.500	0
Bis (2-Ethylhexyl) Phthalate	μg/kg	1197.000	3	150.000	150.000	150.000	0
Diazinon	μg/kg	2.880	3	2.500	2.500	2.500	0
Di-N-Butyl Phthalate	μg/kg	505.120	3	25.000	25.000	25.000	0
Chlordane	μg/kg	6.000	2	1.500	1.500	1.500	0
DDD (Dichlorodiphenyldichloride)	μg/kg	3.000	2	1.500	1.500	1.500	0
DDE (Dichlorodiphenylethylene)	μg/kg	5.510	2	0.750	0.750	0.750	0
DDT (Dichlorodiphenyltrichloroethane)	μg/kg	3.000	2	1.500	1.500	1.500	0
Dieldrin	μg/kg	1.000	2	1.000	1.000	1.000	0
Endrin	μg/kg	1.500	2	1.500	1.500	1.500	0
Heptachlor	μg/kg	0.250	2	0.250	0.250	0.250	0
Heptachlor Epoxide	μg/kg	0.500	2	0.500	0.500	0.500	0
Hexachlorobenzene	μg/kg	0.500	0	NAV	NAV	NAV	0
Malathion	μg/kg	2.500	2	2.500	2.500	2.500	0

Table III-8 (Continued)

Toxic Substances in Sediment for Colorado River Below Smithville (Segment 1402)

Parameters	Units	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Number of Values Outside Criterion or Screening Levels
Methoxychlor	µg/kg	5.000	2	5.000	5.000	5.000	0
Parathion	µg/kg	1.500	3	1.500	1.500	1.500	0
PCBs (Polychlorinated Biphenyls)	µg/kg	10.000	3	10.000	10.000	10.000	0
Aroclor 1254	µg/kg	25.000	0	NAV	NAV	NAV	0
PCP (Pentachlorophenol)	µg/kg	2.500	0	NAV	NAV	NAV	0
Silvex	µg/kg	5.000	0	NAV	NAV	NAV	0
Toxaphene	µg/kg	25.000	2	25.000	25.000	25.000	0
2,4-Dichlorophenoxyacaetic acid	µg/kg	25.000	0	NAV	NAV	NAV	0
2,4,5-Trichlorophenol	µg/kg	5.000	0	NAV	NAV	NAV	0

[1]Screening levels were developed utilizing a 10 year period of record (January 1983-December 1992). For this assessment, 50 percent of a reported detection limit was computed and used in developing the screening levels.

Legend: mg/kg = milligrams per kilogram
µg/kg = micrograms per kilogram
NAV = Not Available

Source: TNRCC 1994b

Table III-9

Toxic Substances in Water for Colorado River Below Smithville (Segment 1402)

Parameters ($\mu g/\ell$)	Freshwater Acute Criteria	Freshwater Chronic Criteria	Number of Samples	Minimum	Maximum	Mean	Number of Values Outside Acute Criteria	Mean Exceeds Chronic Criteria
Aluminum	991.000	None	15	5.000	70.000	17.333	0	NA
Arsenic	360.000	190.000	11	0.500	4.000	2.136	0	NO
Cadmium	70.320	1.893	11	0.500	0.500	0.500	0	NO
Chromium, Hexavalent	16.000	11.000	0	NAV	NAV	NAV	NAV	NO
Copper	35.489	22.343	11	1.000	5.000	2.727	0	NO
Lead	187.315	7.299	11	0.500	3.649	0.968	0	NO
Mercury	2.400	1.300	11	0.050	0.100	0.555	0	NO
Nickel	2462.768	273.784	15	0.500	0.500	1.467	0	NO
Selenium	20.000	5.000	15	0.500	1.000	0.533	0	NO
Zinc	203.380	184.210	11	1.500	10.000	5.227	0	NO

Legend: $\mu g/\ell$ = micrograms per liter
NAV = Not Available
NA = Not Applicable

Source: TNRCC 1994b

increasing eutrophication, the proportion of *Flavobacterium* and *Achromobacter* diminishes and representatives of *Pseudomonas, Bacillus*, and the Enterobacteriaceae increase. The number of soil bacteria (*Azotobacter* and nitrifying forms - *Nitrosomonas* and *Nitrobacter*) in flowing waters is generally high. In addition, lotic systems also regularly yield vibrios, thiobacilli, streptomycetes, spirilla, micrococci, cytophageae, and spirochaetes. Sewage-laden streams and rivers carry more or less numerous sewage bacteria (i.e., the intestinal bacteria *Escherichia coli*, coliform strains, and pathogenic salmonellae), while flowing waters heavily loaded with organic waste are the favorite habitat for *Sphaerotilus natans* and related sheated bacteria (Rheinheimer 1985).

Fungi also occur regularly in lotic waters. Some colonize rivers which are relatively poor in nutrients; others prefer more eutrophic flowing waters. Fungi are represented by a number of parasitic phycomycetes (Chytridiales), ascomycetes and Fungi Imperfecti on dead plant material and wood, and yeasts, especially in sewage-laden waters. Besides bacteria and fungi, viruses (i.e., bacteriophages) are also found in lotic habitats (Rheinheimer 1985). Protozoans, namely flagellates and ciliates, are largely determined in lotic systems by water velocity. In rivers the most diverse and dense protozoan population tend to develop in pond-like situations where the velocity of the current is not great. The actual number of protozoan species was lowest in the lotic system with greatest flow, next highest in the system with the least flow, and highest in those systems with an intermediate flow (Cairns 1969).

Fecal coliform levels are routinely analyzed by the LCRA, USGS, and TNRCC during water quality monitoring of the Colorado River. Recent LCRA samples (90 records) indicate that mean fecal coliforms levels are 196 (range 0-5,800) colonies per 100 milliliters (colonies/100 mℓ) upstream and 337 (range 0-3,800) colonies/100 mℓ downstream of the proposed intake site on the Colorado River (Patek 1994). Coliform levels (five samples) for the Colorado River at Wharton from October 1993 to September 1994 ranged from 20 to 2,000 colonies/100 mℓ with one sample exceeding the standard criteria (Gandara et al. 1995). The fecal coliform level of TNRCC monitoring samples for Segment 1402 in 1994 exceeded the standard criteria six of 38 times (x = 489; range 6-7,900) colonies/100 mℓ (TNRCC 1994b). This segment occasionally exceeds standard criteria and is ranked as partially supporting contact recreation use due to elevated levels of fecal coliform bacteria (TNRCC 1994b).

- General Ecology

The longitudinal profile of rivers always show great fluctuations in microbial numbers due mainly to the effect of tributaries, floodplains, and sewage input. In large rivers, production by suspended microbes can be substantial (Meyer 1990). Downstream from cities/towns a decrease in microbial counts occurs because of self-purification of the river. This is followed by a marked rise in microbial counts in the vicinity of the next adjacent municipalities and a considerable drop again further downstream. In areas of dense population with more pollution, the fluctuations are greater, while non-polluted areas of the river are presumably less. In contrast to the longitudinal profile, the transverse and the vertical profiles show relatively small differences in microbial numbers, as the currents, wind, and navigation cause a continuous mixing of water which leads to a comparatively even distribution of microbes and nutrients. However, along the banks and immediately above the bottom, deviations of some magnitude may be found (Rheinheimer 1985).

A marked rhythm of microbial numbers is evident in sewage-laden rivers with a clear-cut winter maximum and summer minimum. The higher microbial numbers obtained during the cold season are due to the favorable conditions at lower water temperatures for the nutrition and life of saprophytes, putrefying bacteria, coliforms, and yeasts which come mainly from sewage, whereas the nitrifying bacteria have their maximum in summer. In contrast, rivers where loading with sewage is negligible, the total microbial counts and saprophytes will depend much more on the nutrients produced in the river, particularly by the phytoplankton. Thus their maximum will occur in spring and autumn or late summer. The yearly rhythm can be distributed by extreme hydrographic conditions, especially high water or very low water supply (Rheinheimer 1985).

Some microbes are pathogenic, either producing diseases directly through infection or producing toxins which result in illness, paralysis, or death. The organisms most often associated with outbreaks of waterborne disease are: bacteria - *Salmonella typhi* (e.g., typhoid fever, gastrointestinal disorders), *Shigella* (e.g., diarrheal diseases), certain enterotoxigenic *Escherichia coli* serotypes (e.g., nausea, dehydration, and diarrhea), pathogenic *Leptospia* (e.g., kidney, liver, and central nervous system infections), *Pasteurella* (e.g., tularemia), and *Vibrio cholerae* (e.g., cholera); pathogenic parasitic protozoans *Cryptosporidium*, *Microsporidium*, *Giardia lamblia/intestinalis*, and *Entamoeba histolytica* (e.g., dysentery); and viruses (e.g., polio, Coxsackie, E.C.H.O., infectious hepatitis A, reovirus, adenovirus, enteroviruses, rotaviruses, and Norwalk) which produce paralytic poliomyelitis, aseptic meningitis, respiratory diseases, flu, eye infections, and gastroenteritis. These pathogenic organisms find their way into the aquatic habitat in the urine or feces of domestic/wild animals and man. Contamination occurs through domestic effluents, storm sewer run-off, and run-off from natural areas as well as feed lots (Bott 1973; Lederberg et al. 1992).

3.1.2.2 Phytoplankton

- Community Composition

Information on the composition of phytoplankton (microscopic plants - algae) communities in or near the proposed intake site on the Colorado River is not available. The phytoplankton (algal) community of the Colorado River can, however, be generally characterized by a review of pertinent literature from similar riverine systems.

The major sources of phytoplankton in riverine systems are the results of cell displacement from benthic algae, backwaters or stagnant arms of a stream, lakes or impoundments along the river's course, and reflected wash-out and export rather than a true "potamoplankton" (Allan 1995). However, in rivers of considerable length (like the Colorado), the residence time of water mass can be sufficient for true plankton to colonize and reproduce. Under these conditions, phytoplankton almost always is present and at times can develop substantial populations (Hynes 1970). It is doubtful that any planktonic organisms are restricted only to flowing water, thus the truly planktonic species found in rivers are drawn from the same pool of species found in standing water. The presence of lakes, ponds and backwaters, and more recently the creation of impoundments (reservoirs) can be of great importance in seeding a river with plankton.

The most frequently encountered truly planktonic algae found in rivers, like the Colorado, are *Asterionella*, *Tabellaria*, *Fragilaria*, and the disc-shaped forms *Melosira*, *Cyclotella*, *Cosconodiscus*, and *Stephanodiscus*. During the summer, or in permanently warm rivers, a variety of truly planktonic green algae (Chlorophyceae), such as *Scenedesmus*, *Ankistrodesmus*, and *Pediastrum*, and a variety of flagellates, including *Cryptomonas*, *Mallomonas*, *Chlamydomonas*, *Trachelomonas*, *Euglena*, *Synura*, and *Ceratium*, usually occur. Blue-green algae (Cyanophyta), such as *Gomphosphaeria*, *Aphanizomenon*, *Anacystis*, *Anabaena*, and *Lyngbya*, occur when the water is warm (Hynes 1970). Blooms of diatoms (Bacillariophyta) (e.g., *Melosira distans* var. *alpigena* - Sabine River) occur in the spring or early summer in major rivers. Green algae, blue-green algae, and diatom blooms (e.g., *Cyclotella meneghianiana* - Sabine River) are common in late summer and fall (Williams 1972).

- General Ecology

Phytoplankton develops self-sustaining populations only under certain conditions in large lowland rivers, like the Colorado River. The first condition that must be met is a sufficient residence time to allow biomass to increase faster than it is transported downstream. Nutrients are usually not a critical limiting factor for river phytoplankton. The magnitude of the spring bloom of diatoms may be limited by exhaustion of some essential nutrient as nitrogen, silicon, phosphorus or iron (Fogg 1965; Hutchinson 1967), while the fall bloom of green algae, blue-green algae, and diatoms can be enhanced by trace elements such as molybdenum and zinc (Goldman and Wetzel 1963), by coenzymes (Provasoli 1958), by organic nitrogen (Manny 1969), or by secretions of vitamins and amino acids into the environment (Aaronson et al. 1971). Light often becomes the limiting factor in large rivers. The depth of light penetration usually is only a small fraction of depth to the bed of a large turbid river, and because the water column is typically well-mixed, phytoplankton communities experience little or no light much of the time. Indeed, the opportunities for photosynthesis may be so limited that phytoplankton populations in rivers require input from tributaries and floodplain lakes to maintain their presence in rivers. Under these conditions, phytoplankton blooms can develop. In comparison to standing waters of comparable nutrient status, river phytoplankton biomass is substantially lower. Moreover, although the knowledge of grazing pressure of river phytoplankton is scant, this also does not appear to be a strongly limiting factor. Thus, in contrast to standing waters where phytoplankton communities frequently are limited by some combination of nutrient supply and grazing, these factors usually are considerably less important in rivers. Current evidence suggests that downstream export (i.e., current and discharge) rather than in situ energy processing is the dominant factor controlling riverine phytoplankton production (Allan 1995).

3.1.2.3 Periphyton

- Community Composition

Periphyton (attached microscopic algae) samples and macroalgal samples of *Cladophora*, an attached filamentous green alga, were collected at Longhorn Dam, and periphyton samples were taken at Webberville on the Colorado River monthly from June through October and in December 1991, and once in May 1992 (Table III-10). Green algae, blue-green algae, and diatoms were reported to be the dominant epiphytic forms on *Cladophora* at Longhorn Dam; green algae, blue-green algae, and diatoms were abundant in summer and fall, and diatoms were abundant in winter and spring. Blue-green algae and diatoms were the dominant periphyton, with blue-greens being abundant in summer and diatoms being abundant in fall, winter, and spring. Periphytic forms at the Webberville site were dominated by diatoms while blue-green algae comprised a small portion of the community. Epiphytes attached on *Cladophora* were dominated by the green algal species *(Protoderma* and *Protonema)*, diatoms *(Rhociosphenia* and *Cocconeis)*, and blue-green algae *(Lyngbya)*. The periphytic community at Longhorn Dam was dominated by the blue-green alga *Lyngbya* and the diatom *Navicula*, while diatoms (*Navicula* and *Cocconeis*) dominated the periphytic community at Webberville. In summary, the periphyton composition in the Colorado River at and in the vicinity of intake site/low head dam would probably be composed of green algae, blue-green algae, and diatoms with the highest variability among site-specific habitats (Stevenson et al. 1991).

- General Ecology

Periphyton, which is comprised of diatoms, green algae, blue-green algae, and a few other groups, occurs on various every surface in running waters including stones, soft sediments, and macrophytes. High discharge, which dislodges cells, flips stones, and scours surfaces, often restricts periphyton growth to lower flow periods. There is also growing evidence that nutrient limitation of periphyton is widespread, most often due to a short supply of phosphorus. In addition, small periphytic autotrophs are vulnerable to a wide variety of herbivorous zooplankters, macroinvertebrates, and fishes, and grazing by these communities can cause significant losses (Allan 1995).

Table III-10

Periphyton Species Collected in the Lower Colorado River (1991-1992)

	Longhorn Dam							Webberville						
Taxa	6/91	7/91	8/91	9/91	10/91	12/91	5/92	6/91	7/91	8/91	9/91	10/91	12/91	5/92
CHLOROPHYTA														
Cladophora	X	X	X	X	X	X	X							
Microspora													X	
Protoderma					X[2]									
Protonema		X[2]	X[2]			X								
CYANOPHYTA														
Lyngbya	X[1]	X[1,2]	X[1,2]	X	X			X	X	X	X			X
BACILLARIOPHYTA														
Cocconeis	X	X	X	X[2]		X[2]	X[2]	X	X			X[1]	X	
Cymbella		X	X				X			X		X	X	X
Gomphonema	X	X	X	X	X	X	X			X			X	X
Pleurosigma													X	
Navicula	X	X	X	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X[1]	X	X[1]	X[1]
Rhociosphenia	X[2]	X		X		X	X	X						

[1]Dominant species
[2]Dominant epiphyte on *Cladophora*

Source: Smith 1950; Groeger 1992

The species composition of the periphyton assemblage varies seasonally, and since this occurs even in constant temperature springs, changing light conditions must be partly responsible. Diatoms dominate during winter and continue to be a major component of the flora in spring and early summer although the species composition changes. Total abundance generally is greatest in the spring, and a secondary peak can occur in autumn. Other groups can become abundant during summer, particularly green and blue-green algae. Periphyton communities often decrease during summer and increase again in the fall due to reduced shading or changes in other environmental physicochemical conditions (Allan 1995).

3.1.2.4 Aquatic Plants

- Community Composition

The Colorado River supports a varied and substantial growth of submerged and emergent aquatic vegetation (Table III-11). Composition and distribution are strongly influenced by substrate, depth, and hydraulic characteristics. Submerged forms are abundant in the main river in Travis and upper Bastrop counties, but are essentially confined to sloughs, marshy regions, backwaters, and tributaries below central Bastrop County. Tilton (1961) reported abundant submerged aquatics (i.e., changeleaf parrot's feather [*Myriophyllum heterophyllum*]; pondweed [*Potamogeton* spp.]) in backwater areas with still water over silt bottoms above and below the proposed intake area. Studies by Werkenthin (1985) and Mosier and Ray (1992) reported dense mats of water stargrass (*Heteranthera dubia*) in shallow areas of gravel/cobble riffles. Recent biomass sampling of the river indicates that water stargrass comprises roughly 80 percent of the biomass of submerged aquatic macrophytes present in the river, while water feather (*Myriophyllum brasiliense*) comprises approximately 10 percent (Armstrong et al. 1987a). Both species occur in dense beds that occupy significant portions of the river channels in some reaches, while other reaches are essentially devoid of submerged macrophytes. In very localized areas, various species of *Potamogeton* are abundant. Several types of filamentous algae may become abundant at some times in many places, either as floating mats, or more commonly attached to rocks, roots, or other aquatic plants. Other aquatic plants which occur less commonly along the banks or floating in quiet water include smartweed (*Polygonum*), duckweed (*Lemna*), and pennywort (*Hydrocotle*). Many sandbars or banks between the low and high water stages are partially vegetated by herbaceous/woody wetland species.

Table III-11

Aquatic Vegetation Collected in the Lower Colorado River Between 1956-1987

Common/Scientific Name	1956	1961	1980	1985	1987
STONEWORTS					
Stoneworts/*Chara* sp.	X				
CATTAILS					
Common cattail/*Typha latifolia*		X	X		X
PONDWEEDS					
Pondweeds/*Potamogeton* sp.		X			
Sago pondweed/*Potamogeton pectinatus*					X
Curled pondweed/*Potamogeton crispus*					X
American pondweed/*Potamogeton nodosus*					X
GRASSES					
Southern wildrice/*Zizaniopsis milacea*	X	X	X		X
Paspalum/*Paspalum* sp.					X
DUCKWEEDS					
Duckweed/*Lemna* sp.			X	X	X
BOGMOSSES					
Bogmoss/*Mayaca aubletii*					X
PICKEREL WEEDS					
Water stargrass/*Heteranthera dubia*				X	X
Water hyacinth/*Eichornia crassipes*					X
BUCKWHEATS					
Smartweed/*Polygonum* sp.			X		X
WATER LILIES					
Water lilly/*Nymphae* sp.		X			
Yellow water lilly/*Nuphar* sp.		X			
Fanwort/*Cabomba caroliniana*					X
EVENING PRIMROSES					
False loosestrife/*Ludwigia* sp.					X
Smooth water primrose/*Ludwigia peploides*			X		
WATER-MILFOILS					
Water-milfoil/*Myriophyllum* sp.	X		X		X
Changeleaf parrot's feather/*Myriophyllum heterophyllum*		X			
Water feather/*Myriophyllum brasiliense*					X
PARSLEYS					
Water pennywort/*Hydrocotyle* sp.					X
FIGWORTS					
Water hyssop/*Bacopa* sp.					X

Legend: sp. = species

Source: Fasset 1969; Armstrong et al. 1987a; Koenig 1987

- General Ecology

Aquatic macrophytes, including some large algae, bryophytes, and vascular plants, are found in flowing water mainly where neither the depth nor the current is great. The length of the growing season, current, and light appear to be major limiting factors for aquatic macrophytes. Grazing on living plants is in most instances a minor factor, and the bulk of plant production enters the detritus pool after senescence. In addition, riverine macrophytes can alter flow characteristics and create reduced current velocities near the substrate. They also provide more substrate surface area, more fine particle sediments, and more detritus which can result in a higher biomass of epiphytic forms (i.e., diatoms) in slower currents and an increase in invertebrate and fish microdistribution, and potentially population density, by providing shelter, oviposition sites, and substrate for colonization (Gregg and Rose 1982; Allan 1995).

3.1.2.5 Zooplankton

- Community Composition

Information on the composition of zooplankton (microscopic/macroscopic animal) communities in the Colorado River is not available. However, zooplankton studies of similar river systems can be used to characterize zooplankton communities in the Colorado River.

Riverine zooplankton communities include protozoans, mainly *Arcella* and *Difflugia*, and sometimes ciliates, which are especially numerous in polluted water; however, zooplankton communities are usually dominated by truly planktonic rotifers, such as *Keratella*, *Synchaeta*, *Polyarthra*, *Asplanchna*, *Brachionus*, *Kellicottia*, *Trichocera*, *Triarthra*, *Notholca*, *Rattulus*, and *Euchlanis*. Crustaceans (water fleas, copepods), which are so important in still-water plankton, may be abundant in the open waters of rivers, and those that are found there usually belong to the genera *Cyclops* or *Bosmina*, *Alona*, *Chydorus*, and *Diaptomus*. Table III-12 lists the common riverine zooplankters some of which would occur in the Colorado River (Hynes 1970; Winner 1975).

Table III-12

Common River Zooplankton

PROTOZOA	ROTIFERA (Continued)
Arcella sp.	*Keratella quadrata*
Bursaria sp.	*Keratella tripica**
Codonella cratera	*Notholca acuminata*
Colpidium sp.	*Polyarthra euryptera*
Colpoda sp.	*Polyarthra vulgaris*
Difflugia sp.	*Synchaeta oblonga*
Euplotes sp.	*Synchaeta pectinata*
Frontonia sp.	*Synchaeta stylata*
Halteria sp.	*Trichocerca longiseta*
Paramecium sp.	
Stentor sp.	**CLADOCERA**
Strombidium sp.	*Bosmina coregoni*
Tintinnidium sp.	*Bosmina longirostris*
Vorticella sp.	*Ceriodaphnia pulchella*
	Chydorus sphaeicus
ROTIFERA	*Daphnia cucullata*
Asplanchna brightwelli	*Daphnia longispina*
Asplanchna priodonta	*Diaphanosoma brachyurum*
Brachionus angularis	*Leptodora kindtii*
Brachionus budapestinensis	*Bythotrephes longimanus*
Brachionus calyciflorus f. *typical*	
Brachionus calyciflorus f. *amphiceros*	**COPEPODA**
Brachionus calyciflorus f. *dorcas*	*Acanthocyclops vernalis*
Brachionus caudatus	*Cyclops rubens*
*Brachionus falcatus**	*Eudiaptomus gracilis*
Brachionus quadridentatus	*Eudiaptomus graciloides*
Brachionus urceolarus	*Eurytemora lacustris*
Conochiloides dossaurius	*Eurytemora affinis*
Filinia longiseta	*Limnocalanus macrurus*
*Filinia opolienis**	
Keratella cochlearis	**INSECTA**
Keratella earlinae	*Chaoborus* sp.

*Common in tropical rivers

Legend: sp. = species
f. = form

Source: Winner 1975

- General Ecology

Planktonic communities in lotic systems (rivers) probably differ more than lentic system (lakes/reservoirs) assemblages because the physical parameters of the rivers are relatively more disparate. In comparison with lakes and reservoirs, main channels in rivers are well-mixed vertically and, therefore, rarely show thermal or chemical stratification (Thorp et al. 1994). The seasonal dynamics of nutrients (e.g., nitrogen and phosphorus) are apparently regulated by variations in riverine discharge (i.e., physical processes) rather than by aquatic biota. Advective transport and suspended sediment concentration also have substantial effects on diversity and net secondary production of riverine zooplankton. Although rotifers and cladocerans/copepods are usually the numerically dominant groups in riverine habitats this varies between rivers and seasons. Densities and reproductive rates of zooplankton in rivers are not often significantly correlated with phytoplankton abundance (Pace et al. 1992) but are closely tied to current velocities and suspended sediment concentrations (Saunders and Lewis 1988). Densities tend to peak in late spring through midsummer, often with different density modes for rotifers and microcrustaceans.

Thorp et al. (1994) reported that zooplankton populations occupying littoral and pelagic areas of rivers differ to a certain degree. Although species richness was similar in shallow (nearshore) and deepwater (midchannel) areas, average annual densities of total zooplankton were significantly higher nearshore (principally in summer). On an annual basis, copepods and cladocerans tended to be more abundant in the littoral zone of rivers, whereas rotifers were usually more abundant in deeper and faster main channel waters. These trends may not reflect distinctive niches for zooplankton, however, because the greater density in shoreline areas may be a simple result of lower velocities which tend to retain species and magnify densities. It is evident that physical factors (current velocity, turbidity, and temperature) strongly influence zooplankton. In rivers with low head dams, zooplankton assemblages appear to vary between some habitats (littoral versus pelagic) but not others (upper versus lower pool and floodplain versus constricted channels and pools). Zooplankters clearly reproduce in the pelagic areas of rivers, but immigrants from tributaries also may contribute significantly to the community of the main channel. In addition, river zooplankton community size structure appears to be more uniformly dominated by small species (i.e., rotifers) than is the case in lakes (Shiel et al. 1982). A number of factors probably favor small river zooplankters: short generation times; ability to feed and grow more successfully than large species when high concentrations of filamentous/gelatinous and/or toxic algae are present; and the ability to withstand turbid environments (Pace et al. 1992).

3.1.2.6 Benthic Macroinvertebrates

- Community Composition

Information on the composition of benthic macroinvertebrate communities (aquatic insects, crustaceans, mollusks associated with bottom or solid-water interface) in or near the proposed intake site on the Colorado River is not available. However, in 1993 the LCRA initiated a study to characterize the macrobenthic community downstream from Austin. The initial sampling effort was aimed primarily at aquatic insects in the area between Austin and Columbus (Patek 1994). Data from this initial survey were reviewed to determine if the sample data could be utilized to characterize the macrobenthic community in the vicinity of the proposed intake site on the Colorado River.

General habitat characteristics of sampling stations were subsequently compared to descriptions of habitat for the Egypt Reach (Mosier and Ray 1992; Patek 1994). The stations sampled in the Austin to Columbus stretch of the Colorado River were characterized by gravel/cobble and riffle/pool sequences. In contrast, the habitat of the study area (i.e., the Egypt Reach) is comprised mainly of extensive sandy reaches with a few gravel/cobble riffles (Patek 1994). A review of the habitat assessment data sheets revealed that three sampling stations (i.e., numbers 6, 9, and 13) generally matched habitat conditions (i.e., low instream cover and embeddedness) which would be expected to occur at or in the vicinity of the proposed intake site. Although site specific-data are preferred, the macrobenthic species recorded from these stations can be used to qualitatively represent the benthic invertebrate fauna which could potentially occur in the vicinity of the proposed intake site.

Flatworms, aquatic insects, and mollusks comprised the benthic macroinvertebrate fauna at these stations (Table III-13). Aquatic insects and mollusks co-dominated the benthic fauna. Mayflies (Ephemeroptera-Tricorythidae and Leptophlebiidae) and caddisflies (Trichoptera-Glossosomatidae) were the dominant orders of aquatic insects. The most abundant ephemeropterans were *Tricorythodes* and *Thraulodes*, while the dominant trichopteran was *Glossosoma*. The introduced Asiatic clam (*Corbicula fluminea*) was the dominant pelecypod.

In addition to the Asiatic clam, Howells (1995a, 1995b) reported a total of 27 species of freshwater mollusks from the Colorado River Basin (Table III-14). Fourteen of there species are commonly found

Table III-13

Qualitative List of Benthic Macroinvertebrates
Potentially Occurring in the Egypt Reach of the Colorado River

Order	Family	Genus	Tolerance Value	Feeding Group
Triciadida	Planariidae	*Dugesia*	4	Collector
Plecoptera	Perlidae	*Neoperia*	1	Predator
Ephemeroptera	Tricorythidae	*Tricorythodes*	4	Collector
		Leptohyphes	4	Collector
	Leptophlebiidae	*Thraulodes*	2	Collector
	Baetidae	*Dactylobaetis*	4	Collector
		Baetis	4	Collector
	Heptageniidae	*Stenonema*	4	Scraper
Anisoptera	Gomphidae	*Erpetogomphus*	1	Predator
Hemiptera	Naucoridae	*Limnocoris*	5	Piercer
		Cryphocricos	5	Piercer
Trichoptera	Hydropsychidae	*Cheumatopsyche*	4	Collector
		Hydropsyche	4	Collector
		Leptonema	4	Collector
	Helicopsychiidae	*Helicopsyche*	3	Scraper
	Glossosomatidae	*Glossosoma*	0	Scraper
		Culoptila	0	Scraper
		Protoptila	0	Scraper
	Leptoceridae	*Oecetis*	4	Collector
	Hydroptilidae	*Hydroptila*	4	Piercer
		Ochrotrichia	4	Piercer
Lepidoptera	Pyralidae	*Petrophila*	5	Shredder
Diptera	Empididae	*Hemerodromia*	6	Predator
	Tanypodinae	*Thienemannimyia*	6	Predator
	Orthocladiinae	*Cricotopus*	7	Shredder
		Corynoneura	7	Collector
		Thienemanniella	6	Collector
	Chironominae	*Cryptochironomus*	8	Predator
		Dicrotendipes	8	Collector
		Polypedilum	8	Shredder
		Pseudochironomus	5	Collector
		Cladotanytarsus	7	Collector
Pelecypoda	Corbiculidae	*Corbicula*	4	Filterer

[1]0 = Low pollution tolerance   0 = Least sensitive
10 = High pollution tolerance   10 = Tolerant

Source: Modified from Patek 1994; Thorp and Covich 1991

Table III-14

List of Freshwater Mollusks
Potentially Occuring in the Colorado River Basin

Common Name	Scientific Name
UNIONIDAE	
Threeridge	*Amblema plicata**
Giant floater	*Anodonta gradis**
Paper pondshell	*Anodonta imbecillis**
Rock-pocketbook	*Arcidens confragosus*
Tampico pearlymussel	*Cyrtonaias tampicoensis*
Round pearlshell	*Glebula rotundata?*
Texas fatmucket	*Lampsilis bracteata*
Louisiana fatmucket	*Lampsilis hydiana*
Yellow sandshell	*Lampsilis teres**
Fragile papershell	*Leptodea fragilis**
Pond mussel	*Ligumia subrostrata**
Washboard	*Megalonaias nervosa**
Pink papershell	*Potamilus ohiensis?*
Bleufer	*Potamilus purpuratus**
Southern mapleleaf	*Quadrula apiculata**
Golden orb	*Quadrula aurea*
Smooth pimpleback	*Quadrula houtonensis*
Texas pimpleback	*Quadrula petrina*
False spike	*Quincuncina mitchelli*
Squawfoot	*Strophitus undulatus*
Lilliput	*Toxolasma parvus**
Texas lilliput	*Toxolasma texasensis**
Pistolgrip	*Tritogonia verrucosa*
Texas fawnsfoot	*Truncilla macrodon*
Tapered pondhorn	*Uniomerus declivis**
Pondhorn	*Uniomerus tetralasmus**
SPHAERIIDAE	
Fingernail clam	*Sphaerium* spp.*
CORBICULIDAE	
Asiatic clam	*Corbicula fluminea**

* Common occurring species
? Distribution in Colorado River is questionable

Legend: spp. = species

Source: Turgeon et al. 1988; Howells 1995a throughout the Colorado River Basin of the Central Texas Subprovince of freshwater clams. The Central Texas Subprovince consists of the following major streams (i.e., Brazos, Colorado, Guadalupe, San Antonio, and Nueces) plus the shorter coastal plain streams (i.e., San Bernard, Lavava, Mission, and Aransas rivers) and the creeks feeding into the Baffin Bay system (Neck 1982). Howells (1995c) found Asiatic clams but no unionids in a Colorado River mussel habitat (sand, mud, gravel) at U.S. Highway 59 at Wharton.

The abundance and occurrence of benthic invertebrates at the proposed intake site would be slightly different than the upstream locations. Functional groups of benthic invertebrates require different types of substrates and plant/animal food resources and, therefore, can be used to characterize the benthic fauna at the proposed intake site. Functional/feeding groups present in the Colorado River include collectors, shredders, piercers, filterers, scrapers, predators, and miners (see Table III-13). Collectors (e.g., ephemeropterans and some trichopterans) feed on animal and plant detrital matter and generally require substrates with large surface areas (e.g., cobble and gravel). Fewer ephemeropterans would be expected to occur at the intake site due to the general decrease in the size of bottom material from upstream (i.e., cobble) to downstream (i.e., sand) locations. Shredders, which feed primarily on leaf litter, include moths (Lepidoptera) and flies (Diptera). The occurrence of these functional groups would also be expected to decrease since upstream areas would allow more accumulation of leaf litter in the interstices created by cobble substrates. Piercers are herbivores and predators, feeding on animals and vascular plants. The occurrence of piercers (e.g., herbivorous trichopterans and predatory heteropterans [true bugs]) in the Colorado River is related directly to the distribution and abundance of the dominant macrophyte, water stargrass. Since macrophyte occurrence/abundance has not been studied in the vicinity of the proposed intake site, the potential occurrence and/or abundance of piercers in the vicinity site is unknown. Filterers (e.g., mollusks) collect particulate plant and animal material by filtering it from the water column. Smaller mollusks would tend to increase in occurrence/abundance with decreasing downstream particle size, if water quality parameters meet their requirements. Scrapers (i.e., some ephemeropterans and trichopterans) are predominantly herbivores that feed on algae attached to submerged objects (e.g., rocks, logs, etc.). Lower numbers of scrapers would potentially occur downstream due to the decrease in embeddedness and instream cover. Predators (e.g., stoneflies-Plecoptera, dipterans) feed on other aquatic invertebrates and would tend to increase in number downstream. Miners (e.g., oligochaetes) burrow through the substrate and feed on detritus and would be expected to increase in occurrence and abundance as the current decreases and at locations (pools) dominated by muck and or silt substrates.

In summary, benthic invertebrate diversity at the proposed intake site would be expected to be lower than upstream locations due to decreased instream cover and smaller embeddedness (i.e., particle size) values. Diversity and density (abundance) of ephemeropterans and some trichopterans would be expected to be lower while dipteran diversity and density would generally be higher. Higher densities of the invasive Asiatic clam would potentially occur if water quality conditions are favorable. Oligochaete densities would also be higher if the substrate is dominated by silt and detritus.

- General Ecology

A variety of abiotic and biotic factors regulate occurrence and distribution of benthic invertebrates in lotic (river) communities. Hynes (1970) considered four abiotic factors: current velocity, temperature, substrate, and water quality (e.g., dissolved substances), to be the most important regulatory factors. Current velocity often determines macroinvertebrate microhabitat selection. For example, the retreats and nets of some caddisflies (i.e., *Hydropsyche instabilis* and *Plectrocnemia conspersa*) are only constructed in a specific range of current velocities. Temperature, which can affect reproduction, egg development, and growth, may be a critical factor for some benthic invertebrates depending on their tolerance range. The structural composition and size of the substrate (i.e., boulders to small sand grains or clay particles) provide a variety of microhabitats for benthic invertebrates. Higher densities of benthic macroinvertebrates usually occur on larger substrates (boulders, cobbles, etc.). Woody substrates are often very important for benthic macroinvertebrates in sandy streams when other cover is not present (Webber et al. 1992; Allan 1995). Water chemistry/quality is also a major influence in determining benthic community composition. For example, pH and phosphorus have been suggested as primary determinants in structuring invertebrate communities (Jackson and Harvey 1993). The effects of drought/floods, food, interspecific competition, predation, shade, and zoogeography are also important factors (Webber et al. 1992). In summary, the response of benthic macroinvertebrates to environmental changes is complex and is dependant on many different abiotic/biotic factors (Jackson 1992).

3.1.2.7 Amphibians/Reptiles

During the literature search, no specific survey data for amphibians and reptiles in the vicinity of the proposed intake site was located. Based on historic county occurrence records and habitat requirements, 15 amphibian/reptilian species are known to occur in the Colorado River Basin near or in the vicinity of the proposed intake site (Dixon 1987; Appendix A-1). All of these species could utilize the Colorado River during their life cycle (Table III-15).

Adult central newts (*Notophthalmus viridescens lousianensis*) may be found in quiet backwater habitats of the Colorado River. Cope's gray treefrog (*Hyla chrysocelis*), green treefrog (*H. cinera*), and gray treefrog (*H. versicolor*) are primarily terrestrial, but may utilize shallow backwater areas and aquatic vegetation in the Colorado River for reproduction. Spotted chorus (*Pseudacris clarkii*) and pickerel frogs (*Rana palustris*) may use marshy or aquatic habitats in or adjacent to Colorado River backwaters near the intake site (Garrett and Barker 1987).

Softshell turtles (*Apalone* spp.) may be relatively common in the study area due to their preference for riverine habitats. The common snapping turtle (*Chelydra serpentina serpentina*) may occur in quiescent pools. The Texas river cooter (*Pseudemys texana*) and red-eared slider (*Trachemys scripta elegans*) would probably occur in areas of aquatic vegetation. Turtles would potentially be more common than amphibians due to their preference for aquatic habitat. Several species of aquatic and semiaquatic snakes would also occur. The western cottonmouth (*Agkistodon piscivorus leuicostoma*) and diamondback water snake (*Nerodia rhombifera rhombifera*) may be common near quiet pools and backwaters. The blotched water snake (*Nerodia erythrogaster transversa*) may inhabit rocky areas in the river. The Mississippi green water snake (*Nerodia cyclopion*) may be found in marshy areas near backwaters (Tennant 1990).

- General Ecology

Amphibians are usually restricted to moist or wet habitats with at least a nearby water source. The larval phases of most amphibians require water for transformation into the adult phase while most reptiles do not require water for adult maturation. Microhabitat components for amphibians and reptiles are site-specific physical entities which provide environmental conditions necessary for a wide variety of ecological functions (i.e., reproduction, foraging, predator avoidance/escape, thermoregulation, and

Table III-15

List of Amphibians and Reptiles Potentially Occurring in the Colorado River Basin

Common Name	Scientific Name
NEWTS	
Central newt	*Notophthalmus viridescens louisianensis*
TREEFROGS	
Cope's gray treefrog	*Hyla chrysocelis*
Green treefrog	*Hyla cinerea*
Gray treefrog	*Hyla versicolor*
CHORUS FROGS	
Spotted chorus frog	*Pseudacris clarkii*
TRUE FROGS	
Pickerel frog	*Rana palustris*
SOFTSHELL TURTLES	
Midland smooth softshell	*Apalone mutica mutica*
Guadalupe spiny softshell	*Apalone spinifera guadalupensis*
SNAPPING TURTLES	
Common snapping turtle	*Chelydra serpentina serpentina*
COOTERS	
Texas river cooter	*Pseudemys texana*
SLIDERS	
Red-eared slider	*Trachemys scripta elegans*
COPPERHEADS/COTTONMOUTHS	
Western cottonmouth	*Agkistrodon piscivorus leucostoma*
WATER SNAKES	
Diamondback water snake	*Nerodia rhombifer rhombifer*
Blotched water snake	*Nerodia erythrogaster transversa*
Mississippi green water snake	*Nerodia cyclopion*

Source: Dixon 1987; Garrett and Barker 1987; Collins 1990; Tennant 1990

resting). Amphibians and reptiles are ectothermic (cold-blooded) animals which derive their body temperature from the surrounding environment. Therefore, these animals are often very dependent on certain microhabitats to thermoregulate. Without habitat for thermoregulation, other ecological functions cannot be completed since internal temperature regulation determines the intensity of the activity (Jones 1986).

3.1.2.8 Fish

The freshwater fish community in the Colorado River Basin includes 86 species of fish, 70 which are native to the basin and 16 exotic species which have either been introduced or invaded in recent years (Appendix A-2). Recent collections in the Colorado River and its tributaries below Austin indicate the occurrence of 58 freshwater species, 50 which are native and eight which are exotic/introduced species (Table III-16).

Fish in the Colorado River Basin can be classified into three functional groups. Species which are more successful in lentic rather than lotic water are functionally termed obviate riverine species (e.g., gizzard shad [*Dorosoma cepedianum*], largemouth bass [*Micropterus salmoides*]). Obligate species (e.g., blue sucker [*Cycleptus elongatus*], dusky darter [*Percina sciera*]) are fish which are dependent on flowing water for long-term survival. Facultative species (e.g., channel catfish [*Ictalurus punctatus*], flathead catfish [*Pylodictis olivaris*]) do well in either flowing or standing water.

Construction of reservoirs has altered fish community structure in the Colorado River by creating large areas of deep, standing water habitat which was not historically present (Patek 1994). Native fish species in Colorado riverine pool habitats (e.g., gizzard shad, largemouth bass) adapted well in the newly created reservoirs, while other species requiring normal riverine flow regimes (e.g., blue sucker) decreased in abundance.

Mosier and Ray (1992) recently classified fish habitats in the Colorado River below Austin by mean depth, mean velocity, and substrate use by fish species. Fish habitats present downstream from Austin include rapids, deep riffles, shallow riffles, sandy runs, fast pools/chutes, pools with boulders, shallow pools, quiescent pools, edges of pools and riffles, and backwaters. Representative fish species for each fundamental habitat group in the Colorado River below Austin are listed in Table III-17. Based on the

Table III-16

List of Freshwater Fishes Found in the Colorado River and its Tributaries Downstream of Austin

Common Name	Scientific Name	Status	Reported Occurrences 1950s	Recent
GARS				
Spotted gar	*Lepisosteus oculatus*	N	X	X
Longnose gar	*Lepisosteus osseus*	N	X	X
Alligator gar	*Lepisosteus spatula*	N	X	X
BOWFINS				
Bowfin	*Amia calva*	N	A	A
FRESHWATER EELS				
American eel	*Anguilla rostrata*	N	X	X
HERRINGS				
Gizzard shad	*Dorosoma cepedianum*	N	X	X
Threadfin shad	*Dorosoma petenense*	N	X	X
CARPS/MINNOWS				
Central stoneroller	*Campostoma anomalum*	N	X	X
Red shiner	*Cyprinella lutrensis*	N	X	X
Blacktail shiner	*Cyprinella venusta*	N	X	X
Common carp	*Cyprinus carpio*	E	X	X
Ribbon shiner	*Lythrurus lirus*	N	X	X
Speckled chub	*Macrhybopsis aestivalis*	N	X	X
Golden shiner	*Notemigonus crysoleucas*	N	X	X
Texas shiner	*Notropis amabilis*	N	X	X
Pallid shiner	*Notropis amnis*	N	X	X
Silverband shiner	*Notropis shumardi*	N	X	X
Sand shiner	*Notropis stramineus*	N	X	X
Weed shiner	*Notropis texanus*	N	X	X
Mimic shiner	*Notropis volucellus*	N	X	X
Pugnose minnow	*Opsopoeodus emiliae*	N	X	X
Suckermouth minnow	*Phenacobius mirabilis*	N	X	X
Fathead minnow	*Pimephales promelas*	N	X	
Bullhead minnow	*Pimephales vigilax*	N	X	X
SUCKERS				
River carpsucker	*Carpiodes carpio*	N	X	X
Blue sucker	*Cycleptus elongatus*	N	A	X
Smallmouth buffalo	*Ictiobus bubalus*	N	X	X
Gray redhorse	*Moxostoma congestum*	N	X	X
CHARACINS				
Mexican tetra	*Astyanax mexicanus*	E	X	X
BULLHEADS/CATFISHES				
Black bullhead	*Ameiurus melas*	N	X	X
Yellow bullhead	*Ameiurus natalis*	N	X	X
Blue catfish	*Ictalurus furcatus*	N	X	A
Channel catfish	*Ictalurus punctatus*	N	X	X

Table III-16 (Continued)

List of Freshwater Fishes Found in the Colorado River and its Tributaries Downstream of Austin

Common Name	Scientific Name	Status	Reported Occurrences 1950s	Reported Occurrences Recent
BULLHEADS/CATFISHES (Cont.)				
Tadpole madtom	*Noturus gyrinus*	N	X	X
Flathead catfish	*Pylodictis olivaris*	N	X	X
PIRATE PERCHES				
Pirate perch	*Aphredoderus sayanus*	N	X	X
KILLIFISHES				
Blackstripe topminnow	*Fundulus notatus*	N	X	X
LIVEBEARERS				
Mosquitofish	*Gambusia affinis*	N	X	X
Sailfin molly	*Poecilia latipinna*	E	X	X
TEMPERATE BASSES				
White bass	*Morone chrysops*	E	X	X
Striped bass	*Morone saxatilis*	E		X
SUNFISHES				
Redbreast sunfish	*Lepomis auritus*	E	X	X
Green sunfish	*Lepomis cyanellus*	N	X	X
Warmouth	*Lepomis gulosus*	N	X	X
Orangespotted sunfish	*Lepomis humilis*	N	X	
Bluegill	*Lepomis macrochirus*	N	X	X
Longear sunfish	*Lepomis megalotis*	N	X	X
Redear sunfish	*Lepomis microlophus*	N	X	X
Spotted sunfish	*Lepomis punctatus*	N	X	X
Bantam sunfish	*Lepomis symmetricus*	N	X	X
Spotted bass	*Micropterus punctulatus*	N	X	X
Largemouth bass	*Micropterus salmoides*	N	X	X
Guadalupe bass	*Micropterus treculi*	N	X	X
White crappie	*Pomoxis annularis*	N	X	X
PERCHES				
Logperch	*Percina caprodes*	N	U	X
Dusky darter	*Percina sciera*	N	U	X
CICHLIDS				
Rio Grande cichlid	*Cichlasoma cyanoguttatum*	E	X	X
Blue tilapia	*Tilapia aurea*	E		X

Legend: N = Native to the Colorado River Basin
E = Exotic to the Colorado River Basin
X = Collected in the Colorado River mainstem
A = Reliable anecdotal accounts of occurrence in the basin
U = Unknown

Source: Robbins et al. 1991; Patek 1994

Table III-17

Fundamental Habitat Groups Derived from Cluster Analysis of Depth, Velocity, and Substrate Use of Fish Collected in the Colorado River Downstream from Austin in 1989 and 1990

Habitat/Representative Species	N	Mean Depth (ft)[a]	Mean Velocity (ft/sec)[a]	Primary Substrate
RAPIDS	22	(1.5 - 2.7)	(1.5 - 2.9)	Boulders/Bedrock
Blue sucker (Prespawning males)	16	2.1	2.2	
DEEP RIFFLES	269	(0.9 - 1.7)	(0.9 - 2.3)	Rubble (32 - 64 mm)
Dusky darter	75	1.3	1.5	
Logperch	75	1.3	1.9	
Channel catfish (<180 mm)	75	1.3	1.4	
Flathead catfish (<200 mm)	44	1.2	1.5	
SHALLOW RIFFLES	105	(0.5 - 1.2)	(0.6 - 2.0)	Undetermined
Orangethroat darter	75	0.9	1.3	
Stoneroller	30	0.7	1.3	
SANDY RUNS		(0.6 - 1.2)	(1.6 - 2.3)	Sand and small gravel
Speckled chub	75	0.9	2.0	
FAST POOLS/CHUTES	216	(1.8 - 4.6)	(0.3 - 1.6)	Undetermined
Gray redhorse	99	3.3	0.9	
Channel catfish (>180 mm)	53	3.1	1.2	
Guadalupe bass (>170 mm)	52	3.3	0.8	
Blue sucker (Prespawning females)	12	2.9	1.5	
POOLS WITH BOULDERS		(4.3 - 6.5)	(0.5 - 0.9)	Large boulders/bedrock
Blue sucker	38	5.5	0.7	
SHALLOW POOLS	142	(1.5 - 3.3)	(0.1-1.2)	Undetermined
Longear sunfish (>80 mm)	44	2.2	0.9	
Guadalupe bass (<170 mm)	85	2.4	0.6	
QUIESCENT POOLS	81	(<1.1)	(0.0 - 0.9)	Silt and sand
Largemouth bass	20	5.1	0.2	
Gizzard shad	61	3.1	0.4	
EDGES OF POOLS/RIFFLES	459	(0.5 - 2.1)	(0.4 - 1.6)	Undetermined
Bullhead minnow	75	1.0	0.9	
Blacktail shiner	75	1.5	1.1	
Red shiner	75	0.5	0.9	
Mimic shiner	45	0.7	0.5	
BACK WATERS[b]	105	(0.3 - 1.5)	(<0.8)	Silt to medium gravel
Mosquitofish	75	0.4	0.1	
Blackstripe topminnow	4	0.8	<0.1	

[a]Confidence limits (P=0.50) for each group in parenthesis
[b]Included sailfin molly and Rio Grande perch, exotic species common in the Webberville study reach, but not collected elsewhere

Legend: mm = millimeter ft = feet ft/sec = feet per second

Source: Patek 1994

habitat described for the study area (i.e., Egypt Reach) by Mosier and Ray (1992), the dominant habitats in the vicinity of the proposed intake site would be edges of pools and riffles and shallow riffles, respectively. Other habitats, in order of decreasing importance, are quiescent pools, backwaters, fast pools/chutes, shallow pools, sandy runs, and deep riffles. Based on the habitat available in the Egypt Reach, dominant families of fish expected to occur at the proposed intake site would be minnows and darters. A total of 20 fish species were recently found during surveys in the Egypt Reach of the Colorado River (Table III-18). Most of these species would be expected to occur in the general vicinity of the proposed intake structure.

- General Ecology

Abiotic and biotic factors control the occurrence, distribution, and abundance of fish communities. Important abiotic factors include physicochemical parameters (i.e., current velocity, oxygen concentration, temperature, turbidity) and substrate. Interspecific competition, availability of food, susceptibility to predation, parasitism, and disease are some of the biotic factors which influence fish communities (Hynes 1970; Power et al. 1988).

In flowing water, one of the most important abiotic factors is temperature. Many fish have a wide temperature tolerance and can survive in intermittent pools (e.g., creek chub [*Semotilus atromaculatus*], white sucker [*Catostomus commersoni*], and black bullhead [*Ameiurus melas*]). However, sudden changes, without adequate time to acclimate, may be lethal. Current velocity often determines the occurrence/distribution of the species. Several researchers (Gerking 1945; Swingle 1954; Lachner 1956; Minckley 1963) have noted changes in fish composition as current speed decreases and substrates change (Table III-19). Temperature and current velocity affect oxygen content (Hynes 1970). High temperatures and low current velocities decrease available oxygen, limiting survival to fish which have a high tolerance for low oxygen levels. Substrates such as fallen logs and large rocks provide shelter for fish species. Presence and abundance of shelter sites often determine occurrence and abundance of riverine fish species.

Biotic factors include species-specific tolerances to competition and adaptability to abiotic and biotic conditions. Some species, like the fathead minnow (*Pimephales promelas*), are intolerant of competition and tend to occur alone (Hynes 1970). Other species may have adaptive feeding strategies (e.g.,

Table III-18

List of Fish Collected in the Egypt Reach of the Colorado River in 1990

Common Name	Scientific Name
HERRINGS	
Gizzard shad	*Dorosoma cepedianum*
CARPS/MINNOWS	
Red shiner	*Cyprinella lutrensis*
Blacktail shiner	*Cyprinella venusta*
Speckled chub	*Macrhybopsis aestivalis*
Texas shiner	*Notropis amabilis*
Mimic shiner	*Notropis volucellus*
Bullhead minnow	*Pimephales vigilax*
Suckermouth minnow	*Phenacobius mirabilis*
SUCKERS	
River carpsucker	*Carpiodes carpio*
Blue sucker	*Cycleptus elongatus*
Smallmouth buffalo	*Ictiobus bubalus*
Gray redhorse	*Moxostoma congestum*
BULLHEADS/CATFISHES	
Channel catfish	*Ictalurus punctatus*
Flathead catfish	*Pylodictis olivaris*
SILVERSIDES	
Inland silverside	*Menidia beryllina*
SUNFISHES	
Green sunfish	*Lepomis cyanellus*
Longear sunfish	*Lepomis megalotis*
Guadalupe bass	*Micropterus treculi*
PERCHES	
Logperch	*Percina caprodes*
Dusky darter	*Percina sciera*

Source: Robbins et al. 1991; Mosier and Ray 1992

Table III-19

Ecological Distribution of Fish Species in the Ohio River and Tributary Streams[1]

RIVER FISHES

River Channel				Backwater
Skipjack Herring	Mooneye	Longnose Gar	Gizzard Shad	Golden Shiner
Silver Chub	Emerald Shiner	Silvery Minnow	Common Carp	Quillback
Shorthead Redhorse	River Shiner	Ghost Shiner	River Carpsucker	Highfin Carpsucker
Walleye	Sand Shiner	Mimic Shiner	Smallmouth Buffalo	Black Buffalo
	Channel Catfish	Steelcolor Shiner	Silver Redhorse	Spotted Sucker
		Flathead Catfish	Spotted Bass	Bluegill
		Freshwater Drum		Largemouth Bass
				White Crappie
				Black Crappie

STREAM FISHES

Riffles			Pools
Suckermouth Minnow	Rainbow Trout	Creek Chub	Bigeye Chub
Stonecat	Central Stoneroller	Northern Hogsucker	Rosefin Shiner
Greenside Darter	Silver Shiner	Fantail Darter	Common Shiner
Banded Sculpin	Blacknose Dace		Spotfin Shiner
	Smallmouth Bass		White Sucker
	Rainbow Darter		Black Redhorse
			Yellow Bullhead
			American Eel
			Rock Bass
			Green Sunfish
			Longear Sunfish
			Grass Pickerel
			Log Perch
			Southern Redbelly Dace
			Silverjaw Minnow
			Fathead Minnow
			Bluntnose Minnow
			Golden Redhorse
			Black Bullhead
			Warmouth
			Orange-Spotted Sunfish

[1]Fish are grouped according to the apparent relations to current, depth, substratum, beginning with those of relatively swift, deep (river) or shallow (stream), hard-bottomed areas to the left and terminating with deep, quiet, soft-bottomed areas to the right

Source: Minckley 1963

omnivorous) and thus have a better chance of surviving than species which are more selective (e.g., planktivores). The interaction of these and other biotic factors with the abiotic environment determines the composition of river fish communities.

3.1.2.9 Endangered, Threatened, and Candidate Species

The Endangered Species Act (ESA) of 1973 (Public Law [P.L.] 93-205; 16 U.S. Code [U.S.C.] 1531 et seq.) as amended, provides for the conservation of ecosystems upon which threatened and endangered species of fish, wildlife, and plants depend, both through federal action and by encouraging the establishment of state programs. The ESA defines "conserve" as the use of all methods and procedures which are necessary to bring any endangered species or threatened species to the point at which the measures provided pursuant to this Act are no longer necessary..." All federal agencies are required to implement protection programs for these designated species and to use their authorities to further the purposes of the act. Responsibility for the identification of a threatened or endangered species and any potential recovery plans lies with the Secretary of the Interior and the Secretary of Commerce.

The U.S. Fish and Wildlife Service (USFWS) and the National Marine Fisheries Service (NMFS) are the primary agencies responsible for implementing the ESA. Under the ESA the USFWS responsibilities include: (1) the identification of threatened and endangered species; (2) the identification of critical habitats for listed species; (3) implementation of research on, and recovery efforts for, these species; and (4) consultation with other federal agencies concerning measures to avoid harm to listed species.

An endangered (E) species is a species which is in danger of extinction throughout all or a significant portion of its range. A threatened (T) species is a species likely to become endangered within the foreseeable future throughout all or a significant portion of its range. Proposed species are those which have been formally submitted to Congress for official listing as endangered or threatened. Species may be considered endangered or threatened if they meet any of the five following criteria: (1) present or threatened destruction, modification, or curtailment of their habitat or range; (2) overuse of the species for commercial, recreational, scientific, or educational purposes; (3) disease or predation; (4) inadequacy of existing regulatory mechanisms; and (5) other natural or man-made factors affecting its continued existence (Fay and Thomas 1983). In addition, the USFWS has identified species which are candidates for listing as a result of identified threats to their continued existence. The three candidate categories are as follows: (1) Candidate Category 1 (C1) are those species for which the USFWS has on file sufficient information on biological vulnerability and threats to support proposals to list them as threatened or endangered; (2) Candidate Category 2 (C2) are taxa for which information now in possession of the USFSW indicates that proposing to list as endangered or threatened is possibly appropriate, but for substantial data on biological vulnerability and threat are not currently available to support a proposed listing; and (3) Candidate Category 3 (C3) species are considered for listing as threatened or endangered but are no longer under such consideration (USFWS 1995a). The ESA also calls for the conservation of Critical Habitat - the areas of land, water, and air space which an endangered species needs for survival. These areas include sites with food and water, breeding areas, cover or shelter sites, and sufficient habitat to provide for normal population growth and behavior.

The State of Texas has separate laws and regulations governing the listing of T/E species (plants: Chapter 88 of the Texas Parks and Wildlife [TPW] Code and Sections 69.01-69.14 of the TAC; animals: Chapters 67 and 68 of the TPW Code and Section 65.171-65.184 of Title 31 of the TAC). The TPWD Natural Heritage Program does not list species the same as the federal government. TPWD has two species status categories, endangered in the State of Texas and threatened in the State of Texas. Plants which are on the federal list are listed by the state. Animals which are or are not currently on the federal list may be listed as state endangered/threatened. The state does not have any authority to list invertebrates. The Resources Protection Division of the TPWD (Natural Heritage Program) maintains computerized records of state endangered and threatened species by county.

The Texas Organization for Endangered Species (TOES), a private, non-profit organization formed in 1972 is comprised of biologists, conservationists, and natural resource managers who study the plight of vanishing plants and animals in Texas and encourage conservation through education of these native organisms. For endangered and threatened plant species, TOES follows federal and state classifications. Animal species are classified as endangered (E), threatened (T), or placed on a "watch list" (WL). Species are classified as endangered if in danger of extinction in all or most of the species range in the United States, particularly in Texas, and threatened if depleted or impacted by man so as likely to become endangered in the near future. TOES has also developed a "watch list" for plant and animal species, which are not listed as endangered/threatened by the ESA or the State of Texas, and a list of invertebrates of special concern which includes all species currently being considered by the USFWS. The term TOES "watch list" includes those species potentially endangered or threatened in the United States, especially Texas, although not necessarily in its range as a whole.

Two federally listed C2 and TOES "watch list" species, blue sucker (also listed as state threatened) and Guadalupe bass (*Micropterus treculi*) are listed for the Colorado River. Based on recent surveys conducted in the Egypt Reach of the Colorado River by Ray and Mosier (1992), both of these species occur in the study reach of proposed project location. Another TOES "watch list" species, the American alligator (*Alligator mississippiensis*), could also potentially occur in backwater areas of the Colorado River (TOES 1995; TPWD 1995a; USFWS 1994, 1995b). TOES has also identified an invertebrate of special concern (also listed as federal C2 species [USFWS 1994]), disjunct crawling water beetle (*Haliplus nitens*), which may occur in the project area. The distribution of this species in Texas has not been determined (TOES 1988).

Federal endangered/threatened mollusks are not listed for the West-Central/South-Central study areas (USFWS 1995c, 1995d). However, false spike (*Quincuncina mitchilli*) has been proposed as a candidate for federal protection (Neves 1993) and is considered as a species of concern by TOES (1988). This species is known to occur in the Colorado River Basin (Howells 1995a, 1995b). Native mollusks of the United States and Canada were recently evaluated and ranked by researchers as endangered, threatened, or special concern species (Williams et al. 1993). These rankings are not legally binding but do provide an insight to species of mollusks which could potentially be listed in the near future. One endangered, two threatened, and two special concern species of mollusks are listed by these researchers for the Colorado River Basin. The only endangered species is Texas fawnsfoot (*Truncilla macrodon*). Threatened species include Texas pimpleback (*Quadrula petrina*) and smooth pimpleback (*Q.* houstonensis). Special concern species are Texas fatmucket (*Lampsilis bracteata*) and golden orb (*Quadrula aurea*).

3.2 Sandy Creek

3.2.1 Abiotic Environment

3.2.1.1 Physiographic Location

Sandy Creek originates from two source tributaries (East and Middle Sandy Creek) north of the town of Sheridan in western Colorado County. The east and middle branch join to form Sandy Creek east-southeast of Sheridan. West Sandy Creek flows into Sandy Creek farther downstream just east of the Colorado/Lavaca county line. Sandy Creek flows southeast approximately 37 mi through western Colorado, eastern Lavaca, western Wharton, and Jackson counties, and drains approximately 289 square mi (mi^2) as it flows through the Gulf Coastal Plain to its terminus at Lake Texana (U.S. Department of Interior [USDI] 1974; Armstrong et al. 1987b) (Figure III-5).

3.2.1.2 Physical Characteristics

The physical characteristics of the Sandy Creek drainage have not been described in detail by previous researchers. Therefore, this section is based on recent qualitative observations of Sandy Creek and a nearby tributary, West Mustang Creek.

Sandy Creek, immediately above Lake Texana, is a broad, relatively shallow creek with a sandy bottom. The lower reaches of Sandy Creek vary from approximately 30 to 70 ft wide (Choffel 1995b). Based on observations of nearby West Mustang Creek, moderately defined bends with exposed sand banks and sand bars would be expected to occur in Sandy Creek (Bayer et al. 1992). Broad shallow runs and glides would predominate in the lower reaches of the creek immediately above Lake Texana. Riffles, runs, glides, and some deeper pools would occur in the middle reaches. Although the predominant habitats would be runs, glides, riffles, and pools, some undercut banks would probably occur. Instream habitat (i.e., root snags, woody debris, etc.) would be minimal in areas adjacent to agricultural land use.

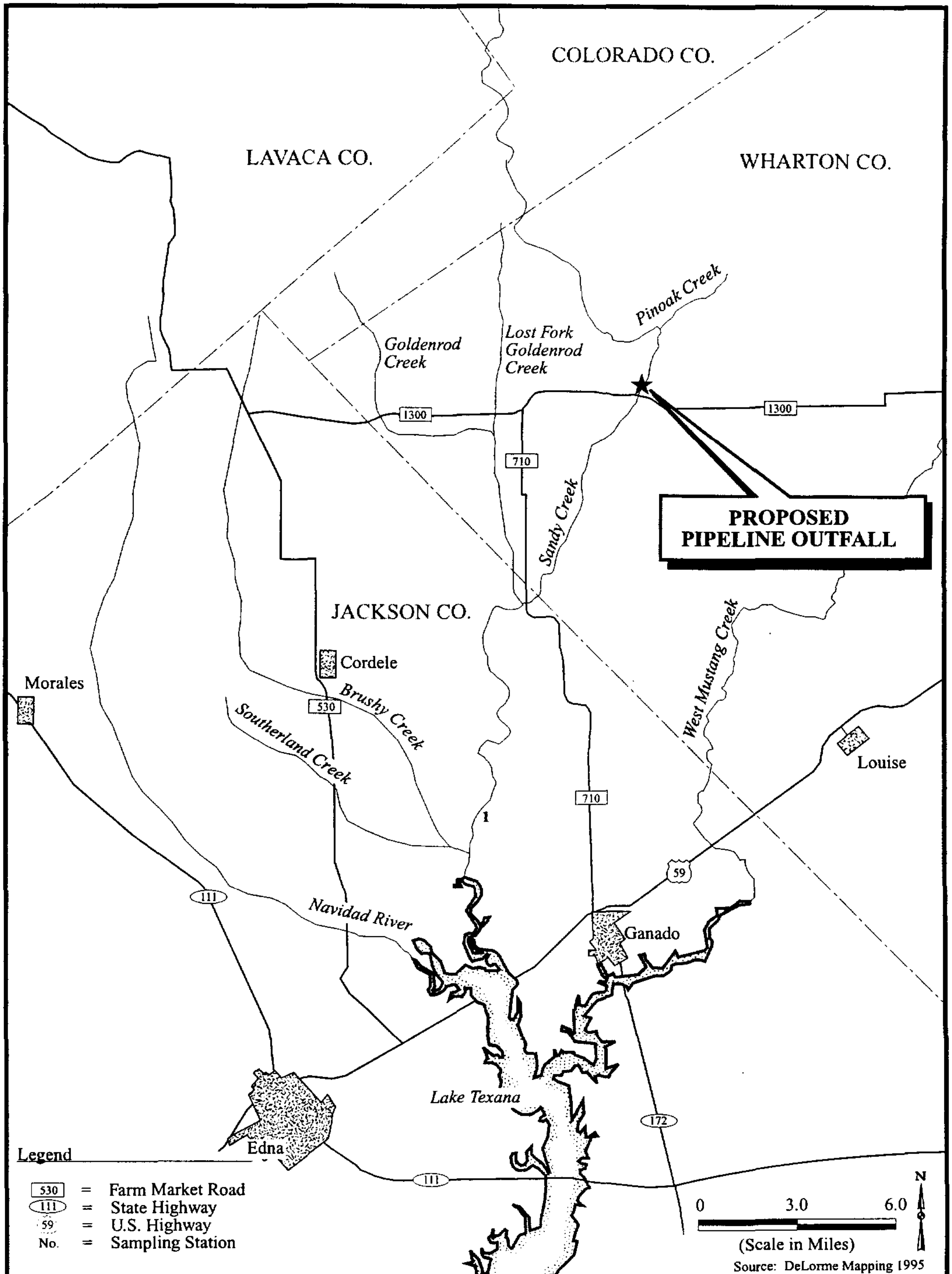


Figure III-5. Location of Sandy Creek.

3.2.1.3 Hydrology

Flow in Sandy Creek is intermittent and highly variable (Armstrong et al. 1987b). Recent water discharge records from Sandy Creek near Louise (Station 08164450) indicate flows varied from 0 to 8,310 cfs from October 1992 through September 1993 and from 10 to 3,450 cfs during the period from October 1993 to September 1994. Flows are generally lower in late summer, fall, and early winter. Most of the low flow during the irrigation season (April to September) is a result of drainage from nearby rice fields irrigated by water originally withdrawn from the Colorado River at Garwood (Gandara et al. 1994, 1995).

3.2.1.4 Physicochemical Characteristics

Recent water quality assessments of the Lavaca-Navidad Basin have been conducted by Lavaca-Navidad River Authority and USGS. Although there are some instances of elevated concentrations of phosphorus in some of the stream segments, water quality in the basin is generally good. Pesticides and PCBs were not detected in water samples, however, they were found in sediment samples (Texas Water Commission [TWC] 1992a). The major water quality concerns in the fresh waters of the basin include potentially undesirable levels of nutrients and herbicides in return flows from rice irrigation, and the threat of surface water pollution from spills and illegal dumping of petroleum waste products (TWC 1992a).

A water quality assessment was conducted in lower Sandy Creek above Lake Texana in 1985-1986 (Armstrong et al. 1986). Thirteen water quality parameters were measured during the five sampling dates (Table III-20). Only one exceedance for pH occurred during the sampling periods (see Table III-20). The USGS routinely conducts water quality assessments on Sandy Creek near Louise. USGS water quality data from October 1993 to September 1994 are presented in Table III-21.

Table III-20

Water Quality Data for Sandy Creek, Jackson County, Texas
(October 27, 1985 - July 19, 1986)

Parameters	Oct 26	Feb 22	Apr 26*	Jun 25	Jul 19	Water Quality Standards
Temperature[1]	22.7	10.3	27.5	30.6	26.2	35
pH[2]	7.3	5.7	7.1	7.3	7.4	6.5-9.0
Dissolved Oxygen[3]	8.6	9.5	9.1	7.5	7.5	5.0
Conductivity[4]	375	278	635	206	501	NA
Total Alkalinity[3]						
as Calcium Carbonate)	89.0	75.1	138.0	65.5	135.7	NA
Total Kjeldahl Nitrogen[3]	1.0	0.31	1.28	1.08	-	NA
Ammonia - Nitrogen	0.02	0.17	0.18	<0.02	0.09	NA
Nitrite - Nitrogen	0.12	0.01	<0.01	0.02	<0.01	NA
Nitrate - Nitrogen	0.09	<0.02	0.16	0.24	0.10	NA
Total Phosphorus[3]	0.28	0.14	0.17	0.16	0.12	NA
Orthophosphorus[3]	0.20	0.06	0.13	0.11	0.06	NA
Turbidity (NTU)	19	11	10	19	13	NA
Chlorophyll A[5]	-	-	-	39.5	19	NA

*Low flow condition
[1]°C (degrees Celsius)
[2]pH (hydrogen-ion)
[3]mg/ℓ (milligrams per liter)
[4]μmhos/cm (micromhos per centimeter)
[5]μg/ℓ (micrograms per liter)

Legend: NTU = Nephelometric Turbidity Units
NA = Not Applicable

Source: Armstrong et al. 1986

Table III-21

Water Quality Parameters - Sandy Creek near Louise, Texas
(October 1993 - September 1994)

Parameters	Nov 4	Mar 25	Jun 30	Aug 29	Water Quality Standard
Regulated					
pH[1]	8.2	7.3	8.2	7.8	6.5-9.0
Temperature[2]	18.0	20.0	31.0	29.5	32.8
Dissolved Oxygen[3]	9.0	8.0	7.8	5.9	5.0
Dissolved Sulfate[3]	21.0	9.5	15.0	10.0	30
Dissolved Chloride[3]	55.0	18.0	51.0	56.0	100
Dissolved Fluoride[3]	0.2	0.2	0.3	0.3	4000
Total Dissolved Solids[3]	247.0	100.0	211.0	284.0	550
Suspended Sediment[4]	NS	NS	NS	NS	NA
Dissolved Aluminum[4]	NS	NS	NS	NS	991
Dissolved Barium[4]	-	-	110.0	-	1000
Dissolved Selenium[4]	-	-	<1.0	-	20/5*
Dissolved Silver[4]	-	-	<1.0	-	0.92/0.49*
Non-Regulated					
Specific Conductance[5]	431.0	171.0	400.0	491.0	NA
Turbidity (NTU)	NS	NS	NS	NS	NA
Total Hardness[3]	130.0	47.0	130.0	140.0	NA
Alkalinity[3]	100.0	45.0	96.0	120.0	NA
Dissolved Silica[3]	28.0	11.0	12.0	47.0	NA
Total Nitrogen - Nitrate[3]	0.088	0.22	0.20	0.44	NA
Dissolved Phosphorus[3]	0.11	0.07	0.06	0.29	NA
Dissolved Orthophosphorus[3]	0.03	0.06	0.02	0.26	NA
Dissolved Orthophosphate[3]	0.09	0.18	0.06	0.80	NA

*Acute/chronic criteria
[1]pH (hydrogen-ion)
[2]°C (degrees Celsius)
[3]mg/ℓ (milligrams per liter)
[4]μg/ℓ (micrograms per liter)
[5]μS/cm (microsiemens per centimeter)

Legend: NTU = Nephelometric Turbidity Units
NS = Not Sampled
NA = Not Applicable

Source: Gandara et al. 1995; 30 TAC § 307

3.2.2 Biotic Environment

3.2.2.1 Microbes

- Community Composition

With the exception of fecal coliforms, specific investigations on most microbial communities have not been conducted in Sandy Creek. The microbial community in Sandy Creek would be expected to be similar to that described for the Colorado River (see Section 3.1.2.1).

Recent analyses of fecal coliform levels have not been conducted in Sandy Creek. Historic data from Sandy Creek indicate fecal coliform levels in 1978 exceeded the historic standard criteria (200 colonies/100 mℓ) seven out of 10 times with an overall mean of 1,390 colonies/100 mℓ. The maximum fecal coliform level was 11,000 colonies/100 mℓ and the minimum was 26 colonies/100 mℓ (Davis et al. 1978).

- General Ecology

Microbial production in stream ecosystems is likely to be influenced by environmental conditions, especially the amount and quality of organic substrate available (Cole et al. 1988). The yearly rhythm of microbial numbers will have their maximum in spring and autumn or late summer. Current evidence indicates that benthic microbes are far more active and abundant than suspended microbes (Edwards et al. 1990). In small streams, production by microbes suspended in the water column is often though to be minor, originating from sloughing of cells from the surface of sediments and epiphytes, and subject to continual wash-out. Particularly with streams, hydrographic disturbances are frequently caused by irregular loading (e.g., heavy rains which wash inorganic matter [soil and forest litter]; temporary introductions of sewage). Kaplan and Bott (1989) reported that microbial densities are an order of magnitude or more higher in sandy sediments (e.g., Sandy Creek) than found on stony substrates.

3.2.2.2 Phytoplankton

- Community Composition

Based on the literature search, no recent data are available on the phytoplankton community of Sandy Creek. Monthly phytoplankton samples were collected from Sandy Creek at Ganado-Cordele Road (Station 1) from February through December in 1978 (see Figure III-5). The phytoplankton community of Sandy Creek, a coastal lowland stream, can be characterized as consisting of a true plankton of diatoms and green algae, blue-green algae, flagellates, and algal components containing representatives of benthic diatoms and green algae (Table III-22). Studies conducted on lower Sandy Creek reported green algae and diatoms to be dominant; green algae and diatoms were abundant in winter, early spring, and early summer/early fall, and diatoms were abundant in mid-summer and winter. Both flagellates and blue-green algae comprised a smaller portion of the community. Flagellates were observed in early spring, mid-summer, fall, and winter, while blue-green algae were observed only in late fall and winter. Green algae were dominated by the species *Oocysyis, Chlorella, Pediastrum, Ankistrodesmus,* and *Scenedesmus*, while the diatom community was dominated by *Cyclotella*, and the periphytic diatoms *Navicula*, *Nitszchia*, and *Pleurosigma*. The flagellates were represented by the species *Euglena* and *Phacus*, and the blue-green algal community was represented by the attached forms *Oscillatoria* and *Lyngbya* (Davis et al. 1978).

- General Ecology

Phytoplankton develops self-sustaining populations only under certain conditions in small streams, like Sandy Creek. The first condition that must be met is a sufficient residence time to allow biomass to increase faster than it is transported downstream. Nutrients are usually not critical limiting factor for stream phytoplankton. In shallow streams, light penetration may be limited by the density/height of trees along the banks. Light penetration to significant depths occurs only when discharge is low. Under these conditions, phytoplankton blooms can develop. In comparison to standing waters of comparable nutrient status, stream phytoplankton biomass is substantially lower. Moreover, although the knowledge of grazing pressure of stream phytoplankton is scant, this also does not appear to be a strongly limiting factor. Thus, in contrast to standing waters where phytoplankton communities frequently are limited by

Table III-22

Phytoplankton Species Collected in Sandy Creek in 1978

Taxa	2/18	3/13	4/13	5/23*	6/20	7/20	8/24*	9/23	10/12	11/10	12/4
CHLOROPHYTA											
Volvox	X										
Oocystis	X[1]		X		X			X[1]			
Pediastrum	X[1]								X		
Coelastrum		X									
Chlorella	X	X[1]	X[1]		X[1]	X			X[1]	X	X
Ankistrodesmus	X[1]	X[1]	X			X		X[1]		X	X
Scendesmus	X	X[1]			X[1]				X[1]	X	X
Actinastrum		X	X							X	
Closterium		X									
Spirogyra										X	
Ulothrix						X					
Microspora		X				X					
CYANOPHYTA											
Microcystis		X									
Oscillatoria									X	X	X
Lyngbya					X						
BACILLARIOPHYTA											
Cyclotella	X[1]	X	X		X	X[1]		X[1]			X
Caloneis						X					
Cymatopleura						X					
Cymbella						X					
Gyrosigma		X								X	X
Navicula	X[1]	X	X		X[1]	X				X	
Nitzschia	X[1]	X[1]	X[1]			X[1]		X	X[1]	X[1]	X[1]
Pleurosigma		X			X[1]	X			X		
Surirella					X	X					
Synedra	X										
EUGLENOPHYTA											
Euglena acus										X	
Euglena		X	X			X		X	X		X
Phacus						X		X[1]			

*No sample, dry creek bed
[1]Dominant forms

Source: Smith 1950; Davis et al. 1978

some combination of nutrient supply and grazing, these factors usually are considerably less important in streams (Allan 1995).

3.2.2.3 Periphyton

- Community Composition

Information on the composition of periphyton communities in Sandy Creek is not available. The periphyton community of Sandy Creek can, however, be generally characterized by a review of pertinent literature from similar stream systems.

Stream periphyton communities can be categorized as macroalgae (benthic forms having a mature thallus) or microalgae. Macroalgal communities form mats and gelatinous colonies/filaments, while microalgal communities occur on stones (epilithon), soft sediments (epipelon), and other plants (epiphyton). Epipelic taxa form films or mats on silt and mud bottoms, and typically are motile and easily swept away by increased current. Unlike epipelic species, epiphytic and epilithic taxa are usually firmly attached by mucilaginous secretions or via a basal cell and stalk; thus, they are much less likely to be carried by currents unless flow is substantial (Allan 1995). Table III-23 lists the types of epipelic, epilithic, metaphytonic, and epiphytic species commonly found in lotic systems (Round 1964; Hynes 1970).

Diatoms typically comprise the majority of species within the periphyton community, although green algae and blue-green algae are well represented and can dominate the biomass of benthic communities under some circumstances. All, or almost all, the diatoms which occur on stream/river silts are motile and include such epipelic genera as *Nitzschia*, *Navicula*, *Caloneis*, *Gyrosigma*, *Surirella*, and *Cymatopleura*. Also motile are the epipelic filamentous Cyanophyta, *Oscillatoria* and *Phormidium*. Epilithic and epiphytic genera are either firmly stuck down by jelly (e.g., *Cocconeis*, a common epiphyte, and *Chamaesiphon*, a small blue-green alga), or stalked, as are many diatoms (e.g., *Cymbella*, *Achnanthes*, *Gomphonema*). Several types of stream algae, including *Rivularia*, *Nostoc*, *Schizothrix*, *Vaucheria*, and the tube-dwelling desmid *Oocardium* also grow as cushion-like clumps which divert the

Table III-23

Distribution of Some Common Benthic Algae in Subcommunities of Freshwater Streams

Epiphytic	Epilithic	Metaphyton(ic)	Epipelic
Chamaesiphon	*Hildenbrandia rivularis*	*Scenedesmus* and other Chlorococcales	*Melosira varians*
Oncobyrsa	*Lithoderma fluviatilis*		*Fragilaria intermedia*
Dermocarpa	*Chamaesiphon*	*Euglena*	*Frustulia*
Rivularia	*Rivularia*	*Phacus*	*Gyrosigma*
Aphanochaete	*Meridion circulare*	Desmids: *Staurastrum*	*Caloneis*
Chaetophora	*Diatoma hiemale*	Desmids: *Cosmarium*	*Neidium*
Oedogonium	*Cocconeis placentula*	Desmids: *Euastrium*, etc.	*Diploneis*
Bulbochaete	*Achnanthes*	*Spirogyra*	*Stauroneis*
Cocconeis	*Synedra*	*Mougeotia*	*Navicula*
Achananthes	*Gomphonema*	*Zygnema*	*Amphiprora*
Synedra	*Cladophora*		*Amphora*
Cymbella	*Vaucheria*		*Cymbella* (motile spp.)
Gomphonema	*Lemanea*		*Bacillaria*
			Nitzschia
			Cymatopleura
			Surirella
			Scenedesmus
			Pediastrum
			Oscillatoria
			Spirulina

Legend: spp. = species

Source: Round 1964

current over them. Others are attached firmly by rhizoid-like structures at the base of filaments which trail out as tassels into the current, as in many filamentous Chlorophyceae (e.g., *Cladophora*, *Oedogonium*, and *Ulothorix*). In addition to the attached algae which occur in the current, many streams also contain unmodified species which are normal inhabitants of pools and edges of ponds. They occur in quiet areas behind obstructions, in vegetation, and in little bays along the banks, and include filamentous Chlorophyceae such as *Spirogyra*, *Zygnema*, and *Mougeotia*, various Chlorococcales and desmids, and often green flagellates. Based on this data, the periphyton composition in Sandy Creek would be expected to be comprised of green algae, blue-green algae, and diatoms with the highest variability among site-specific habitats (Stevenson et al. 1991).

- General Ecology

Periphyton occurs on various every surface in running waters including stones, soft sediments, and macrophytes. High discharge, which dislodges cells, flips stones, and scours surfaces, often restricts periphyton growth to lower flow periods. Light can also be a limiting factor, particularly in small streams which have dense forest canopies. There is also growing evidence that nutrient limitation of periphyton is widespread, most often due to a short supply of phosphorus. In addition, small periphytic autotrophs are vulnerable to a wide variety of herbivorous zooplankters, benthic organisms, and fishes. Grazing by these communities can cause significant losses (Allan 1995).

The species composition of the periphyton assemblage varies seasonally, and since this occurs even in constant temperature springs, changing light conditions must be partly responsible. Diatoms dominate during winter and continue to be a major component of the flora in spring and early summer although the species composition changes. Total abundance generally is greatest in the spring, and a secondary peak can occur in autumn. Other groups can become abundant during summer, particularly green and blue-green algae. Periphyton communities often decrease during summer and increase again in the fall due to reduced shading or changes in other environmental physicochemical conditions (Allan 1995).

3.2.2.4 Aquatic Plants

- Community Composition

Information on the composition of the aquatic plant communities in or near the proposed outfall site on Sandy Creek is not available. The aquatic macrophyte community in Sandy Creek can, however, be generally characterized by a review of pertinent literature.

Flowering plants, mosses and liverworts, a few species of encrusting lichens, and other large algal species constitute the marcophyte community of flowing waters (Hynes 1970). Most of the groups can also be found in standing water, but as flows increase, the flora becomes restricted to the small number of species able to withstand current. Macrophytes exhibit few adaptations to life in flowing water and are most successful in slow current areas such as deltas and backwaters. Certain characteristics permit establishment and maintenance of populations in appreciable current. Tough, flexible stems and leaves;

firm attachment by adventitious roots, rhizomes, or stolons; and vegetative reproduction typify most macrophytic species (Hynes 1970; Westlake 1975).

- General Ecology

Marcophytes can be classified according to their growth form, their manner of attachment, and, more specifically, by the range of environmental conditions that a species inhabits. Four major growth forms are recognized by Westlake (1975): (1) emergents occur on stream banks/shoals, have leaves and reproductive organs, and are rooted in soil that is close to or below water level much of the year; (2) floating-leaved macrophytes occupy margins of slow streams, rooted in submerged soils with leaves and reproductive organs floating or aerial; (3) free-floating plants are usually not attached to the substrate and can form large mats, often entangled with other species and debris, in slow subtropical streams; and (4) submerged macrophytes are attached to the substrate, their leaves are entirely submerged, and they typically occur in midstream unless the water is too deep.

Aquatic macrophytes, including some large algae, bryophytes and vascular plants, are found in flowing water mainly where neither the depth nor the current is great. In longitudinal view, therefore, one expects the macrophytic composition to exhibit a downstream succession from bryophytes to freshwater angiosperms such as crowsfoot (*Ranunculus* spp.), to flowering plants such as pondweed and waterweed (*Elodea* sp.), which are more typical of slower and more fertile waters, to emergent and floating-leaved plants in the slowest and deepest sections (Allan 1995). Streams of intermediate size, canals, and stream margins usually support the greatest biomass of these groups.

The length of the growing season, current, and light appear to be major limiting factors for aquatic macrophytes. Grazing on living plants is in most instances a minor factor, and the bulk of plant production enters the detritus pool after senescence. In addition, stream macrophytes can alter flow characteristics and create reduced current velocities near the substrate. They also provide more substrate surface area, more fine particle sediments, and more detritus which can result in a higher biomass of epiphytic forms (i.e., diatoms) in slower currents and an increase in invertebrate and fish microdistribution and potentially population density, by providing shelter, oviposition sites, and substrate for colonization (Gregg and Rose 1982; Allan 1995).

3.2.2.5 Zooplankton

- Community Composition

Based on the literature search, only historic data are available on the zooplankton community of Sandy Creek. Monthly zooplankton samples were collected from Sandy Creek at Ganado-Cordelle Road (Station 1) from February through December 1978 (see Figure III-5). The zooplankton community of Sandy Creek can be characterized as consisting of a true plankton of protozoans, rotifers, cladocerans, and copepods (Table III-24). Rotifers are the dominant component in winter, early spring, mid-summer, and fall. Protozoans, cladocerans, and copepods are expected to comprise a smaller portion of the community. Protozoans and cladocerans were observed in early spring and summer, while copepods were observed in winter, early spring, mid-summer, and fall. Protozoan species of tintinnids and *Stylonychia*, cladocerans (e.g., *Daphnia* and *Bosmina*), immature copepods (nauplii), and calanoid copepods comprised the zooplankton population (Davis et al. 1978).

- General Ecology

Compared with lakes and large rivers, streams typically support a more disparate zooplankton community and a biomass less than would be expected based on the amount of phytoplankton. Rotifers and smaller crustaceans usually predominate because of their shorter generation times, and even these taxa can build up their numbers only during low-flow periods. Discharge conditions determine the species and size composition of zooplankton, and strongly constrain their ability to exert strong grazing pressure. Densities tend to peak in late spring through mid-summer, often with different density modes for rotifers and crustaceans. The amount and variety of zooplankton starts to decline in autumn and in represented by a few rotifers in the winter months (Williams 1966; Hynes 1970; Allan 1995).

3.2.2.6 Benthic Macroinvertebrates

- Community Composition

Based on a search of available technical literature, recent aquatic ecological surveys of benthic macroinvertebrate communities in Sandy Creek have not been conducted. A benthic invertebrate survey

Table III-24

Zooplankton Species Collected in Sandy Creek in 1978

Taxa	2/18	3/13	4/13	5/23*	6/20	7/20	8/24*	9/23	10/12	11/10	12/4
PROTOZOA											
Tintinnids			X								
Stylonychia					X[1]						
ROTIFERA	X[1]	X[1]	X			X[1]		X[1]	X[1]	X[1]	X[1]
Euchlanis					X						
CLADOCERA											
Daphnia			X			X[1]					
Bosmina					X						X
COPEPODA											
Nauplii	X	X				X[1]			X	X	X
Calanoid	X	X	X[1]			X[1]					X

*No sample, dry creek bed
[1]Dominant forms

Source: Davis et al. 1978; Thorp and Covich 1991

was conducted in Sandy Creek near Ganado-Cordelle Road (Station 1) from February through August 1978 (see Figure III-5). Damselfly nymphs (odonates) and backswimmers (Hemiptera) were the dominant organisms collected (Davis et al. 1978). Due to the similarity in substrate and general flow characteristics of the two streams, the benthic fauna of Sandy Creek can be characterized by utilizing benthic data from nearby West Mustang Creek (Bayer et al. 1992). Caddisflies (Trichoptera-Hydropsychidae) and flies (Diptera-chironomids) would potentially be the most abundant aquatic insects (Table III-25). The trichopteran community would potentially be dominated by *Cheumatopsyche* sp., while the chironomid community would potentially be dominated by *Polypedium* and *Tanytarsus*. Other potentially important groups of aquatic insects include ephemeropterans and coleopterans (beetles). Other benthic invertebrates which would potentially occur include worms (oligochaetes), round worms (nematodes), and clams/snails (mollusks).

Table III-25

Benthic Macroinvertebrates Potentially Occurring in Sandy Creek[1]

Phylum or Order	Family	Genus/Species	Number per Square Meter	Feeding Group
Nematoda	Unknown	Unknown	4	Unknown
Mollusca	Ancylidae	*Ferrissia rivularis*	4	Scraper
	Corbiculidae	*Corbicula fluminea*	4	Filterer
	Planorbidae	*Helisoma anceps*	4	Scraper
	Physidae	*Physella virgata*	29	Scraper
Annelida	Tubificidae	*Branchiura sowerbyi*	4	Miner
		Limnodrilus sp.	4	Miner
Ephemeroptera	Caenidae	*Caenis* sp.	642	Collector
	Heptageniidae	*Stenacron* sp.	50	Gatherer
	Tricorythidae	*Tricorythodes albilineatus*	18	Collector
Odonata	Coenagrionidae	*Ischnura* sp.	18	Predator
Trichoptera	Hydroptilidae	*Neotrichia* sp.	4	Unknown
	Hydropsychidae	*Cheumatopsyche* sp.	5475	Collector
	Leptoceridae	*Oecetis* sp.	4	Predator[2]
	Polycentropodidae	*Cyrnellus fraternus*	4	Unknown
Megaloptera	Corydalidae	*Corydalus cornutus*	4	Piercer
Heteroptera	Corixidae	*Trichocorixa* sp.	7	Piercer
	Hydrometridae	*Hydrometra* sp.	4	Piercer[3]
	Veliidae	*Rhagovelia* sp.	4	Piercer[3]
Coleoptera	Dryopidae	*Helichus suturalis*	25	Unknown
	Helodidae	*Scirtes* sp.	47	Shredder
	Elmidae	*Heterelmis vulnerata*	43	Unknown[2]
		Stenelmis grossa	54	Scrapers[2]
		Stenelmis occidentalis	61	Scrapers
	Noteridae	*Suphisellus bicolor*	4	Herbivore
Diptera	Ceratopogonidae	*Probezzia* sp.	29	Predator
	Chironomidae	*Ablabesmyia parajanta*	22	Predator
		Cricotopus bicinctus	68	Collector
		Conchapelopia sp.	90	Predator
		Chironomus decorus	115	Collector
		Dicrotendipes neomodestus	614	Collector
		Cladotanytarsus sp.	90	Collector
		Cladotanytarsus mangus	90	Collector
		Phaenospectra sp.	22	Scraper
		Polypedilum convictum	47	Shredder
		Polypedilum illinoense	341	Shredder
		Polypedilum scalaenum	230	Shredder
		Paracladopelma doris	90	Unknown
		Saetheria sp.	90	Unknown
		Tanytarsus glabrescens	294	Collector
		Tanytarsus sp.	90	Collector

[1]Based on data from nearby West Mustang Creek
[2]Also scrapers/herbivores/collectors
[3]Also carnivores

Legend: sp. = species

Source: Merritt and Cummins 1978; Bayer et al. 1992

- General Ecology

A variety of abiotic and biotic factors regulate occurrence and distribution of benthic invertebrates in stream communities. Hynes (1970) considered four abiotic factors, current velocity, temperature, substrate, and water quality (i.e., dissolved substances), to be the most important regulatory factors. Current velocity often determines macroinvertebrate microhabitat selection. For example, the retreats and nets of some caddisflies (e.g., *Hydropsyche instabilis* and *Plectrocnemia conspersa*) are only constructed in a specific range of current velocities. Temperature, which can affect reproduction, egg development, and growth, may be a critical factor for some benthic invertebrates depending on their tolerance range. The structural composition and size of the substrate (i.e., boulders to small sand grains or clay particles) provide a variety of microhabitats for benthic invertebrates. Higher densities of benthic macroinvertebrates usually occur on larger substrates (boulders, cobbles, etc.). Woody substrates are important habitats for macroinvertebrates in sandy streams when other cover is not present (Webber et al. 1992; Allan 1995). Water chemistry/quality is also a major influence in determining benthic community composition. For example, pH and phosphorus have been suggested as primary determinants in structuring invertebrate communities (Jackson and Harvey 1993). The effects of drought/floods, food, interspecific competition, predation, shade, and zoogeography are also important factors (Webber et al. 1992). In summary, the response of benthic invertebrates to environmental changes is complex and is dependant on many different abiotic/biotic factors (Jackson 1992).

3.2.2.7 Amphibians/Reptiles

- Community Composition

Although specific surveys have not been conducted for amphibians and reptiles along and in Sandy Creek, the potential presence of amphibian and reptilian species can be predicted based on historic occurrence records and habitat requirements of the species. A total of 33 species of amphibians and reptiles are known to occur in the Lavaca/Navidad Basin (Dixon 1987; Appendix A-1). Based on habitat requirements of these species, 20 species would potentially use habitat in and/or immediately adjacent to Sandy Creek (Table III-26).

Table III-26

List of Amphibians and Reptiles Potentially Occurring in or Adjacent to Sandy Creek

Common Name	Scientific Name
MOLE SALAMANDERS	
Smallmouth salamander	*Ambystoma texanum*
NEWTS	
Central newt	*Notophthalmus viridescens louisianensis*
SIRENS	
Western lesser siren	*Siren intermedia nettingi*
CRICKET FROGS	
Blanchard's cricket frog	*Acris crepitans blanchardi*
TOADS	
Gulf Coast toad	*Bufo valliceps valliceps*
Woodhouse's toad	*Bufo woodhouseii woodhouseii*
NARROWMOUTH TOADS	
Eastern narrowmouth toad	*Gastrophryne carolinensis*
TREEFROGS	
Cope's gray treefrog	*Hyla chrysocelis*
Green treefrog	*Hyla cinerea*
Gray treefrog	*Hyla versicolor*
CHORUS FROGS	
Strecker's chorus frog	*Pseudacris streckeri streckeri*
TRUE FROGS	
Rio Grande frog	*Rana berlandieri*
Bullfrog	*Rana catesbeiana*
Bronze frog	*Rana clamitans clamitans*
Southern leopard frog	*Rana utricularia*
COOTERS	
Texas river cooter	*Pseudemys texana*
COPPERHEADS/COTTONMOUTHS	
Western cottonmouth	*Agkistrodon piscivorus leucostoma*
WATER SNAKES	
Diamondback water snake	*Nerodia rhombifera rhombifera*
Blotched water snake	*Nerodia erythrogaster transversa*
Mississippi green water snake	*Nerodia cyclopion*

Source: Dixon 1987; Garrett and Barker 1987; Collins 1990; Tennant 1990

The smallmouth salamander (*Ambystoma texanum*) is presumed to utilize aquatic habitat in Sandy Creek for breeding and the adjacent riparian community for forage and shelter. The central newt may use quiet water areas (i.e., small tributary sloughs, temporary pools), if present, in or adjoining the creek. Blanchard's cricket frog (*Acris crepitans blanchardi*) may be present along sunny creek banks or in aquatic vegetation, if present, in the creek. The Gulf Coast (*Bufo valliceps valliceps*) and Woodhouse's (*Bufo woodhouseii woodhouseii*) toads are primarily terrestrial but could use isolated pools in the creek for breeding. The eastern narrowmouth toad (*Gastrophryne carolinensis*) could use bottomland area in or adjacent to the creek. Cope's gray treefrog, green treefrog, gray treefrog, and Strecker's chorus frog (*Psuedacris streckeri streckeri*) are primarily terrestrial but may use low flow areas in or immediately adjacent to the creek (Garrett and Barker 1987). Habitat for the true frogs and most turtles would probably be minimal; however, intermittent pools and backwaters, if present, may provide some habitat for these species. Western cottonmouth, diamondback water snake, blotched water snake, and Mississippi green water snake could occur in or immediately adjacent to the creek (Tennant 1990).

- General Ecology

Amphibians are usually restricted to moist or wet habitats with at least a nearby water source. The larval phases of most amphibians require water for transformation into the adult phase while most reptiles do not require water for adult maturation. Microhabitat components for amphibians and reptiles are site-specific physical entities which provide environmental conditions necessary for a wide variety of ecological functions (i.e., reproduction, foraging, predator avoidance/escape, thermoregulation, and resting). Amphibians and reptiles are ectothermic (cold-blooded) animals which derive their body temperature from the surrounding environment. Therefore, these animals are often very dependent on certain microhabitats to thermoregulate. Without habitat for thermoregulation, other ecological functions cannot be competed since internal temperature regulation determines the intensity of the activity. Factors which determine or regulate amphibian/reptilian populations in lotic systems include riffle/run/pool ratios, water temperature, turbidity, dissolved oxygen, organic content, siltation, and pollutants (Jones 1986).

3.2.2.8 Fish

- Community Composition

Based on the literature search, a historic fish survey was conducted in Sandy Creek in 1973 prior to impoundment of Lake Texana (USDI 1974). This historical data along with the fish community in nearby West Mustang Creek (Bayer et al. 1992), where recent surveys have been conducted, was used to generally characterize the fish community in Sandy Creek.

A total of 16 species were recorded for Sandy Creek in 1973 and 12 fish species were collected in West Mustang Creek in 1990 (Table III-27). The fish community in these creeks was comprised of obviate (e.g., gars), obligate (e.g., pugnose minnow [*Opsopoeodus emiliae*], tadpole madtom [*Noturus gyrinus*], and facultative species (i.e., channel catfish, flathead catfish). During the 1970s lower Sandy Creek (now partially inundated by Lake Texana) was classified as a "highest-valued fishery resource" by the USFWS, while upper Sandy Creek was not classified (Davis et al. 1978).

- General Ecology

Abiotic and biotic factors control the occurrence, distribution, and abundance of fish communities. Important abiotic factors include physicochemical parameters (i.e., current velocity, oxygen concentration, temperature, turbidity) and substrate. Interspecific competition, availability of food, susceptibility to predation, parasitism, and disease are some of the biotic factors which influence fish communities (Hynes 1970).

In flowing water, one of the most important abiotic factors is temperature. Many fish have a wide temperature tolerance and can survive in intermittent pools (e.g., yellow bullhead [*Ameiurus natalis*], longear sunfish). However, sudden changes without adequate time to acclimate, may be lethal. Current velocity often determines the occurrence/distribution of the species. Several researchers (Gerking 1945; Swingle 1954; Lachner 1956; Minckley 1963) have noted changes in fish composition as current speed decreases and substrate change (see Table III-19). Temperature and current velocity affect oxygen content (Hynes 1970). Higher temperatures and low current velocities decrease available oxygen, limiting

Table III-27

List of Fish Species Potentially Occurring in Sandy Creek[1]

Common/Scientific Name	Sandy Creek	West Mustang Creek
GARS		
Spotted gar/*Lepisosteus oculatus*		X
Longnose gar/*Lepisosteus osseus*		X
HERRINGS		
Threadfin shad/*Dorosoma petense*	X	
CARPS/MINNOWS		
Red shiner/*Cyprinella lutrensis*	X	X
Blacktail shiner/*Cyprinella venusta*	X	X
Common carp/*Cyprinus carpio*	X	
Texas Shiner/*Notropis amabilis*	X	
Pugnose minnow/*Opsopoeodus emiliae*	X	X
Bullhead minnow /*Pimephales vigilax*		X
SUCKERS		
River Carpsucker/*Carpiodes carpio*	X	
BULLHEADS/CATFISHES		
Yellow bullhead/*Ameiurus natalis*		X
Channel catfish/*Ictalurus punctatus*	X	X
Tadpole madtom/*Noturus gyrinus*		X
Freckled Madtom/*Noturus nocturnus*	X	X
Flathead catfish/*Pylodictis olivaris*	X	X
LIVEBEARERS		
Mosquitofish/*Gambusia affinis*	X	X
SUNFISHES		
Green sunfish/*Lepomis cyanellus*	X	
Warmouth/*Lepomis gulosus*	X	
Longear sunfish/*Lepomis megalotis*	X	X
Bantam sunfish/*Lepomis symmetricus*	X	
PERCHES		
Dusky darter/*Percina sciera*	X	

[1]Based on historical data from Sandy Creek and recent data from nearby West Mustang Creek

Source: USDI 1974; Robbins et al 1991; Bayer et al. 1992 survival to fishes which have a high tolerance for low oxygen levels. Substrates such as fallen logs and large rocks provide shelter for fish species. Presence and abundance of shelter sites often determine occurrence and abundance of riverine fish species.

Biotic factors include species-specific tolerances to competition and adaptability to abiotic and biotic conditions. Some species, like the bullhead minnow (*Pimephales vigilax*), are intolerant of competition and tend to occur alone. Other species may have adaptive feeding strategies (e.g., omnivorous) and thus have a better chance of surviving than species which are more selective (e.g., planktivores). The interaction of these and other biotic factors with the abiotic environment determines the composition of stream fish communities.

3.2.2.9 Endangered and Threatened Species

Federally listed aquatic endangered, threatened, and candidate category species have not been reported for Sandy Creek in Wharton County (USFWS 1995b). One state-listed species, the threatened blue sucker, is listed for Wharton County. Three TOES watch list species, American alligator, blue sucker, and the Guadalupe bass, potentially occur in Wharton County (TOES 1995). TOES has also identified an invertebrate of special concern (also listed as federal C2 species [USFWS 1994]), disjunct crawling water beetle, which may occur in Wharton County (i.e., the distribution of this species in Texas has not been determined [TOES 1988]).

3.3 Lake Texana

3.3.1 Abiotic Environment

3.3.1.1 Physiographic Location

Lake Texana (formerly Palmetto Bend Reservoir) is located in the West Gulf Coastal Plain physiographic province about midway between Houston and Corpus Christi and 6.8 mi southeast of the town of Edna in Jackson County, Texas (Figure III-6). The reservoir was created in 1980 by impoundment of the Navidad River approximately 4.9 mi upstream from its confluence with the Lavaca River. The reservoir

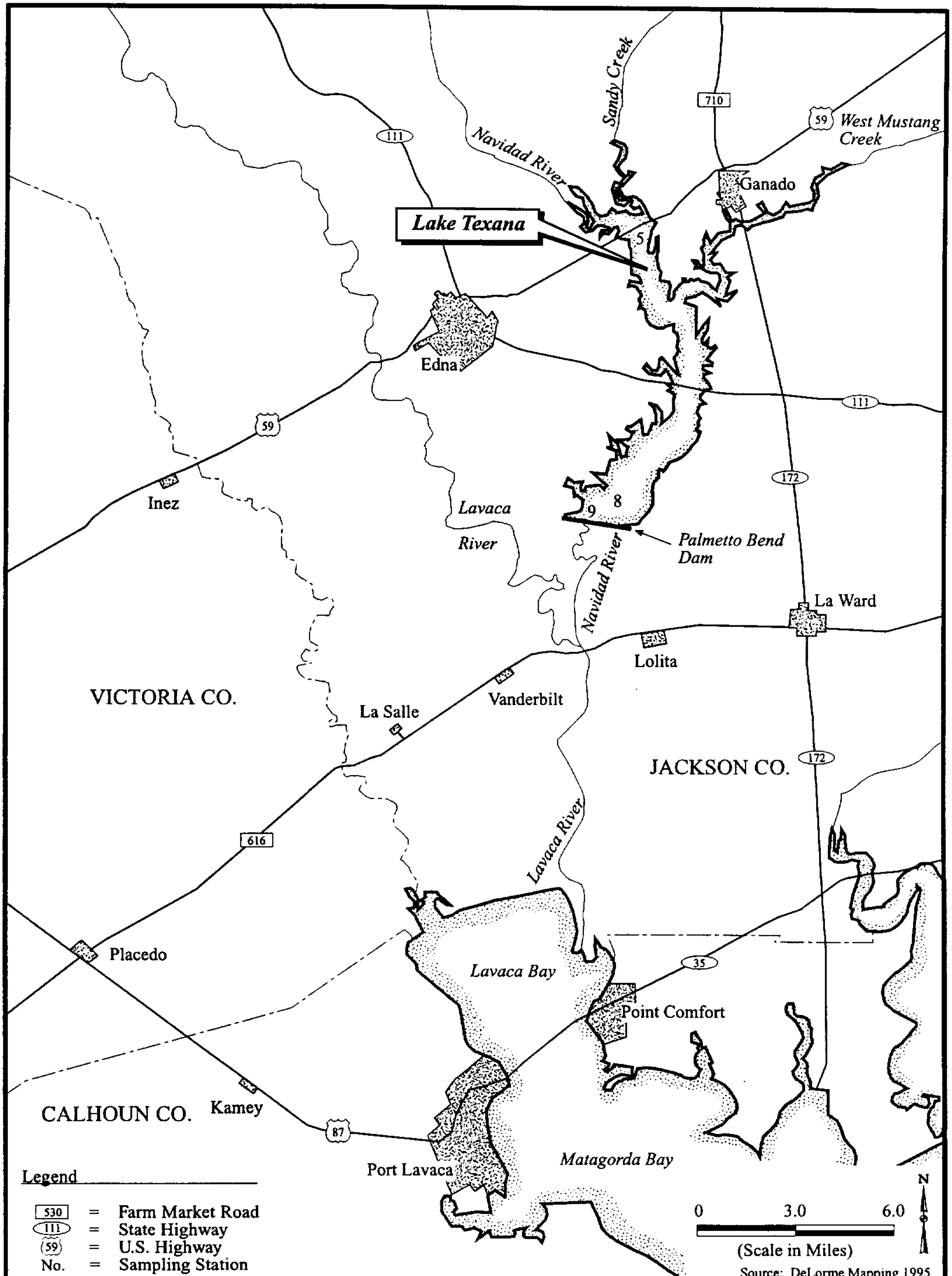


Figure III-6. Location of Lake Texana.

area includes an 18-mi reach of the Navidad River Valley and the lower portions of Sandy Creek and Mustang Creek valleys (USDI 1974; Armstrong et al. 1987b).

3.3.1.2 Physical Characteristics

The West Gulf Coastal Plain is very flat and subject to steady southeast winds in the summer and infrequent high northerly winds in the winter. Based on its location, Lake Texana would probably be classified as a warm monomictic lake of the third class. A lake of this type, as described by Hutchinson (1957), is characterized by surface temperatures which typically do not fall below 4°C. Lake water contents either go through a complete mixing cycle or circulation period during the winter or do not significantly stratify at any time.

In the lower Navidad River Valley, the bordering slopes of Lake Texana consist largely of Beaumont clay and clayey fine sand; but in the upper part of the lake, the slopes may be of silty fine sand at the top of the Lissie formation of the Pleistocene age. The floor of the reservoir is underlain by floodplain alluvium comprised of silt, clay, and sand with some scattered gravel up to 50 ft thick (USDI 1974; Armstrong et al. 1987b).

Lake Texana is relatively shallow, with an average depth of approximately 16 ft and a maximum depth of 58 ft when the reservoir stage is at normal operating level (44 ft above mean sea level [msl]). At normal operating stage, the lake has a storage capacity of 165,506 ac-ft, covers 10,995 ac, and has a sustainable yield of about 80,000 ac-ft/year (ac-ft/yr). At maximum flood pool (47 ft above mean sea level [msl]), an additional 1,500 ac are inundated. The mean annual inflow into Lake Texana from the Navidad River is 393,200 ac-ft (USDI 1974; Maeng 1983; HDR Engineering 1995).

3.3.1.3 Hydrology

Lake Texana occupies the lower portion of the Lavaca-Navidad River Basin. The Lavaca-Navidad River Basin is situated on the southwestern edge of the humid coastal zone within the West Gulf Coastal Plain physiographic province. The basin is bounded on the east by the Colorado River and Colorado-Lavaca coastal basins and on the west by the Guadalupe River and Lavaca-Guadalupe coastal basins. Rising in southern Fayette County, the Navidad River is a principal tributary of the Lavaca River. The Navidad River drains approximately 1,402 mi^2.

The flow of the Navidad River is very erratic and has varied from months of very little or no flow to days of major flooding. Flows have ranged from zero on many consecutive days during long droughts to a maximum peak discharge of 94,000 cfs at the Navidad River gaging station near Guando (USGS Station 08164500). Most of the flow volume consists of surface runoff resulting from storm runoff. Between normal and wet climatic periods, there is an appreciable dry weather flow derived partly from return flows from irrigated lands and partly from groundwater and streams in the basin. The average flow of the Navidad River into Lake Texana for the 1941-1986 period was 411,000 ac-ft/yr. Annual flows have varied from 13,000 ac-ft in 1954 and 14,000 ac-ft in 1956 to a maximum of 1,038,000 ac-ft in 1941. Monthly flows have varied from zero during several months to a maximum of 358,000 ac-ft during June 1968 (USDI 1974; Armstrong et al. 1987b). The Navidad River is tidal below Lake Texana. Sandy Creek, draining approximately 289 square miles or 21 percent of the total drainage area above Lake Texana, and Mustang Creek, draining approximately 264 square miles or 19 percent of the total drainage area for Lake Texana, are the other major tributaries of Lake Texana (USDI 1974; Armstrong et al. 1987b).

3.3.1.4 Physicochemical Characteristics

The Lavaca-Navidad River Authority has conducted water quality assessments for the Lavaca River Basin. Water quality in the basin is generally satisfactory. Lake Texana (Segment 1604) is classified as water quality limited with the following designated water uses: (1) contact recreation; (2) high quality aquatic habitat; and (3) public water supply. Tables III-28, III-29, III-30, III-31 and III-32 list water quality data collected by Armstrong et al. (1986), TNRCC (1994b), and Gandara et al. (1995).

According to the TWC (1992b) and the TNRCC (1994b), there are no known water quality problems in Segment 1604. Dissolved oxygen violations have been reported in Lake Texana below the confluence of the Navidad River and Sandy Creek and near the dam site in 1986 and 1994. Two sulfate, one chloride, and one total dissolved solids violations were reported for the period January 1989 - December 1992. Ortho and total phosphorus levels were also elevated in this segment. However, the USGS reported excessive levels of lead, cadmium, or mercury at Lake Texana near Edna at the old river channel

Table III-28

Water Quality Parameters - Lake Texana (Station DC*) in 1994

Parameters	February 25 Sfc	February 25 Mid	February 25 Bot	May 20 Sfc	May 20 Mid	May 20 Bot	Aug 25 Sfc	Aug 25 Mid	Aug 25 Bot	Water Quality Standards
Regulated										
pH[1]	8.1	8.1	8.1	7.0	7.0	7.0	7.4	7.3	7.4	6.5-9.0
Temperature[2]	16.0	15.5	15.5	24.5	25.0	24.5	29.5	28.5	28.5	33.9
Dissolved Oxygen[3]	7.8	7.4	8.0	3.6	3.1	1.8	4.8	3.6	4.2	5.0
Dissolved Sulfate[3]	9.6	-	9.6	5.4	-	4.5	12.0	-	12.0	25
Dissolved Chloride[3]	34.0	-	35.0	9.8	-	8.2	53.0	-	54.0	80
Dissolved Fluoride[3]	0.20	-	0.20	0.10	-	0.10	0.20	-	0.20	4000
Total Dissolved Solids[3]	196.0	-	197.0	105.0	-	103.0	236.0	-	243.0	450
Suspended Sediment[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
Dissolved Aluminum[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	991
Dissolved Barium[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	1000
Dissolved Selenium[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	20/5**
Dissolved Silver[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	0.92/0.49**
Non-Regulated										
Specific Conductance[5]	334.0	335.0	336.0	156.0	156.0	166.0	417.0	431.0	428.0	NA
Turbidity (NTU)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NA
Total Hardness[3]	120.0	-	120.0	55.0	-	64.0	120.0	-	120.0	NA
Alkalinity[3]	110.0	-	110.0	72.0	-	66.0	120.0	-	120.0	NA
Dissolved Silica[3]	14.0	-	14.0	12.0	-	13.0	16.0	-	17.0	NA
Total Nitrogen[3]	0.18	0.20	0.19	0.19	0.19	0.20	-	-	-	NA
Dissolved Phosphorus[3]	0.05	0.05	0.05	0.12	0.14	0.18	0.05	0.07	0.07	NA
Dissolved Orthophosphorus[3]	0.04	0.04	0.04	0.11	0.13	0.18	0.04	0.04	0.05	NA
Dissolved Orthophosphate[3]	0.12	0.12	0.12	0.34	0.40	0.55	0.12	0.12	0.12	NA
Chlorophyll A[4]	11.0	-	-	4.2	-	-	9.2	-	-	NA
Chlorophyll B[4]	0.80	-	-	0.20	-	-	0.80	-	-	NA

*Below the confluence of the Navidad River and Sandy Creek
**Acute/chronic criteria
[1]pH (hydrogen-ion)
[2]°C (degrees Celsius)
[3]mg/ℓ (milligrams per liter)
[4]µg/ℓ (micrograms per liter)
[5]µS/cm (microsiemens per centimeter)

Legend:
Sfc = Surface
Mid = Middle
Bot = Bottom
NTU = Nephelometric Turbidity Units
NA = Not Applicable
NS = Not Sampled
µg/kg = micrograms per kilogram

Note: Testing for the following pesticides (Diazinon; Disyston; Ethion; Malathion; Methyl Parathion; Parathion; Phoraite; Silvex; Trithion; 2,4-D; 2,4-DP; 2,4,5-T) was conducted on February 25, May 20, and August 25 and found to range from <0.01 to <0.2 µg/ℓ or µg/kg

Source: Gandara et al. 1995; 30 TAC § 307

Table III-29

Water Quality Data for Lake Texana (Station 5*)
(October 26, 1985 - July 19, 1986)

Parameters	Oct. 26			Feb. 22			Apr. 26**			Jun 25			Jul 19		
	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot
Temperature[1]	24.5	24.3	24.3	15.5	15.5	15.4	24.1	23.5	23.2	31.1	28.3	27.9	30.6	29.0	29.5
pH[2]	7.3	7.2	7.3	7.1	7.1	7.1	7.8	7.4	7.2	7.7	7.1	7.1	7.2	7.3	7.1
Dissolved Oxygen[3]	6.4	6.4	6.2	9.8	9.2	9.1	8.5	7.0	4.9	6.9	1.9	1.3	6.6	5.1	1.0
Conductivity[4]	338	341	341	329	332	332	365	378	412	155	163	160	218	223	344
Total Alkalinity[3] (as Calcium Carbonate)	88.2	89.9	88.8	100.86	103.01	103.01	124.2	124.2	124.2	63.18	65.52	60.84	80.5	73.6	78.2
Total Kjeldahl Nitrogen[3]	0.78	0.69	0.80	0.52	0.62	0.75	0.90	1.02	0.96	1.32	1.88	1.75	-	-	-
Ammonia - Nitrogen	0.37	0.11	0.38	0.30	0.25	0.41	0.27	1.05	0.28	0.25	0.16	0.27	0.15	0.08	0.11
Nitrite - Nitrogen	0.010	0.005	0.008	0.01	0.01	0.01	<0.01	<0.01	<0.01	0.024	0.025	0.025	<0.01	<0.01	<0.01
Nitrate - Nitrogen	<0.02	0.02	0.01	0.16	0.19	0.14	<0.02	<0.02	<0.02	0.026	0.075	0.085	<0.02	<0.02	<0.02
Total Phosphorus[3]	0.15	0.17	0.15	0.13	0.13	0.13	0.14	0.14	0.14	0.15	0.17	0.19	0.13	0.12	0.13
Orthophosphorus[3]	0.033	0.034	0.045	0.018	0.012	0.013	0.12	0.12	0.12	0.099	0.138	0.130	0.032	0.034	0.040
Turbidity (NTU)	29.0	30.0	31.0	15.0	15.0	14.0	16.0	14.0	15.0	25.0	32.0	48.0	16.0	18.0	25.0
Chlorophyll A[5]	0.9	-	-	-	-	-	38.0	-		53.2	31.9	31.9	48.66	33.45	33.45

* Below the confluence of the Navidad River and Sandy Creek
**Low flow condition
[1] °C (degrees Celsius)
[2] pH (hydrogen-ion)
[3] mg/ℓ (milligrams per liter)
[4] μmhos/cm (micromhos per centimeter)
[5] μg/ℓ (micrograms per liter)

Legend: Sfc = Surface
Mid = Middle
Bot = Bottom
NTU = Nephelometric Turbidity Units

Source: Armstrong et al. 1986

Table III-30

Water Quality Data for Lake Texana Dam Site
(October 26, 1985 - July 19, 1986)

Parameters	Oct 26			Feb 22			Apr 26*			Jun 25			Jul 19		
	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot	Sfc	Mid	Bot
Temperature[1]	24.7	24.7	23.8	13.6	13.5	13.3	22.1	21.7	20.6	30.2	29.3	25.3	30.9	28.8	27.8
pH[2]	8.1	8.2	7.9	7.5	7.0	6.9	7.4	7.3	7.1	8.6	8.6	7.7	8.1	7.7	7.4
Dissolved Oxygen[3]	9.1	8.8	7.2	10.5	9.7	9.6	9.0	8.3	7.3	9.6	7.6	0.3	8.6	6.0	2.1
Conductivity[4]	230	230	228	185	186	185	195	196	190	187	196	218	189	189	194
Total Alkalinity[3]															
(as Calcium Carbonate)	66.2	65.4	63.7	55.8	57.94	55.8	66.7	64.4	66.7	67.86	67.86	67.86	64.4	62.1	66.7
Total Kjeldahl Nitrogen[3]	0.26	0.27	0.43	0.14	0.25	0.39	0.58	0.64	0.68	1.22	1.05	1.02	-	-	-
Ammonia - Nitrogen	0.27	0.11	0.19	0.16	0.13	0.37	0.14	0.61	0.65	0.06	0.05	0.07	0.25	0.09	0.14
Nitrite - Nitrogen	0.008	0.008	0.007	0.01	0.01	0.02	<0.01	<0.01	<0.01	0.014	<0.01	0.019	<0.01	<0.01	<0.01
Nitrate - Nitrogen	0.17	0.28	0.26	0.42	0.41	0.43	0.36	0.39	0.43	0.086	0.09	<0.001	<0.002	<0.002	<0.002
Total Phosphorus[3]	0.12	0.13	0.12	0.14	0.14	0.15	0.17	0.15	0.16	0.09	0.06	0.07	0.08	0.09	0.08
Orthophosphorus[3]	0.056	0.059	0.063	0.078	0.080	0.078	0.12	0.12	0.12	0.038	0.029	0.062	0.038	0.044	0.056
Turbidity (NTU)	27.0	26.0	25.0	33.0	33.0	35.0	24.0	25.0	27.0	10.0	7.0	14.0	3.0	3.0	5.0
Chlorophyll A[5]	1.0	-	-	1.6-2.2	-	-	16.8	-	-	53.2	45.6	21.6	34.97	24.98	23.06

*Low flow condition
[1]°C (degrees Celsius)
[2]pH (hydrogen-ion)
[3]mg/ℓ (milligrams per liter)
[4]µmhos/cm (micromhos per centimeter)
[5]µg/ℓ (micrograms per liter)

Legend: Sfc = Surface
Mid = Middle
Bot = Bottom
NTU = Nephelometric Turbidity Units

Source: Armstrong et al. 1986

Table III-31

Water Quality Parameters - Lake Texana Dam Site in 1994

Parameters	Feb 25 Sfc	Feb 25 Mid	Feb 25 Bot	May 20 Sfc	May 20 Mid	May 20 Bot	Aug 25 Sfc	Aug 25 Mid	Aug 25 Bot	Water Quality Standards
Regulated										
pH[1]	8.1	8.1	7.9	7.5	7.5	7.2	7.6	7.1	6.9	6.5-9.0
Temperature[2]	14.5	14.0	12.5	25.5	25.0	22.0	29.0	28.0	23.5	33.9
Dissolved Oxygen[3]	9.0	9.0	8.8	6.1	6.1	4.0	6.4	3.9	0.0	5.0
Dissolved Sulfate[3]	6.3	-	6.3	8.6	-	7.6	7.3	-	4.9	25
Dissolved Chloride[3]	22.0	-	22.0	21.0	-	24.0	19.0	-	21.0	80
Dissolved Fluoride[3]	0.10	-	0.10	0.10	-	0.20	0.20	-	0.20	4000
Total Dissolved Solids[3]	143.0	-	142.0	134.0	-	150.0	131.0	-	152.0	450
Suspended Sediment[3]	NS	NS	NS	NS	NS	NS	NS	NS	NS	-
Dissolved Aluminum[4]	NS	NS	NS	NS	NS	NS	NS	NS	NS	991
Dissolved Barium[4]	90.0	-	86.0	97.0	-	100.0	87.0	-	120.0	1000
Dissolved Selenium[4]	<1.0	-	<1.0	<1.0	-	<1.0	<1.0	-	<1.0	20/5*
Dissolved Silver[4]	<1.0	-	<1.0	<1.0	-	<1.0	<1.0	-	<1.0	0.92/0.49*
Non-Regulated										
Specific Conductance[5]	232.0	232.0	232.0	237.0	243.0	257.0	224.0	223.0	255.0	NA
Turbidity (NTU)	46.0	-	44.0	53.0	-	66.0	34.0	-	22.0	NA
Total Hardness[3]	86.0	-	86.0	79.0	-	89.0	79.0	-	90.0	NA
Alkalinity[3]	79.0	-	79.0	66.0	-	83.0	72.0	-	89.0	NA
Dissolved Silica[3]	15.0	-	15.0	12.0	-	14.0	13.0	-	17.0	NA
Total Nitrogen[3]	0.25	-	0.27	0.67	0.72	0.41	0.25	0.32	-	NA
Dissolved Phosphorus[3]	0.07	-	0.08	0.09	0.90	0.07	0.08	0.09	0.50	NA
Dissolved Orthophosphorus[3]	0.07	-	0.07	0.10	0.09	0.07	0.07	0.08	0.48	NA
Dissolved Orthophosphate[3]	0.21	-	0.21	0.31	0.28	0.21	0.21	0.25	1.50	NA
Chlorophyll A[4]	2.1	-	-	4.5	-	-	4.9	-	-	NA
Chlorophyll B[4]	0.1	-	-	<0.1	-	-	0.3	-	-	NA

*Acute/chronic criteria
[1]pH (hydrogen-ion)
[2]°C (degrees Celsius)
[3]mg/ℓ (milligrams per liter)
[4]μg/ℓ (micrograms per liter)
[5]μS/cm (microsiemens per centimeter)

Legend: Sfc = Surface; Mid = Middle; Bot = Bottom; NA = Not Available; NS = Not Sampled; NTU = Nephelometric Turbidity Units

Note: Testing for the following pesticides (Diazinon; Disyston; Ethion; Malathion; Methyl Parathion; Parathion; Phoraite; Silvex; Trithion; 2,4-D; 2,4-DP; 2,4,5-T) was conducted on August 25 and found to be <0.01 μg/ℓ

Source: Gandara et al. 1995; 30 TAC § 307

Table III-32

Field Measurements and Water Chemistry for Lake Texana (Segment 1604)

Parameters	Standards Criteria	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Values Outside Criteria or Screening Levels	
							Number	Mean
Water Temperature[1]	33.89		22	11.6	31.5	22.86	0	0.0
Dissolved Oxygen[2]	5.00		22	5.10	10.40	7.95	0	0.0
pH[3]	6.50-9.00		22	6.90	8.90	7.75	0	0.0
Chloride[2]	80.00		25	1.00	84.00	29.12	1	84.0
Sulfate[2]	25.00		24	1.00	28.00	12.90	2	27.5
Conductivity Field[4]			65	138.00	704.00	344.77	0	0.0
Total Dissolved Solids[2]	450.0		22	89.70	457.60	223.93	1	457.6
Ammonia[2]		1.00	25	0.01	0.19	0.07	0	0.0
Nitrates + Nitrites[2]		1.00	25	0.01	0.82	0.30	0	0.0
Orthophosphorus[2]		0.10	19	0.04	0.30	0.13	9	0.2
Total Phosphorus[2]		0.20	24	0.08	0.43	0.16	6	0.3
Chlorophyll A[5]		30.00	18	1.00	31.00	10.08	1	31.0

[1] °C (degrees Celsius)
[2] mg/ℓ (milligrams per liter)
[3] pH (hydrogen-ion)
[4] μmhos (micromhos)
[5] μg/ℓ (micrograms per liter)

Source: TNRCC 1994b

on the Navidad River. The USGS data also showed minute quantities of the pesticides Dichlorodiphenyldichloroethane (DDD); Dichlorodiphenylethylene (DDE); 2, 4, 5-Trichlorophenol; and 2, 4-Dichlorophenoxyacaetic Acid (herbicide) as well as Polychlorinated Biphenyls (PCBs) in water and sediment samples. Oil field brine from petroleum wastes has been reported as entering Lake Texana (TWC 1992a). The TNRCC (1994b) recently analyzed Lake Texana (Segment 1604) for toxic substances in sediment and found one toxic substance (BIS [2-Ethylhexyl] Phthalate) above the screening level (Table III-32).

The most important water quality concerns within Lake Texana are potentially undesirable levels of nutrients and herbicides in return flows from rice irrigation; the threat of surface water pollution from spills and illegal dumping of petroleum wastes, especially oil field brine; and periodically low levels of dissolved oxygen in the bottom layers (TWC 1992a).

3.3.2 Biotic Environment

3.3.2.1 Microbes

- Community Composition

Specific investigations on most microbial communities, with the exception of fecal coliforms, have not been conducted in Lake Texana. A general characterization of the microbial community expected to occur in Lake Texana is presented below based on a review of pertinent lentic literature.

The communities of aquatic microbes may be divided into four distinct populations: (1) free-floating planktonic microbes, (2) microbes adhering to suspended particles, (3) microbes attached to submerged surfaces (epiphytic/epilithic), and (4) microbes occupying the water-filled spaces of the sediment. The structure of the community, the proportion of bacteria, fungi, and protozoa, varies with site and season. Primary producers within the microbial community consist of phototrophic and chemolithotrophic bacteria, while chemo-organotrophic bacteria, fungi, and protozoans are the decomposers (Costeron and Geesey 1979).

Table III-33

Toxic Substances in Sediment for Lake Texana (Segment 1604)

Parameters	Units	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Number of Values Outside Criterion or Screening Levels
Arsenic	mg/kg	18.970	1	1.5000	1.5000	1.5000	0
Barium	mg/kg	280.000	1	241.000	241.000	241.000	0
Cadmium	mg/kg	2.000	1	1.000	1.000	1.000	0
Chromium	mg/kg	34.000	1	26.000	26.000	26.000	0
Copper	mg/kg	34.000	1	20.000	20.000	20.000	0
Lead	mg/kg	60.000	1	0.500	0.500	0.500	0
Manganese	mg/kg	1285.000	1	454.000	454.000	454.000	0
Mercury	mg/kg	0.120	1	0.300	0.300	0.300	0
Nickel	mg/kg	27.000	1	16.000	16.000	16.000	0
Selenium	mg/kg	1.400	1	0.100	0.100	0.100	0
Silver	mg/kg	1.600	1	1.000	1.000	1.000	0
Zinc	mg/kg	116.000	1	80.000	80.000	80.000	0
Aldrin	μg/kg	0.500	4	0.500	0.500	0.500	0
Alpha-Hexachlorocyclohexane	μg/kg	0.500	2	0.500	0.500	0.500	0
Gama-Hexachlorocyclohexane	μg/kg	0.500	4	0.500	0.500	0.500	0
Bis (2-Ethylhexyl) Phthalate	μg/kg	850.000	2	150.000	900.000	525.000	1
Diazinon	μg/kg	2.720	4	2.500	2.500	2.500	0
Di-N-Butyl Phthalate	μg/kg	921.310	2	56.000	86.000	71.000	0
Chlordane	μg/kg	3.000	4	1.500	3.000	1.875	0
DDD (Dichlorodiphenyldichloride)	μg/kg	3.000	4	0.150	3.000	1.538	0
DDE (Dichlorodiphenylethylene)	μg/kg	1.700	4	0.750	1.500	0.938	0
DDT (Dichlorodiphenyltrichloroethane)	μg/kg	3.000	4	1.500	3.000	1.875	0
Dieldrin	μg/kg	1.000	4	1.000	1.000	1.000	0
Endrin	μg/kg	1.500	4	1.500	1.500	1.500	0
Heptachlor	μg/kg	0.250	4	0.250	0.250	0.250	0
Heptachlor Epoxide	μg/kg	0.500	4	0.500	0.500	0.500	0
Hexachlorobenzene	μg/kg	0.500	2	0.500	0.500	0.500	0
Malathion	μg/kg	2.500	4	2.500	2.500	2.500	0

Table III-33 (Continued)

Toxic Substances in Sediment for Lake Texana (Segment 1604)

Parameters	Units	Screening Levels	Number of Samples	Minimum	Maximum	Mean	Number of Values Outside Criterion or Screening Levels
Methoxychlor	μg/kg	5.000	4	5.000	5.000	5.000	0
Parathion	μg/kg	1.500	4	1.500	1.500	1.500	0
Polychlorinated Biphenyls (PCBs)	μg/kg	10.000	4	10.000	10.000	10.000	0
Aroclor 1254	μg/kg	25.000	0	NA	NA	NA	0
Pentachlorophenol	μg/kg	2.500	2	2.500	2.500	2.500	0
Silvex	μg/kg	5.000	2	5.000	5.000	5.000	0
Toxaphene	μg/kg	25.000	4	25.000	25.000	25.000	0
2,4-Dichlorophenoxyacaetic acid	μg/kg	25.000	2	25.000	25.000	25.000	0
2,4,5-Trichlorophenol	μg/kg	5.000	2	5.000	5.000	5.000	0

Legend: mg/kg = milligrams per kilogram
μg/kg = micrograms per kilogram
NA = Not Applicable

Source: TNRCC 1994b

The microbial flora of lentic systems are, however, always quite distinct from that of lotic systems. Non-sporing rods predominate in lakes of the temperate climatic zones with the greatest relative proportion in eutrophic lakes. Although a wide variety of bacterial organisms is usually present, the following types are more common and typical of lacustrine habitats. Gram-positive bacteria include *Bacillus*, *Brevibacteria*, and, less frequently, the streptococci. Gram-negative bacteria usually make up the greater portion of the bacterial flora of lakes for most of the year. The dominant forms in this group are normally the genera *Flavobacterium*, *Pseudomonas*, *Alcaligenes*, and some members of the *Enterobacter-Klebsiella* group. Other types include chemoautotrophic (*Nitrosomonas* and *Nitrobacter*) and photoautotrophic bacteria, aquatic actinomycetes (genus *Streptomycetes*), numerous fungal types such as ascomycetes, Fungi Imperfecti and the phycomycetes (Chytridiales and Saprolegniales), and flagellated and ciliated protozoans (*Paramecium*). In addition, many viruses (i.e., bacteriophages) also occur in lake waters (Cairns 1969; Rheinheimer 1985).

Fecal coliforms (colonies/100 mℓ) reported for Segment 1604 (Lake Texana) from January 1989 through December 1992 were well below the screening level of 400 colonies/100 mℓ. Levels of fecal coliforms ranged from a minimum of 3 colonies/100 mℓ, with a mean of 31 colonies/100 mℓ, to a maximum of 286 colonies/100 mℓ for 13 samples (TNRCC 1994b).

- General Ecology

In relatively clean lakes, the maximum microbial counts are found in spring and early autumn or late summer at the time of greatest production of nutrients by the phytoplankton whereas in lakes polluted by sewage, the microbial population usually increases markedly in the winter. Total microbial numbers in lacustrine systems will range from 50,000 to several millions with eutrophic systems having the largest numbers.

The vertical distribution of microbes in lakes of the temperate climatic zone also exhibits considerable seasonal variation. During the time of summer stagnation, characteristic thermal and chemical stratification takes place in the water with the consequent development of stratification in the number and composition of the microbial population. Particularly striking are the zonal differences in eutrophic lakes, where the oxygen completely disappears in the hypolimnion and hydrogen sulfide is produced. There is one maximum for the number of heterotrophic microbes (proteolytic organisms and photoautotrophic sulphur bacteria) in the region of the thermocline and second (methane producers and sulfate producers) immediately above the bottom (Rheinheimer 1985).

In lakes without a pronounced thermocline (e.g., Lake Texana), the highest total microbial counts are usually obtained in the zone with the most profuse development of algae. At the times of autumn and spring circulations the water is turbulent, which results in a much more even distribution of bacteria. At the same time there is an increase in the available oxygen with a strong decline of the anaerobic sulfur bacteria. In larger lakes, the longitudinal and transverse profiles also show great variations in the microbial counts. Streams and rivers entering a lake affect it to a large degree, but the differences decrease, as a rule, with increasing distance from the banks. After heavy rains, microbial counts and also those of fungal spores rise steeply, though only temporarily, particularly in small lakes (Collins and Willoughby 1962).

3.3.2.2 Phytoplankton

- Community Composition

Maeng (1983) and Armstrong et al. (1986) have conducted studies on phytoplankton communities in Lake Texana near the area of the proposed intake structure. Monthly phytoplankton samples were collected just south of U.S. Highway 59 (Station 5), near the dam (Station 8), and adjacent to the water intake structure (Station 9) in 1981 and bimonthly samples were collected below the confluence of the Navidad River and Sandy Creek (Station 5) and above the dam (Station 8) from 1984 to 1986 (see Figure III-6). The phytoplankton community of Lake Texana is comprised of green algae, blue-green algae, diatoms, and certain types of flagellates (Tables III-33, III-34, and III-35). This composition is typical of southwestern reservoirs.

Maeng (1983) reported an overall equal distribution in densities at Station 5 between the four major algal groups. Flagellates were abundant in February, April through June, November through December and codominant with diatoms in March. Green algae were dominant in January and October, while July and August were dominated by blue-green algae and diatoms. Blue-green algae were dominant at Station 8 with overall densities peaking from August through October. Station 9 was represented by a blue-green algae/diatom complex throughout the year with blue-green algae abundant from August through October

Table III-34

Phytoplankton Species Collected at Sampling Stations 5, 8, and 9 in Lake Texana in 1981

Species	Sampling Stations 5*	8**	9***
CHLOROPHYTA			
Chlamydomonas sp.	X	X	X
Carteria sp.	X	X	X
Platychloris minima	X	X	X
Chlorogonium elongatum		X	X
Pteromonas aculeata		X	
Pteromonas angulosa		X	X
Thoracomonas phacotoides	X	X	X
Pandorina charkowiensis		X	X
Dictyosphaerium sp.	X	X	X
Unidentified palmelloid sp.	X	X	X
Chlorococcum sp.		X	
Pediastrum tetras		X	X
Coelastrum sphaericum	X		
Chlorella sp.	X	X	X
Ankistrodesmus falcatus var. *acicularis*	X	X	X
Ankistrodesmus falcatus var. *mirabilis*	X	X	X
Ankistrodesmus falcatus var. *stipitatus*	X	X	
Ankistrodesmus falcatus var. *tumidus*		X	X
Schroederia ancora		X	X
Schroederia setigera			X
Selenastrum minutum	X	X	X
Selenastrum westii	X	X	X
Kirchneriella sp.		X[1]	X
Tetraëdron constrictum			X
Tetraëdron minimum	X	X	X
Tetraëdron muticum		X	X
Tetraëdron regulare var. *incus*		X	X
Tetraëdron trigonum var. *gracile*	X	X	X
Treubaria triappendiculata		X	
Scenedesmus arcuatus var. *platydisca*		X	X
Scenedesmus bijuga var. *alternans*	X	X	X
Scenedesmus denticulatus		X	X
Scenedesmus dimorphus	X	X	X
Scenedesmus quadricaudata	X	X	X
Crucigenia tetrapedia		X	X
Crucigenia sp.		X	
Tetrastrum heterocanthum	X		X
Tetrastrum staurogeniaeforme	X	X	X
Actinastrum hantzschii	X		
Actinastrum hantzschii var. *fluviatile*	X	X	
Coronastrum sp.		X	
Micractinium pusillum	X[1]	X	X
Closterium sp.		X	
Tetrastrum sp.	X	X	X[1]

Table III-34 (Continued)

Phytoplankton Species Collected at Sampling Stations 5, 8, and 9 in Lake Texana in 1981

	Sampling Stations		
Species	5*	8**	9***
CHLOROPHYTA (Continued)			
Oocystis lacustris			X
Unidentified green flagellates		X	
Unidentified 2-celled green	X	X	X
Dispora crucigenoids	X		
XANTHOPHYTA			
Ophiocytium capitatum var. *longispinum*	X	X	
CYANOPHYTA			
Chroococus limeticus		X	X
Chroococus sp.	X	X	X
Microcystis incerta	X	X	X
Microcystis sp.	X		
Aphanocapsa elachista	X		X
Aphanocapsa sp.	X		
Gomphosphaeria aponia	X		
Merismopedia tenuissima	X	X	X
Merismopedia punctata		X	
Marsoniella elegans	X	X	X
Oscillatoria limnetica	X		
Oscillatoria subtilissima	X	X[1]	X[1]
Oscillatoria sp.	X		
Raphidiopsis curvata		X	
Anabaenopsis sp.	X	X	X
Anabaenopsis elenkinii		X	
Anabaena sp. (straight filaments)	X[1]	X	X
Anabaena sp. (spiraled)		X	X
Aphanizonienon sp.	X		
BACILLARIOPHYTA			
Melosira binderana		X	
Melosira granulata	X	X	X
Melosira granulata var. *angustissima*	X	X	X
Melosira distans	X[1]	X	X
Melosira varians	X		
Cyclotella meneghiniana	X	X	X
Cyclotella glomerata	X	X[1]	X[1]
Cyclotella sp.	X	X	X
Cocconeis sp.			X
Cymbella sp.	X		
Diploneis puella	X		
Eunotia naegella	X		
Fragilaria brevistriata			X
Fragilaria sp.			X

Table III-34 (Continued)

Phytoplankton Species Collected at Sampling Stations 5, 8, and 9 in Lake Texana in 1981

Species	Sampling Stations 5*	8**	9***
BACILLARIOPHYTA (Continued)			
Gomhonema sp.	X		X
Gyrosigma sp.	X	X	
Navicula sp.	X	X	
Nitzschia acicularis	X	X	X
Nitzschia amphibia	X		X
Nitzschia sp.	X	X	X
Stenopterobia pelagica	X	X	
Synedra acus var. *delicatssima*	X	X	X
Synedra ulna	X		
Unidentified pennate no. 1	X	X	X
Unidentified pennate no. 2			X
Unidentified pennate no. 3	X	X	
EUGLENOPHYTA			
Euglena acus	X		
Euglena tripteris	X	X	
Euglena sp.	X	X	X
Phacus curricauda	X		
Phacus longicauda	X	X	X
Phacus pyrum	X		
Trachelomonas hispida	X	X	
Trachelomonas urceolata	X	X	X
Trachelomonas volvocina	X	X	X
Trachelomonas sp.	X		
Unidentified euglenoid	X	X	X
CHRYSOPHYTA			
Synura ulvella	X		
CRYPTOPHYTA			
Cryptomonas ovata	X	X	X
Unidentified cryptomonad	X	X	X
Chroomonas sp.	X[1]	X[1]	X[1]
DINOPHYTA			
Glenodinium sp.	X	X	X
Ceratium hirundinella	X	X	X
Unidentified dinoflagellate		X	X

*Below the confluence of the Navidad River and Sandy Creek
**Near the dam
***Adjacent to the proposed water intake structure on the dam
[1]Dominant species

Legend: sp. = species
var. = variety
no. = number

Source: Smith 1950; Maeng 1983

Table III-35

Phytoplankton Species Collected at Sampling Station 5* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CHLOROPHYTA											
Chlamydomonas sp.	X			X	X	X	X		X		X
Carteria sp.	X		X	X	X	X		X	X[1]		X
Chlorogonium elongatum						X					X
Pteromonas angulosa									X		
Thoracomonas phcotoides									X		
Gonium pectorale					X						X
Pandorina charkowiensis						X	X			X	
Eudorina elegans					X						
Platydorina caudata					X					X	
Sphaerocystis schrosteri		X					X		X		X
Dictyosphaerium sp.										X	
Chlorococcum sp.							X				
Oocystis lacustris			X		X	X	X		X		X
Pediastrum duplex var. *clathratum*					X				X	X	X
Pediastrum simplex var. *duodenarium*										X	
Pediastrum tetras									X	X	
Coelastrum sphaericum			X		X				X	X	X
Ankistrodesmus falcatus									X	X	
Ankistrodesmus falcatus var. *acicularis*			X						X	X	X
Ankistrodesmus falcatus var. *mirabilis*	X		X		X				X	X	X
Ankistrodesmus falcatus var. *stipitatus*	X					X			X		
Ankistrodesmus falcatus var. *tumidus*						X			X	X	
Schroederia setigera							X			X	X
Selenastrum minutum	X		X			X			X	X	
Selenastrum westii							X		X		
Kirchneriella sp.	X								X	X	X
Chodatella subealsa										X	
Franceia droescheri											X
unidentified 2-celled green									X		X
Tetraëdron constrictum						X					

Table III-35 (Continued)

Phytoplankton Species Collected at Sampling Station 5* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CHLOROPHYTA (Continued)											
Tetraëdron hastatum										X	
Tetraëdron muticum							X		X		X
Tetraëdron regulare var. *incus*									X		
Tetraëdron trigonum								X	X		
Tetraëdron trigonum var. *gracile*						X					
Treubaria triappendiculata					X	X			X		X
Scenedesmus acuminatus		X						X			
Scenedesmus arcuatus var. *platydisca*										X	X
Scenedesmus bijuga var. *alternans*	X				X	X					
Scenedesmus bijugatus										X	
Scenedesmus denticulatus											X
Scenedesmus quadricaudata	X	X	X		X	X			X	X	X
Crucigenia crucifera										X	
Crucigenia quadrata	X					X			X		
Crucigenia tetrapedia	X						X				
Tetrastrum staurogeniaeforme									X	X	
Actinastrum hantzschii var. *fluviatile*			X			X[1]			X	X	
Micractinium pusillum					X	X				X[1]	X
Closterium acutum						X			X		
Closterium sp.	X										
Unidentified green						X					
CYANOPHYTA											
Chroococcus limeticus						X	X				
Chroococcus sp.						X					
Microcystis incerta							X		X	X	
Aphanocapsa elachista	X				X	X					X
Eucpasis sp. no. 2 (large)					X						
Aphanothace nidulans	X						X		X	X	X
Merismopedia tenuissima					X	X	X				

Table III-35 (Continued)

Phytoplankton Species Collected at Sampling Station 5* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CYANOPHYTA (Continued)											
Merismopedia punctata					X	X				X	
Maresoniella elegans						X	X		X	X	X
Oscillatoria subtilissima	X	X								X	X
Oscillatoria sp. no. 2				X						X	X
Lyngbya sp.					X						
Anabaena sp. (tightly coiled)						X					
Anabaena spp. (straight filaments)									X	X	
Anabaena helicoidea (spiraled)					X						
BACILLARIOPHYTA											
Coscinodiscus sp.					X						
Melosira binderana									X		X
Melosira distans	X	X		X	X	X	X		X	X	X
Melosira granulata		X			X	X	X		X	X	X
Melosira granulata var. *angustissima*	X	X			X			X			X
Cyclotella meneghiniana		X	X		X	X	X	X	X	X	X
Cyclotella spp.	X[1]		X		X[1]	X[1]	X[1]	X[1]	X	X[1]	X[1]
Cocconeis fluviatilis	X										
Eunotia sp.					X						
Fragilaria brevistriata								X			
Gomphonema sp. no. 1 (nannoplankton)	X										
Navicula cryptocephala				X				X			
Navicula sp. no. 1	X										
Nitzschia acicularis								X			
Nitzschia acicularis var. *closteroides*										X	
Nitzschia filiformis									X		
Nitzschia holsatica					X	X				X	
Nitzschia palea	X		X					X	X	X	
Nitzschia paradoxa									X		
Nitzschia tryblionella	X										
Nitzschia spp.	X										

Table III-35 (Continued)

Phytoplankton Species Collected at Sampling Station 5* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
BACILLARIOPHYTA (Continued)											
Synedra acus							X				X
Synedra ulna						X		X	X		X
Synedra ulna var. *oxyrynchus*	X			X	X				X		
Surirella linearis										X	
Unidentified pennate no. 1		X			X						X
Unidentified pennate no. 2											X
Unidentified pennate no. 3								X			
Unidentified pennate no. 6						X					
Unidentified pennate no. 8	X										
EUGLENOPHYTA											
Euglena acus			X	X	X	X			X	X	
Euglena proxima	X		X	X	X	X	X	X	X	X	X
Euglena tripteris	X			X	X		X			X	
Euglena sp. no. 2	X						X			X	
Lepocinclis sp.										X	
Phacus curvicauda			X		X	X		X	X	X	
Phacus helicoides					X				X		
Phacus longicauda									X		
Phacus pyrum	X										
Trachelomonas hispida					X	X				X	
Trachelomonas urceolata										X	X
Trachelomonas volvocina	X		X	X							
Trachelomonas sp. no. 1	X				X	X			X		X
Unidentified flagellate no. 2									X		
CHLOROMONADOPHYTA											
Gonyostomum semen			X	X	X		X				X
Merotrichia capitata					X	X					X

Table III-35 (Continued)

Phytoplankton Species Collected at Sampling Station 5* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CHRYSOPHYTA											
Synura ulvella											X
CRYPTOPHYTA											
Cryptomonas marsonii							X			X	X
Cryptomonas ovata	X	X[1]	X	X[1]	X	X[1]	X	X	X	X	X
Chroomonas sp.	X[1]	X	X[1]	X[1]	X	X[1]	X		X[1]	X	X
DINOPHYTA											
Glenodinium sp.	X				X	X	X			X	X
Wolosxynskia reticulata					X						
Ceratium hirundinella			X								
Gymnodinium fuscum					X	X	X		X		X
Unidentified dinoflagellate no. 1					X						X
Unidentified dinoflagellate no. 2											X

*Below the confluence of the Navidad River and Sandy Creek
[1] Dominant species

Legend: sp. = species spp. = species (plural)
var. = variety no. = number

Source: Smith 1950; Armstrong et al. 1986

Table III-36

Phytoplankton Species Collected at Sampling Station 8* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CHLOROPHYTA											
Chlamydomonas sp.	X[1]			X[1]							X
Carteria sp.		X	X				X			X	
Gleomonas sp.					X						
Chlorogonium elongatum										X	X
Pteromonas aculeata										X	
Pteromonas angulosa							X			X	
Gonium pectorale						X					
Pandorina charkowiensis							X			X	
Dictyosphaerium sp.					X					X	X
Chlorococcum sp.						X					X
Oocystis lacustris	X	X					X		X		X
Pediastrum duplex var. *clathratum*									X	X	
Pediastrum tetras	X										X
Coelastrum sphaericum									X	X	X
Chlorella sp.										X	X
Ankistrodesmus falcatus			X								X
Ankistrodesmus falcatus var. *acicularis*	X		X						X	X	X
Ankistrodesmus falcatus var. *mirabilis*							X		X		
Ankistrodesmus falcatus var. *stipitatus*								X			
Ankistrodesmus falcatus var. *tumidus*										X	
Schroederia ancora										X	
Schroederia setigera											X
Selenastrum minutum											X
Selenastrum westii										X	
Kirchneriella sp.									X	X	X
Franceia droescheri											X
unidentified 2-celled green									X	X	X
Tetraëdron minimum											X
Tetraëdron muticum										X	
Tetraëdron regulare									X		

Table III-36 (Continued)

Phytoplankton Species Collected at Sampling Station 8* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CHLOROPHYTA (Continued)											
Tetraëdron trigonum var. *gracile*										X	
Treubaria triappendiculata										X	X
Scenedesmus acuminatus		X									X
Scenedesmus arcuatus var. *platydisca*		X									X
Scenedesmus bijuga var. *alternans*										X	X
Scenedesmus bijugatus										X	
Scenedesmus denticulatus											X
Scenedesmus dimorphus										X	
Scenedesmus falcatus		X								X	
Scenedesmus quadricaudata	X		X				X			X	X
Crucigenia crucifera	X										
Crucigenia quadrata			X								
Crucigenia tetrapedia										X	
Tetrastrum heterocanthum										X	
Tetrastrum staurogeniaeforme		X	X								
Tetrastrum sp.	X										
Actinastrum hantzschii							X				
Actinastrum hantzschii var. *fluviatile*						X				X	X
Micractinium pusillum									X[1]	X	X
Mougeotia sp.	X		X	X					X		
Closterium acutum		X				X				X	X
Closterium sp.											
unidentified desmid no. 1											X
XANTHOPHYTA											
Ophiocytium capitatum var. *longispinum*										X	
CYANOPHYTA											
Chroococcus dispersus		X								X	X
Chroococcus limeticus							X			X	

Table III-36 (Continued)

Phytoplankton Species Collected at Sampling Station 8* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
CYANOPHYTA (Continued)											
Chroococcus sp.											X
Microcystis incerta	X	X								X	
Microcystis sp.											X
Aphanocapsa elachista										X[1]	
Aphanothace nidulans											X
Merismopedia tenuissima							X		X	X	
Merismopedia punctata										X	X
Maresoniella elegans									X	X	
Eucpasis sp.										X	
Oscillatoria limnetica		X		X							X
Oscillatoria subtilissima	X	X									
Anabaena sp. (tightly coiled)											X
Anabaena spp. (straight filaments)							X				
BACILLARIOPHYTA											
Coscinodiscus sp.										X	X
Melosira distans	X[1]	X	X	X[1]					X	X	X
Melosira granulata		X				X	X[1]	X[1]	X	X	X
Melosira granulata var. *angustissima*							X				
Stephanodiscus sp.									X		
Cyclotella glomerata ?							X			X	
Cyclotella meneghiniana		X	X		X		X	X	X	X	
Cyclotella spp.	X[1]	X[1]	X			X	X[1]	X[1]	X	X[1]	X[1]
Diploneis puella	X										
Fragilaria brevistriata					X			X[1]	X		
Gomphonema sp. no. 1 (nannoplankton)				X							
Gyrosigma sp.								X			
Navicula sp. no. 1			X								
Nitzschia acicularis		X					X				
Nitzschia holsatica		X								X	
Nitzschia palea										X	X

Table III-36 (Continued)

Phytoplankton Species Collected at Sampling Station 8* in Lake Texana 1984-86

Species	11/29/84	1/19/85	3/9/85	5/11/85	7/18/85	8/14/85	10/26/85	2/22/86	4/26/86	6/25/86	7/19/86
BACILLARIOPHYTA (Continued)											
Nitzschia tryblionella		X							X		
Synedra acus	X										X
Unidentified pennate no. 1		X									
Unidentified pennate no. 8		X									
EUGLENOPHYTA											
Euglena acus	X								X		
Euglena proxima						X	X			X	
Phacus curvicauda						X					
Trachelomonas urceolata										X	
Trachelomonas volvocina			X								
Trachelomonas sp. no. 1										X	X
CRYPTOPHYTA											
Cryptomonas marsonii			X						X	X	
Cryptomonas ovata	X	X[1]	X	X	X[1]	X[1]	X[1]		X	X	X
Chroomonas sp.		X[1]	X[1]	X[1]	X[1]	X[1]	X	X[1]	X[1]	X[1]	X[1]
DINOPHYTA											
Peridinium sp.									X		
Glenodinium sp.										X	
Gymnodinium fuscum										X	
Unidentified dinoflagellate no. 2										X	

*Station 8 is located above the dam
[1] Dominant species

Legend: sp. = species spp. = species (plural) var. = variety no. = number

Source: Smith 1950; Armstrong et al. 1986 and diatoms in March. Both green algae and flagellates were equally distributed at both stations. Green algae were abundant in October at Station 8 and from August through October at Station 9. Flagellates were abundant in March at Station 8 and in April at Station 9. The blue-green algal community was dominated by *Anabena* sp. and *Oscillatoria subtilissima*, while the diatom community was represented by *Cyclotella glomerata* and *Melosira distans*. Flagellates were represented by the species *Chroomonas* and the green algae by *Tetrastrum*, *Kirchneriella*, and *Micratinium pusillum*.

Studies conducted from 1984-1986 on Lake Texana indicated a similar algal community with somewhat different dominant components than reported in 1981 (Armstrong et al. 1986). Station 5 was dominated by either the flagellates, *Chroomonas* sp. or *Cryptomonas ovata*, and the diatom, *Cyclotella* sp. from 1984-1985 except for June when the green algae, *Actinastrum hantzschii* var. *fluviatile* was also abundant. In February and July 1986, *Cyclotella* sp. dominated the phytoplankton community. Flagellate species, both *Carteria* and *Chroomonas*, dominated the April sample, and was codominant with the green algae, *Micratinium pusillum* in June. The flagellate species *Chroomonas* sp. and/or *Cryptomonas ovata* were the dominant phytoplankters at Station 8 from 1984-1985 with the exception of November 1984 and October 1985 when the diatoms *Melosira distans*, *Cyclotella* sp., and *Melosira granulata* were dominant and May 1985 when the green algal flagellates, *Chlamydomonas* sp. and the diatoms *Melosira* were codominants. *Chroomonas* sp. was codominant with the green algal *Micractinium pusillum* in April 1986 and the diatom *Cyclotella* sp. in June 1986. Diatoms dominated both the February (*Melosira granulata*, *Cyclotella* sp. and *Fragilaria brevistrata*) and July (*Cyclotella* sp.) 1986 samples. Compared to the summer algal composition in 1985, an increase was also noted in the various species of green (e.g., *Cateria* sp., *Selenastrum* spp., and *Dictyosphaerium* sp.) and blue-green (e.g., *Aphanocapsa elachista* and *Maresoniella elegans*) algae collected in the lake.

- General Ecology

The predominant types of algae occurring in the reservoirs of the southwest are green algae, blue-green algae, and, to a certain extent, flagellates and diatoms (Silvey and Wyatt 1969). For the most part, the green algal population, consisting of unicellular or small colonial forms, have an almost constant level of population density, with some variations in the spring and early fall. Diatoms may express a sudden increase or "bloom" on occasions following high flows in early spring. Otherwise, the diatom population is somewhat constant, is rather diverse, and does not compose a large portion of the total population.

Phytoplankton communities in southwestern reservoirs are primarily influenced by blue-green algae, particularly during peak populations.

In general, blue-green algae exert the major influence upon the entire aquatic ecosystem, particularly during blooms. Generally, blooms of the highly motile blue-green algal and/or dinoflagellate taxa exist as massive accumulations (100,000 to greater than 10 million cells per milliliter [cells/mℓ]) of a single or, less often, two coexisting nuisance species, with the nuisance species accounting for as much as 95-99 percent of the resident phytoplankton biomass (Paerl 1988). Both the procaryotic blue-green algae and the eucaryotic dinoflagellates constitute major nuisance problems in freshwater habitats.

Observations compiled over the last several years indicate that most algal "blooms" have developed after a severe or abrupt change in reservoir conditions, such as rapid addition or loss of large volumes of water after major weather changes (Silvey and Wyatt 1969). Multiple interacting physical, chemical, and biological factors, in proper combination, lead to the development and persistence of nuisance algal blooms. A combination of the following hydrological, chemical, and biological factors will most likely lead to bloom-sensitive waters:

- a horizontally distinct water mass;
- a vertically stratified water column;
- warm weather conditions, as typified by summer seasons in temperate zones;
- high incident photosynthetically active radiation (PAR);
- enhanced allochthonous organic matter loading (both as dissolved organic carbon [DOC] and particulate organic carbon [POC]) and inorganic nutrient loading (nitrogen and/or phosphorus);
- adequate availability of biologically essential metals (e.g., high amounts of iron, manganese, and zinc);
- smaller amounts of copper, molybdenum, and cobalt, supplied by terrigenous inputs;
- underlying sediments physically and nutritionally (inorganic/organic) suitable as "seed beds" for storing and supplying resting cysts (dinoflagellates) and akinetes (blue-greens);
- algal-bacterial synergism, which exhibits positive impacts on phycosphere nutrient cycling (and hence nutrient availability);

- algal-micrograzer (protists and rotifers) synergism, which also enhances nutrient cycling without consumption of filamentous and colonial nuisance taxa; and
- selective (for non-nuisance taxa) activities of macrograzers (crustacean zooplankton, larval fish), which would allow nuisance blooms to proliferate freely (Paerl 1988).

3.3.2.3 Periphyton

- Community Composition

Information on the composition of periphyton communities in Lake Texana is not available. The periphyton community of Lake Texana can, however, be generally characterized by a review of pertinent literature from similar lacustrine systems.

Characteristic benthic algal communities in Lake Texana would extend from the top of the eulittoral, well above mean water level, to the bottom of the euphotic zone, well below the range of macrophytic vegetation. In general these communities may be classified as haptobenthic, living on solid substrate, and herpobenthic, living in or on mud. Most haptobenthic communities are epilithic on stones, rocks, and other dead solid substrata, or epiphytic on plants, with a rarer epizoic community on animals. The herpobenthos are described as epipelic (Hutchinson 1975).

The haptobentic community comprising the epilithic and epiphytic subcommunities are essentially nonmotile, although there may be a mixture of some motile forms as the flora becomes more dense. Species comprising this flora are characteristically forms with mucilage attachment pads or stalks (e.g., *Achnanthes*, *Cymbella*, *Gomphonema*); prostrate discs (*Coleochaete*, *Stigeoclonium*, etc.); or in the case of some diatoms the mucilage sticks the cell down like a postage stamp (e.g., *Cocconeis*, *Epithemia*). Larger forms (metaphytonic) with modified basal holdfast cells (e.g., *Oedogonium*, *Spirogyra*) occur. The herpobenthic (epipelic) flora is in essence an extension of the soil or beach flora down beneath the water surface. Algal species in the epipelic and soil flora are very similar (e.g., filamentous blue-green algae are common in both, as are unicells such as *Euglena*, *Nitzschia*, *Naviclua*, *Caloneis*, and *Pinnularia*), while mucilaginous colonies such as those of Aphanothecae occur in the epipelic flora and *Stigonema*, *Nostoc*, and *Cylindrocystis* on the soil. Table III-37 lists the types of epipelic, epilithic, metaphytonic, and epiphytic species commonly found in lacustrine habitats (Round 1964).

Table III-37

Distribution of Some Common Benthic Algae in Subcommunities of Freshwater Lakes

Epiphytic	Epilithic	Metaphyton(ic)	Epipelic
Characium	*Gloeocapsa*	*Mougeotia*	*Chroococcus*
Characiopsis	*Nostoc*	*Spirogyra*	*Aphanocapsa*
Ophiocytium	*Calothrix*	*Zygnema*	*Aphanothecae*
Coleochaete	*Scytonema*	*Binuclearia*	*Merismopedia*
Chaetophora	*Tolypothrix*	*Ulothrix*	*Oscillatoria*
Stigeoclonium	*Schizothrix*	*Microspora*	*Phormidium*
Bulbochaete	*Dichothrix*	*Oedogonium*	*Lyngbya*
Oedogonium	*Achananthes*	+ mixture of diatoms,	*Fragilaria*
Gloetrichia	*Eunotia*	flagellates, etc.	*Frustulia*
Synedra	*Cymbella*		*Anomoeoneis*
Tabellaria	*Tabellaria*		*Stauroneis*
Eunotia	*Frustulia*		*Caloneis*
Achnanthes	*Cladophora*		*Neidium*
Cocconeis			*Gyrosigma*
Cymbella			*Navicula*
Gomphonema			*Mastogloia*
Epithemia			*Diploneis*
Rhopalodia			*Amphora*
			Pinnularia
			Nitzschia
			Cymatopleura
			Surirella
			Closterium
			Euastrum
			Synura
			Cryptomonas
			Euglena
			Phacus
			Trachelomonas

Source: Round 1964

- General Ecology

The periphyton community in a lake basin is greatly influenced by the morphometry of the habitat. Thus, the periphyton community may be developed to varying extents in different regions of the lake.

Substrates, inflow/outflow and other currents, wind direction, shading, wave actions, and climatic conditions determine the composition of the periphyton community. Spatial, temporal, internal, and biotic factors also affect the community. Spatial factors relate to the position of the flora relative to latitude and longitude, altitude, depth, rate of flow, nutrient status of water, and substrata chemistry. Temporal factors deal with the flora at various geological times, more recent changes and long-term cyclical phenomena, and with annual and diurnal cycles; all these factors are affected in varying degrees by the spatial factors. Internal factors are concerned with the mode on nutrition of the algae, growth rates, reproductive cycles, movement, and phototaxis, etc., while biotic factors include competition, the production of extracellular products, parasitism, and grazing of the community.

In periphyton communities there is a distinct seasonal pattern of growth. Periphytic flora, which consists mainly of blue-green algae and diatoms, reaches maximum density during the peak growing period in the spring or early summer. After the spring peak(s) there is often a smaller July/October peak, followed by low numbers, prior to the build up of the population during late winter and early spring. The low populations during the October-December period coincide with the lowest values of incident light, which is certainly a limiting factor at this time (Round 1965).

3.3.2.4 Aquatic Plants

- Community Composition

Information on the composition of the aquatic plant communities in or near the proposed intake site on Lake Texana is limited. Noxious aquatic plants, particularly water hyacinth (*Eichhornia crassipas*) and hydrilla (*Hydrilla verticullatus*), have been reported in some of the arms of Lake Texana (TWC 1992a; Helton and Hartman 1995). Other aquatic plants reported in Lake Texana by Armstrong (1995a) include coontail (*Ceratophyllum demersum*) and the floating azolla-duckweed community consisting of mosquito fern (*Azolla caroliniana*), duckmeal (*Wolffia columbiana*), and duckweed (*Lemna minor*, *Lemna* sp.).

Aquatic macrophytes of lacustrine areas are confined to the littoral zone, which consist of the eulittoral and infralittoral zones. The eulittoral zone encompasses the shoreline region between the highest and lowest seasonal water levels and is often influenced by the disturbances of breaking waves. The infralittoral zone is subdivided into three zones in relation to the commonly observed distribution of macrophytic vegetation: (1) an upper infralittoral zone of emergent rooted vegetation; (2) a middle infralittoral zone of floating-leaved rooted vegetation; and (3) the lower infralittoral zone of submersed rooted or adnate macrophytes. Below the littoral is a transitional zone, the littoriprofundal, which is occupied by scattered photosynthetic forms. The upper boundary of the littoriprofundal zone at the lower edge of macrovegetation of the lower infralittoral is usually quite distinct and consists of benthic algae, especially blue-green algae, and photosynthetic bacteria that is less differentiated (Wetzel 1975).

The primary groups of aquatic plants common in lacustrine habitats are those attached to the substratum and those typically not rooted to the substratum. Aquatic macrophytes attached to the substratum include:

- emergent species: these forms occur above the water on submersed soils in the infralittoral zone and are primarily rhizomatous or cormous perennials (e.g., manna grass - *Glyceria*, spikerush - *Eleocharis*, giant reed - *Phragmites*, bulrush - *Scirpus*, sedges - *Carex*, rushes - *Juncus,* cattails - *Typha*, wild rice - *Zizania*);

- floating-leaved species: these species, with their floating leaves on long flexible petioles (e.g., spatterdock - *Nuphar*, white water lilies - *Nymphaea*) or on short petioles from long ascending stems (e.g., water shield - *Brasenia*, pondweed) occur in submerged sediments in the infralittoral zone in water depths of 1.6 to 9.8 ft; and

- submersed species: these forms occur in the lower infralittoral zone and are a heterogeneous group of plants that include filamentous algae (e.g., *Cladophora*); certain macroalgae (e.g., stonewort - *Chara*, *Nitella*); numerous mosses; few pteridophytes (e.g., fern *Isoetes*); and many angiosperms (e.g., naids - *Najas*, waterweed, watermilfoil - *Myriophyllum*, hydrilla - *Hydrilla*).

Aquatic macrophytes that are not typically rooted to the substratum but live unattached in the water include:

- large plants with rosettes of aerial and/or floating leaves, well-developed submersed roots (e.g., water hyacinth, water chestnut - *Trapa*, frog-bit - *Hydrocharis*); minute surface-floating (e.g., duckweed, big duckweed - *Spirodella*, watermeal - *Wolffia*, water velvet - *Azolla*, water fern - *Salvinia*);

- submersed plants with few (e.g., coontail) or no roots (e.g., bladderwort - *Utricularia*); and those with floating or aerial reproductive organs (Sculthorpe 1967; Wetzel 1975).

- General Ecology

The distribution of aquatic plants within their lacustrine habitats are due to such factors as the temperature and depth of the water, physical and chemical properties of the water column/bottom sediment, reaction of the water column and bottom sediment, quantity or quality of dissolved salts or nutrients in the water, and competition with other plants. Production of aquatic macrophytes varies in response to an array of physical and chemical characteristics of both the water and sediment as well as light availability. In general, emergent forms require increased light, higher ambient temperature, and decreasing water levels to promote growth, while submersed forms require higher water levels (i.e., inundation). Sediment composition and a variety of chemical parameters (i.e., inorganic carbon, calcium, phosphorus) also are important factors. Floating-leaved forms are intermediate between these two forms, utilizing abiotic environmental factors from both groups (i.e., depending upon their reproductive state). The overall result is extremes in heterogeneity in both distribution and productivity, spatially and temporally. Seasonal changes in composition and dominance are commonly observed among submersed, floating-leaved, and emergent species. However, introduced or aggressive native species, tend to form monospecific populations, (i.e., water hyacinth, cattails). Vegetative reproduction is prevalent among aquatic macrophytes, and rapid, relatively complete expansion into favorable habitats usually occurs. The importance of geographic and genetic differences of the same species is reflected in their productivity, which varies in a given environment from population to population as well as among populations from one environment to another (Muehscher 1959; Wetzel 1975; Barko et al. 1986).

3.3.2.5 Zooplankton

- Community Composition

The lacustrine freshwater zooplankton community of Lake Texana would consist of a wide variety of organisms, including coelenterates, larval trematode worms, gastrotrichs, mites, larval mollusks, ostracod crustaceans, and larval insects (i.e., *Chaoborus*), but would be largely dominated by three groups: rotifers, copepods, and cladocerans (Hutchinson 1967; Wetzel 1983; Lehman 1988).

Monthly zooplankton samples were collected at numerous stations in Lake Texana from January through September 1981 (Armstrong et al. 1995a). The zooplankton community was dominated primarily by the rotifers *Brachionus*, *Keratella*, and *Trichocerca* (Table III-38). The pelagic zooplankton community was comprised predominately of rotifers, nauplii, microcrustaceans (i.e., postnaupilar free-living copepods [cyclopoids, calanoids] and cladocerans), and protozoans. The most common and widely distributed North American lacustrine species found in Lake Texana included: Copepoda - *Cyclops*, *Mesocyclops*, *Diaptomus*; Cladocera - *Daphnia*, *Bosmina*, *Diaphanosoma*; and Rotatoria - *Keratella*, *Brachionus*, *Filinia*, *Trichocerca*, *Platyias*, *Ascomorpha* (Pennak 1957; Cole 1979). Another important component of the lacustrine community are the planktonic lobose and cilated protozoans, represented by the general *Difflugia* and *Tintinnopsis/Codonella*, respectively (Pace and Orcutt 1981; Laybourn-Parry 1992).

- General Ecology

The composition, seasonal abundance, and dynamics of lacustrine zooplankton communities are complex and influenced by a number of abiotic and biotic variables. Zooplankton communities react differently to these variables according to local habitat. The composition of a zooplankton community depends upon a multitude of factors (i.e., environmental, food type and availability, predation pressure, etc.). Most zooplankton communities include organisms from each of the three main zooplankton groups (rotifers, cladocerans, and copepods). These groups are distributed differently, and occur in different numbers, relative to each other within a body of water (Hutchinson 1967). Rotifers usually are present in large quantities (three to seven species) relative to the cladocerans (two to four species) and copepods (one to three species), but due to their small size rotifers do not make up the greatest proportion of the zooplankton community biomass (Williamson 1991). Cladocerans usually are less abundant than rotifers, but often make up an important part of the community biomass due to their larger size (Dodson and Frey 1991). Along with the cladocerans, copepods usually make up the greatest portion of zooplankton community biomass (Thorp and Covich 1991).

Zooplankton also show marked differences in seasonal abundances. Population may be monocyclic (one population maximum per year), dicyclic (two population maximum), acyclic (no pronounced maxima), or none of the above. The classic cycle for a zooplankton community shows low numbers of organisms during winter, increasing abundance during the spring as the water warms and more food becomes available, and then decreasing abundance during the summer and fall (Pennak 1978). Types of

Table III-38

Zooplankton Species Collected in Lake Texana in 1981

PROTOZOA
Centropyxis aculeata
Codonella cratera
Difflugia lobostoma
Difflugia urceolata
Difflugia urceolata var. *olla*
Loxodes sp.
Metacineta sp.
Paramecium sp.
Pyxicola sp.
Stentor sp.
Tintinnidium fluviatile
Tintinnopsis cylindrata
Vorticella sp.

ROTIFERA
Ascomorpha ovalis
Ascomorpha saltans
Asplanchna sp.
Brachionus angularis
Brachionus bidentata
Brachionus budapestinensis
Brachionus calyciflorus
Brachionus caudatus
Brachionus falcatus
Brachionus havanaensis
Brachionus quadridentatus
Brachionus variabilis
Collotheca pelagica
Conochiloides dossaurius
Conochilius unicornis
Dipleuchlanis propatula
Filinia longiseta
Filinia opolienis
Hexarthra mira
Kellicotia bostoniensis
Keratella cochlearis
Keratella cochlearis var. *hispida*
Keratella serrulata

ROTIFERA (Continued)
Keratella valga
Lecane luna
Monstyla bulla
Notholca acuminata
Polyarthra sp.
Platyias patulus
Platyias quadricornis
Rotaria (?) sp.
Synchaeta sp.
Testudinella patina
Trichocerca capucina
Trichocerca similis
Trichocerca spp.

CLADOCERA
Alona sp.
Bosmina longirostris
Bosmina longirostris var. *cornuta*
Daphnia parvula
Diaphanosoma brachyurum
Pleuroxus sp.

COPEPODA
Diaptomus spp.
Eucyclops sp.
Mesocyclops sp.
Tropocyclops sp.

INSECTA
Chaoborus sp.
Chironomus sp.

PROIFERA
Eunapius fragilis

BRYOZOA
Plumatella repens

Legend: sp. = species
spp. = species (plural)
var. = variety

Source: Armstrong 1995a

zooplankton within a lake/reservoir exhibit distinct patterns of distribution, both horizontally and vertically. Such patterns vary widely among types of organisms and lakes and within individual lakes (Wallace and Snell 1991). Types of zooplankton within a lake tend to be distributed differentially among the open pelagic zone and the shallower, calmer backwaters and littoral zones. Approximately 75 percent of the rotifer species are littoral, although those that are found in open waters tend to be present in greater numbers than littoral species (Hutchinson 1967; Pennak 1978). Among copepods, cyclopoids are generally more littoral, while calanoid are more pelagic (Williamson 1991). There is a tendency for all types of zooplankton to include some genera and species that prefer either open water or backwaters. Thus, the zooplankton communities of reservoirs (Lake Texana) are distributed horizontally in greater densities toward the middle of the reservoir, in the transition zone between the river and lacustrine zones (Soballe et al. 1992).

3.3.2.6 Benthic Macroinvertebrates

- Community Composition

Historic and current benthological investigations of Lake Texana are very limited. A qualitative study of the macroinvertebrates was conducted by Armstrong et al. in 1986. Armstrong et al. (1995a) found bryozoans, flatworms, oligochaetes, mollusks, crustaceans (amphipods), and a variety of insects on floating plant communities (Table III-39). The pleustonic invertebrate community (i.e., associated with the surface film of air-water) was comprised primarily of Collembola (i.e., springtails) and heteropterans (i.e., water striders). The shallow vegetated bays/littoral waters of Lake Texana would provide diverse and varied habitats for aquatic invertebrates. Aquatic insects (e.g., true flies, mayflies, dragonflies) and mollusks would be expected to dominate vegetated aquatic communities (Merritt and Cummins 1978; Ward 1992). The littoral zone of Lake Texana would have a higher number of taxa since diversity generally decreases with depth (Ward 1992). Amphipods, mayflies, true flies, and mollusks would potentially dominate the littoral zone, while the profundal zone would be comprised of oligochaetes and dipterans.

Bryozoans, sponges, turbellarians, oligochaetes, and aquatic insects (ephemeropterans, coleopterans, dipterans) comprise the benthic fauna of Lake Texana (Table III-40). Recent surveys indicate that

Table III-39

Preliminary Taxonomic List of Macroinvertebrates in Floating Azolla-Duckweed Communities of Lake Texana (1986)

Phylum/Family	Genus/Species	Feeding Group
BRYOZOA		
Plumatellidae	*Plumatella repens*	Filterer
PLATYHELMINTHES		
Planariidae	*Dugesia* sp.	Carnivore/Omnivore
ANNELIDA		
Naididae	*Chaetogaster* sp.	Carnivore
	Dero vagus	Detritivore
	Pristina longiseta	Detritivore
MOLLUSCA		
Physidae	*Physa* sp.	Scraper
Planorbidae	*Gyraulus* sp.	Scraper
ARTHROPODA		
Talitridae	*Hyalella azteca*	Omnivore
Ostracoda	Unidentified	Unknown
Isotomidae	*Isotomurus palustris*	Collector
Veliidae	*Rhagovelia* sp.	Piercer
Noteridae	*Hydrocanthus* sp.	Unknown

Table III-40

Preliminary Taxonomic List of Benthic Macroinvertebrates in Lake Texana (1986)

Phylum/Family	Genus/Species	Feeding Group
BRYOZOA		
Urnatellidae	*Urnatella gracilis*	Filterer
Lophopodidae	*Pectinatella* sp.	Filterer
Plumatellidae	*Plumatella* sp.	Filterer
PORIFERA		
Spongillidae	*Eunapsis fragilis*	Filterer
PLATYHELMINTHES		
Planariidae	*Dugesia* sp.	Carnivore/Omnivore
ANNELIDA		
Naididae	*Chaetogaster* sp.	Carnivore
	Dero sp.	Detritivore
Tubificidae	*Branchiura sowerbyi*	Detritivore
ARTHROPODA		
Culicidae	*Chaoborus* sp.	Carnivore
Chironomidae	*Chironomus* sp.	Collector//Gatherer
Haliplidae	*Peltodytes* sp.	Shredder

Legend: sp. = species

Source: Pennak 1978; Merritt and Cummins 1978; Armstrong 1995a mollusks are not present in the littoral zone of upper Lake Texana. Mollusks found near the dam include southern mapleleaf (*Quadrula apiculata*) and giant floater (*Amblema grandis*) (Howells 1995c).

Only a few aquatic invertebrates can be classified as planktonic. Phantom midges occur in Lake Texana can be classified as nekobenthic organisms since they occur as in the water column during the night and in the benthos (bottom sediments) during the day. The early life phases of several other invertebrates (e.g., first instar chiromomid larvae and burrowing mayfly nymphs) would also occur occasionally in the water column. Although not collected during Armstrong's study, other nekobenthic organisms (i.e., those capable of swimming) such as water boatman (Corixidae) and back swimmers (Notonectidae) could occur in Lake Texana.

- General Ecology

Benthic invertebrate community structure in lentic (standing) waters is generally characterized by a diverse fauna in the littoral (shallow water) zone because of substratum heterogeneity and a lower diversity in the profundal (deep water) zone due to more homogenous conditions. Therefore, species diversity generally decreases with increasing depth. As lakes and reservoirs age, they become more productive, the profundal zone becomes more homogenous, and the species diversity decreases.

In lakes and reservoirs, the range and competitive abilities of benthic invertebrates are controlled by phytoplankton and aquatic macrophyte production (i.e., food supply and physicochemical characteristics). These factors affect both distribution and abundance of benthic invertebrates. Littoral zone species diversity decreases when phytoplankton densities increase to the point where they shade out aquatic macrophytes, an important substrate and food source for many aquatic invertebrates. As the eutrophication process continues, diversity and quantity of benthic macroinvertebrates in the littoral zone continues to decrease. At this stage, most of the benthic biomass is produced in the profundal zone, often by a few species (Wetzel 1983).

The macroinvertebrate community in the littoral zone of lakes is a crucial link in the transfer of energy from primary producers (e.g., aquatic macrophytes) and detritus to fish (McQueen et al. 1986) and waterfowl (Danell and Sjoberg 1982). Recent empirical studies indicate that the total abundance of both epiphytic and benthic invertebrates is correlated with macrophyte biomass and weedbed characteristics

(Rasmussen 1988). Furthermore, the abundance of some epiphytic macroinvertebrate species varies greatly between host plant species (Cyr and Downing 1988). It follows that the size-structure of littoral macroinvertebrate communities might also vary with the plant species composition (Chambers and Prepas 1990).

3.3.2.7 Amphibians/Reptiles

- Community Composition

Based on the literature search, no surveys have been specifically conducted for amphibians and reptiles at Lake Texana. Thirty-three species of amphibians/reptiles potentially occur in the Lavaca-Navidad River Basin (Appendix A-1). Based on habitat requirements of these species, 18 species would potentially occur in Lake Texana (Table III-41).

The central newt, western lesser siren (*Siren intermedia nettingi*), Blanchard's cricket frog, upland chorus frog, Southern leopard frog (*Rana utricularia*), Mississippi mud turtle (*Kinosternon subrubrum hippocrepsis*), yellow mud turtle (*Kinosternum flavescens flavescens*), red-eared slider, American alligator, western cottonmouth, and Mississippi green water snake would potentially occur in the quiet, shallow arms or bays of Lake Texana in areas of submerged vegetation with a mud bottom. The Gulf Coast toad, green treefrog, and eastern garter snake (*Thamnophis sirtalis sirtalis*) would potentially be found in moist habitats along the lake shore. The spotted chorus frog may occur in marshy areas around the lake if prairie habitat is nearby. The common snapping turtle would occur in shallower waters with dense submerged vegetation and in deeper areas with a mud bottom. The Gulf crayfish snake (*Regina rigida sinicola*) may occur along the lake margins and near areas of emergent aquatic vegetation. The western mud snake (*Farancia abacura reinwardti*) may occur if abundant supplies of western lesser sirens are present in Lake Texana (Garrett and Barker 1987; Tennant 1990).

- General Ecology

Amphibians are usually restricted to moist or wet habitats with at least a nearby water source. The larval phases of most amphibians require water for transformation into the adult phase while most reptiles do

Table III-41

List of Amphibians and Reptiles Potentially Occurring in and Adjacent to Lake Texana

Common Name	Scientific Name
NEWTS	
Central newt	*Notophthalmus viridescens louisianensis*
SIRENS	
Western lesser siren	*Siren intermedia nettingi*
CRICKET FROGS	
Blanchard's cricket frog	*Acris crepitans blanchardi*
TOADS	
Gulf Coast toad	*Bufo valliceps valliceps*
TREEFROGS	
Green treefrog	*Hyla cinerea*
CHORUS FROGS	
Spotted chorus frog	*Pseudacris clarkii*
Upland chorus frog	*Pseudacris feriarum*
TRUE FROGS	
Southern leopard frog	*Rana utricularia*
SNAPPING TURTLES	
Common snapping turtle	*Chelydra serpentina serpentina*
MUD TURTLES	
Yellow mud turtle	*Kinosternon flavescens flavescens*
Mississippi mud turtle	*Kinosternon subrubrum hippocrepis*
SLIDERS	
Red-eared slider	*Trachemys scripta elegans*
ALLIGATORS	
American alligator	*Alligator mississippiensis*
COPPERHEADS/COTTONMOUTHS	
Western cottonmouth	*Agkistrodon piscivorus leucostoma*
MUD SNAKES	
Western mud snake	*Farancia abacura reinwardtii*
WATER SNAKES	
Mississippi green water snake	*Nerodia cyclopion*
CRAYFISH SNAKES	
Gulf crayfish snake	*Regina rigida sinicola*
GARTER/RIBBON SNAKES	
Eastern garter snake	*Thamnophis sirtalis sirtalis*

Source: Dixon 1987; Garrett and Barker 1987; Collins 1990; Tennant 1990

not require water for adult maturation. Microhabitat components for amphibians and reptiles are site-specific physical entities which provide environmental conditions necessary for a wide variety of ecological functions (i.e., reproduction, foraging, predator avoidance/escape, thermoregulation, and resting). Amphibians and reptiles are ectothermic (cold-blooded) animals which derive their body temperature from the surrounding environment. Therefore, these animals are often very dependent on certain microhabitats to thermoregulate. Without habitat for thermoregulation, other ecological functions cannot be completed since internal temperature regulation determines the intensity of the activity (Jones 1986).

3.3.2.8 Fish

- Community Composition

Recent field surveys indicate the presence of at least 35 fish species in Lake Texana (Table III-42). Two primary fish habitats, the littoral (nearshore vegetated) and open water (offshore pelagic), occur in Lake Texana. Gars, carps/minnows, suckers, bullheads, silversides, pipefishes, and the sunfishes would utilize littoral habitats. Herrings, large catfish (blue catfish [*Ictalurus furcatus*], channel catfish, and flathead catfish), temperate basses, freshwater drum, and mullet would primarily utilize open water habitats. These open water species would potentially occur in the vicinity of the intake structure near the Palmetto Bend Dam on Lake Texana (Chilton 1995; Jons 1995).

- General Ecology

Interaction between a complex array of abiotic factors and biotic factors determines the composition and abundance of the fish community in lakes/reservoirs. Lake morphometry (i.e., maximum/mean depth, length, area, volume, etc.) is one of the most important abiotic factors (Reid 1961; Jackson 1992). Gradients in lake morphometry have been correlated with differences in fish species composition and richness (Johnson et. al. 1977; Harvey 1978; Matuszek and Beggs 1988; Jackson and Harvey 1989). For example, the number and size of different habitat types generally increase with the size of the lake. Other important abiotic factors include physicochemical characteristics (i.e., substrate and water quality). For example, cyprinids are relatively tolerant of low dissolved oxygen levels, but many species (e.g., fathead

Table III-42

List of Fish Species[1] Known to Occur or Potentially Occur in Lake Texana

Common Name	Scientific Name
GARS	
Spotted gar	*Lepisosteus oculatus*
Longnose gar	*Lepisosteus osseus*
Alligator gar	*Lepisosteus spatula*
Shortnose gar	*Lepisosteus platostomus*
HERRINGS	
Gizzard shad	*Dorosoma cepedianum*
Threadfin shad	*Dorosoma petenense*
CARPS/MINNOWS	
Grass carp (triploid)[2]	*Ctenopharyngodon idella*
Blacktail shiner	*Cyprinella venusta*
Common carp	*Cyprinus carpio*
Golden shiner	*Notemigonus crysoleucas*
Bullhead minnow (likely)	*Pimephales vigilax*
SUCKERS	
Smallmouth buffalo	*Ictiobus bubalus*
BULLHEADS/CATFISHES	
Black bullhead	*Ameiurus melas*
Yellow bullhead	*Ameiurus natalis*
Blue catfish	*Ictalurus furcatus*
Channel catfish	*Ictalurus punctatus*
Flathead catfish	*Pylodictis olivaris*
PIRATE PERCHES	
Pirate perch	*Aphredoderus sayanus*
SILVERSIDES	
Brook silverside	*Labidesthes sicculus*
Inland silverside	*Menidia beryllina*
PIPEFISHES	
Gulf pipefish	*Syngnathus scovelli*
TEMPERATE BASSES	
White bass	*Morone chrysops*
Striped bass (stocked-not collected)	*Morone saxatilis*
SUNFISHES	
Redbreast sunfish	*Lepomis auritus*
Green sunfish (expected)	*Lepomis cyanellus*

Table III-42 (Continued)

List of Fish Species[1] Known to Occur or Potentially Occur in Lake Texana

Common Name	Scientific Name
SUNFISHES (Continued)	
Warmouth	*Lepomis gulosus*
Bluegill	*Lepomis macrochirus*
Redear sunfish	*Lepomis microlophus*
Longear sunfish	*Lepomis megalotis*
Smallmouth bass	*Micropterus dolomieu*
Largemouth bass	*Micropterus salmoides*
White crappie	*Pomoxis annularis*
Black crappie	*Pomoxis nigromaculatus*
DRUMS	
Freshwater drum	*Aplodinotus grunniens*
MULLETS	
Striped mullet	*Mugil cephalus*

[1]Includes mostly game fish. Other species such as rough fish/shiners are not enumerated or identified during surveys.
[2]Possibly introduced below Lake Texana during flood

Source: Chilton 1995; Jons 1995

minnow) are intolerant of low pH conditions. The distribution of piscivores is often determined by oxygen concentrations since they are generally intolerant of low oxygen levels. Of the biotic factors, predation appears to be one of the most important factors (Jackson 1992). Other biotic factors include but are not limited to interspecific competition for food and nesting site, prey availability, and susceptibility to pathogens.

3.3.2.9 Endangered and Threatened Species

Federally listed aquatic threatened, endangered, and candidate category species are not listed for Lake Texana (USFWS 1995c). The American alligator, a TOES "watch list" species, would potentially be present in the project area (TOES 1995). TOES has also identified an invertebrate of special concern, (also listed as federal C2 species [USFWS 1994]), disjunct crawling water beetle, which may occur in the project area. The distribution of this species in Texas has not been determined (TOES 1988).

4.0 ANALYSIS OF POTENTIAL ECOLOGICAL IMPACTS

Aquatic ecosystems function through a series of complex interactions between abiotic and biotic factors (Figure III-7). The complexity of these interactions in the aquatic environment underscores the difficulty involved in analyzing potential environmental impacts from the proposed interbasin water transfer. A schematic illustrating the various concerns associated with interbasin water transfers is presented in Figure III-8.

General qualitative assessments of the potential aquatic environmental impacts which could result from each of the three segments involved in the proposed transfer from the West-Central Study Area to the South-Central Study Area (i.e., Colorado River to Sandy Creek, Sandy Creek to Lake Texana, Lake Texana to the O.N. Stevens Terminal Water Storage Reservoir) are presented in this section. All assessments are based on historic and/or current abiotic/biotic data. Overall, current data on abundance/composition of aquatic communities, with the exception of macroinvertebrate communities in the Colorado River and fish communities in the Colorado River/Lake Texana is not available. In these instances, a theoretical approach was used to characterize aquatic communities of the study areas. For the reader's convenience, the description of each segment was prepared as self contained sub-section. Aquatic abiotic impacts are discussed first to provide a basis for the analysis of potential interactions with and impacts on the biotic environment. Biotic impacts are subsequently assessed for each major component of the aquatic environment.

The water proposed for withdrawal and transfer from the Colorado River and Lake Texana is in compliance with instream/estuarine flow requirements adopted by the State of Texas (TNRCC 1994a). Therefore, potential impacts of the proposed water withdrawals from the Colorado River and Lake Texana on instream and estuarine (i.e., Colorado and Navidad-Lavaca River basins) inflows are not evaluated in this report. In addition, no adverse environmental effects would occur to the nearby Nueces River Basin since the terminal water storage reservoir at the O.N. Stevens Water Treatment Plant has not in the past and is not planning in the future to discharge any of the water received from the transfer to nearby surface water sources (ponds, lakes, creeks, rivers, streams, and estuaries). Therefore, no environmental analysis is presented for the Nueces River Basin.

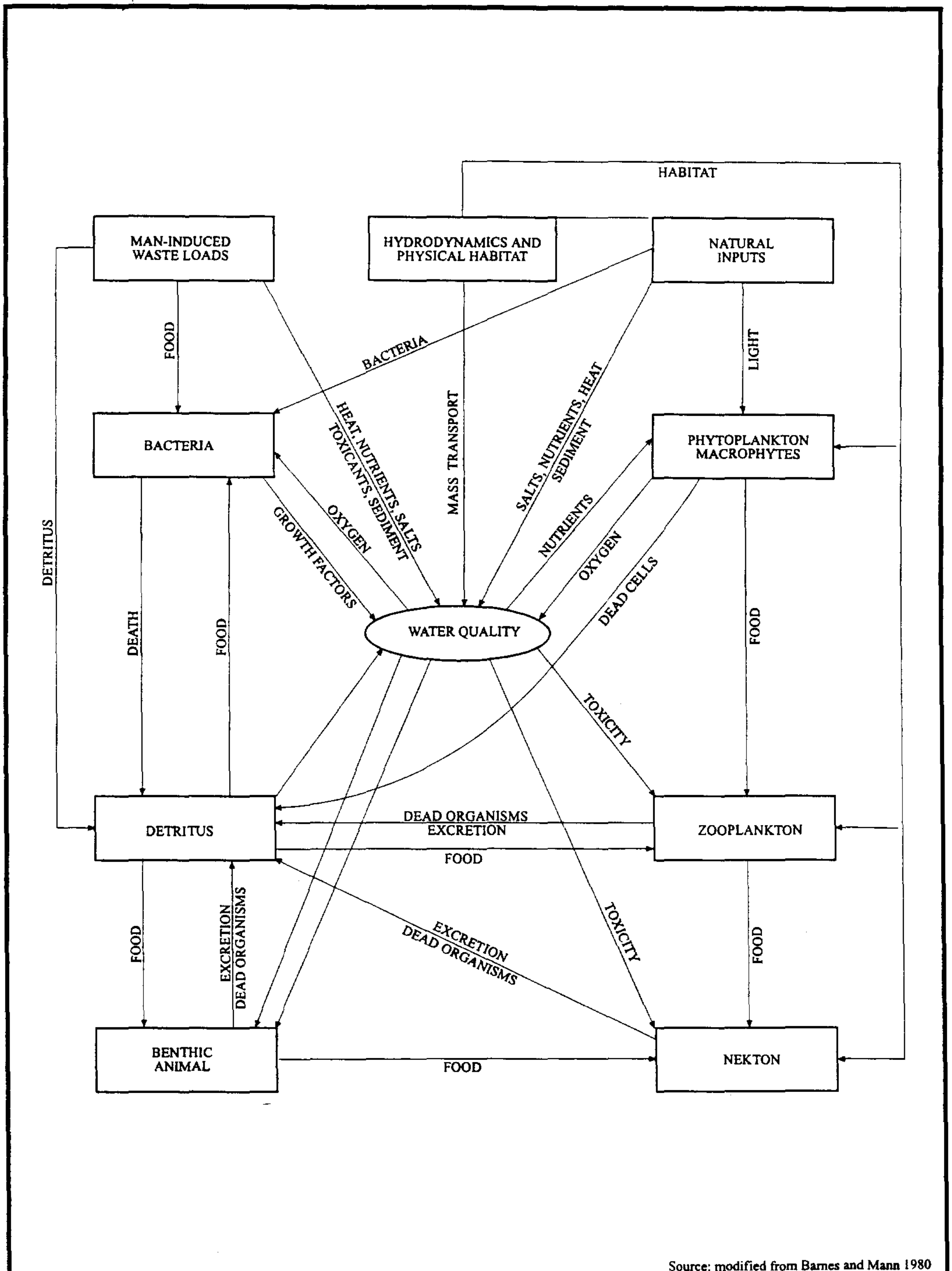


Figure III-7. Major Components of an Aquatic Ecosystem

Table III-43

Percent Increase in Mean Current Flow (cfs)[1]
for Low and High Pumping Alternatives

Month	Mean Current Flow (cfs)	Percent Increase Pumping Alternative	
		Low	High
January	202.0	21	37
February	187.0	19	34
March	74.4	58	98
April	143.0	31	55
May	237.0	18	31
June	216.0	16	27
July	114.0	45	79
August	41.2	221	386
September	192.0	24	42
October	132.0	52	92
November	127.0	38	67
December	98.1	49	86

[1]Based on water years 1978-1994

Legend: cfs = cubic feet per second

Source: modified from Gandara et al. 1995

4.1.1.3 Physicochemical Characteristics

Water quality in the Colorado River and Sandy Creek is suitable for designated uses (contact recreation, high quality aquatic habitat, and public water supply) based on data collected by Armstrong et al. (1986), TNRCC (1994b) and Gandara et al. (1995). Principal local water quality concerns in the Colorado River are occasional exceedances of chloride, sulfate, and total dissolved solids; increased levels of nutrients; and potentially increased levels of fecal coliforms, pesticides, and/or other toxic compounds in bottom sediments and the water column. Sandy Creek occasionally experiences exceedances in chloride, pH, and in levels of phosphorus. Fecal coliform levels in Sandy Creek have not been measured in recent years; historic measurements indicated the occurrence of elevated levels of fecal coliforms (7 of 10 samples) in Sandy Creek (Davis et al. 1978). Both the Colorado River and Sandy Creek have occasionally experienced high salinity concentrations.

4.1.2 Biotic Environment

Potential aquatic biological impacts to the donor system (i.e., Colorado River) and conduit/recipient system (i.e., Sandy Creek) are discussed in this section. Based on the analysis of potential environmental impacts, a qualitative potential impact rating (i.e., low, moderate, high, unknown, or no effect) is subsequently assigned to each aquatic component.

4.1.2.1 Microbes

Microbes could potentially be transferred from the Colorado River via the new channel reservoir to Sandy Creek during the interbasin water transfer. Historic data from Sandy Creek indicate fecal coliforms exceeded the existing criteria level (200 colonies/100 mℓ) seven out of 10 times with an overall mean of 1,390 colonies/100 mℓ (Davis et al. 1978). The maximum fecal coliform level was 11,000 colonies/100 mℓ and the minimum was 26 colonies/100 mℓ. Data for Segment 1402 of the Colorado River from 1989-1992 indicate fecal coliforms exceeded the criteria level (400 colonies/100 mℓ) six out of 38 times with an overall mean of 489 colonies/100 mℓ. The maximum level was 7,900 colonies/100 mℓ and the minimum was 6 colonies/100 mℓ (TNRCC 1994b). During floods, the fecal coliform concentrations in the Colorado River, and therefore Sandy Creek, could increase temporarily due to upstream runoff and potential overflow of wastewater treatment plants. Based on available data, the proposed interbasin water transfer would not significantly increase the density of fecal coliform populations in Sandy Creek since density of coliform bacteria is potentially higher in Sandy Creek than the Colorado River. Other microbes which could affect human health (i.e., *Cryptosporidium* and *Microsporidium*) are probably present in both the Colorado River and Sandy Creek. The potential transfer impacts from other microbes cannot be assessed since presence/absence and density data are not available from the proposed intake site.

A "no effect impact rating" was assigned for fecal coliforms since the water transferred would not significantly increase coliform densities and/or be directly consumed by the public. Although significant impacts would not be expected to occur, an "unknown" rating was assigned to other microbes due to the lack of microbial presence/absence and density data for the intake site on the Colorado River.

4.1.2.2 Phytoplankton

Construction of the low head dam would potentially change the composition and density of the local phytoplankton community by altering the hydrology and habitat (i.e., potential creation of eddies), in the Colorado River. Although local impacts to the phytoplankton community would potentially occur, the phtyoplankton community in the Colorado River would not be significantly affected due to the local nature of the impact.

With the proposed construction of the new channel reservoir along the western shore of the Colorado River, the phytoplankton community in the reservoir could potentially change to a lacustrine-type community capable of producing higher density of noxious blue-green algal blooms than normally occurs in the Colorado River. Although these algae could be transferred to Sandy Creek, they are not expected to survive due to the difference between the habitats (i.e., lacustrine vs. river/stream) and the dispersal of the bloom concentration due to the increase in flow. Since native phytoplankton is unlikely to survive, the Biological Oxygen Demand (BOD) level would potentially increase after the bloom is transferred to Sandy Creek.

An increase in chloride levels (exceeding criteria level of 300 mg/l) over an extended period of time could contribute to golden algal blooms and produce ichthyotoxic impacts (e.g., fish kills). High salinity levels are believed to be the cause of a massive growth of golden algal (*Prymnesiun parvum*) and subsequent fish kills in the upper Colorado River (McCann and Wedig 1993) and the Pecos River (Rhodes and Hubbs 1992). Should a bloom occur under these conditions, the species could be transferred to Sandy Creek and potentially cause fish mortalities.

The proposed continuous pumping cycle would decrease the potential for the development of a phytoplankton bloom in the new channel reservoir and in Sandy Creek. The potential for a golden algal bloom is considered to be very low since chloride levels rarely exceed the criteria level. Therefore, a "low potential impact rating" was assigned for phytoplankton.

4.1.2.3 Periphyton

Local changes in periphyton composition, distribution, and abundance would potentially occur during construction of the low head dam and the subsequent local habitat alterations. As previously stated, a lacustrine-type community would potentially develop in the new channel reservoir. Periphyton is unlikely to be transferred in large densities unless the intake flow dislodges them. Significant impacts would not occur as a result of the transfer of periphyton from the Colorado River to Sandy Creek due to the differences in habitat between the new channel reservoir and Sandy Creek.

Anderson (1990) reported that the periphytic filamentous algae, *Cladophora*, a common component in the Colorado River (Groeger 1992), could potentially cause increased wear on the intake's water pumps due to abrasion. In addition, van Zon (1982) reported that various algae may also cause corrosion in concrete and steel. Periphyton assemblages may change up to 30 percent from year to year within the spring-summer period (Stevenson and Petersen 1989); therefore, effects on pumps and pipelines could vary yearly. A "low potential" (short-term) to "moderate potential (long-term) impact rating" was assigned to periphyton because of potential abrasion and corrosion problems associated with these algal species.

4.1.2.4 Aquatic Plants

Construction of the low head dam may alter river hydrology and/or habitat which could result in either the destruction or establishment of native aquatic macrophytes in the Colorado River. These negative/positive impacts would be local and would not significantly impact the aquatic environment in the Colorado River. Depending on the construction design, native lacustrine-type and aquatic macrophytes could become established in the new channel reservoir. Although native aquatic macrophytes may be transferred to Sandy Creek, establishment of these dominant species and other common river/stream macrophytes are unlikely to occur due to the lack of suitable habitat (i.e., backwater areas, gravel/cobble substrate, etc.) in Sandy Creek. Helton and Hartmann (1995) reported that surveys conducted for aquatic macrophytes in the Colorado River did not locate any noxious aquatic plant communities (Howells 1992); therefore, no impacts would occur from noxious plant species. Based on these analyses, a "no effect impact rating" was assigned to aquatic plants.

4.1.2.5 Zooplankton

Construction of the low head dam may alter either river hydrology and/or habitat for zooplankton in the Colorado River. However, these changes would not be significant because of the small area affected by construction and operational activities. The proposed construction of the new channel reservoir could potentially provide habitat for backwater riverine or lacustrine zooplankton (i.e., microcrustaceans). Depending on the size of the new channel reservoir and the pumping schedule, zooplankton density could increase due to the enclosed habitat provided by the new channel reservoir. Some zooplankton would be transferred successfully (i.e., due to their small size) to Sandy Creek during the interbasin water transfer, via the new channel/reservoir. Establishment, however, is unlikely due to the differences in habitat between the Colorado River/new channel reservoir and Sandy Creek. Although some potential impacts have been discussed, an "unknown potential impact rating" for zooplankton was assigned since very little data on zooplankton species composition/density data for the Colorado River were available.

4.1.2.6 Benthos

The proposed construction would disturb and alter the benthic invertebrate community in the Colorado River. Construction disturbances and subsequent changes in current flow rates and sediment composition/deposition at and in the vicinity of the proposed site for the new channel reservoir would probably result in local changes to the macroinvertebrate community. With the possible exception of mollusks, these impacts would be local and would not significantly affect macroinvertebrate communities in the Colorado River.

Construction of the intake structure and/or new channel reservoir could result in significant impacts to mollusks if the construction disturbs or destroys the habitat of the listed mollusks. The larval (glochidial) phase of a mollusk, which drifts/swims in the current in search of a fish host, could be diverted from an area of suitable habitat in the Colorado River to potentially unsuitable habitat in Sandy Creek. Loss of the fish host species, many of which are species specific for a mollusk, through habitat alteration, impingement/entrainment, or transfer to Sandy Creek would decrease the potential for survival. If the construction site is large enough, near a major isolated mollusk population, or alters habitat (i.e., to lacustrine conditions) then these factors may reduce survival/recruitment rate of the species, decrease the species population, and could potentially result in listing of the species.

The Asiatic clam could cause fouling problems at the intake structure or clog the pipeline to Sandy Creek since this species is known to occur in the Colorado River. Environmental conditions which induce large numbers of Asiatic clams to leave the substratum include high water temperatures, post-spawning activity, low environmental oxygen concentrations, and high levels of chloride (i.e., shock chlorination) (McMahon 1983). One of these factors, high water temperature (i.e., shallower/slower water in the new channel reservoir) could occur. Therefore, if present at or above the proposed low head dam/new channel reservoir, the Asiatic clam could clog the intake structure.

Alterations in the abiotic environment of Sandy Creek would also occur during the interbasin water transfer, potentially causing benthic species composition and abundance to change (Hynes 1970). For example, an increase in current velocity would be associated with the proposed interbasin water transfer. Operation of the interbasin water transfer during months of very low or no flow would potentially change the classification status of Sandy Creek below Highway 1300 from an intermittent to a perennial creek. Benthic invertebrates which utilize habitats with permanent flow (e.g., aquatic coleopterans/beetle larvae) may subsequently colonize the area, thus changing the structure of the macroinvertebrate community in Sandy Creek.

Benthic invertebrates could also be transferred from the Colorado River to Sandy Creek. Based on available data, sand substrates dominate in the Egypt Reach of the Colorado River and in Sandy Creek. Therefore, some species of benthic invertebrates (e.g., midge fly larvae) which inhabit sand substrates in the Colorado River, and which are possibly present in Sandy Creek, could be transferred to and potentially survive in Sandy Creek if habitat parameters (substrate size, current, temperature, and other physicochemical characteristics) are within the species range of requirements. If they survive the transfer, the availability of food would regulate the abundance of the translocated native macroinvertebrates. Any increase in abundance of aquatic organisms would depend on the amount of nutrients and food items introduced from the Colorado River. Small-bodied planktonic organisms (cladocerans, copepods) would be diverted by the low head dam into the new channel reservoir where their populations could increase due to the presence of more lentic (reservoir type) conditions. The transfer of these planktonic food resources to Sandy Creek would probably result in an increase in aquatic organisms in the collector feeding group (e.g., hydropsychid/net-spinning caddisflies). In addition, the Asiatic clam could be transferred from the Colorado River and become established in Sandy Creek. However, the potential for establishment of the Asiatic clam cannot be predicated since site-specific physicochemical conditions are unknown.

One aquatic invertebrate of special concern, (also listed as federal C2 species [USFWS 1994]): the disjunct crawling water beetle, may occur in the study areas; however, specific distribution in Texas is unknown (TOES 1988). If present, this aquatic invertebrate could be affected by construction/operational activities associated with the proposed interbasin water transfers.

Based on these qualitative analyses, the benthic macroinvertebrate community in the Colorado River and Sandy Creek could be moderately affected by the proposed interbasin water transfer. It should be noted, however, that potential effects to Sandy Creek were based on the benthic data from nearby West Mustang Creek which may or may not be representative of Sandy Creek (Bayer et al. 1992). A "moderate potential impact rating" was assigned to benthic invertebrates due to the potential impacts to native mollusks at the construction site; possible introduction and clogging/fouling problems associated with the potentially harmful non-native mollusk, the Asiatic clam; and potentially significant changes to the benthic invertebrate community of Sandy Creek from an increase in current flow.

4.1.2.7 Amphibians/Reptiles

Cope's, gray, and green tree frogs would not be significantly affected by the construction due to the relatively small river bank area needed for construction of the new channel reservoir. The spotted chorus frog, the pickerel frog, and the central newt utilize marsh habitat, habitats with abundant aquatic vegetation, and areas with slow current, respectively, and would only be affected locally if the proposed low dam/new channel reservoir is located within these habitat types (Garrett and Barker 1987).

Larval phases of the amphibians could be transferred from the Colorado River to Sandy Creek if the new channel reservoir is located in suitable nursery habitat. If the new channel/reservoir is lentic, amphibian larvae may become abundant near the intake site. If they survive the transfer, amphibians would not affect the aquatic environment of Sandy Creek since all but the pickerel frog are also known to occur in the Navidad-Lavaca River Basin. The pickerel frog is not expected to become established since suitable habitat (i.e., abundant aquatic vegetation) for this species is unlikely to be present along Sandy Creek (Garrett and Barker 1987).

Amphibians which utilize intermittent pools and/or areas with slow current (e.g., pools, backwaters) in Sandy Creek may be significantly impacted by the potential change in current flow from the proposed transfer. With the increases in flow, breeding and nursery areas (e.g., intermittent pools) may be rendered unsuitable by the change in flow classification (i.e., intermittent to perennial), depth of water, and overall increase of flow in existing quiet pools. The magnitude of this impact would depend primarily on the species present and the current flow.

Significant impacts to the reptilian population are not expected to occur due to the relatively small area which would be affected by the construction. Adult turtles and snakes would not be directly affected by the proposed construction of the new channel reservoir due to their ability to leave the site during construction activities. Although some reptilian species (water snakes and turtles) may be attracted to the new channel reservoir to feed on trapped fish, the possibility of transfer to Sandy Creek is also low due to reptilian mobility. All of the potential reptilian transfer species, with the exception of the Midland smooth softshell turtle (*Apalone muticus muticus*) also occur in the Navidad-Lavaca River Basin and, therefore, would not affect the reptilian community of Sandy Creek if the transfer is successful (Garrett and Barker 1987). Depending on the availability of food and competition with other aquatic animals, the Midland smooth softshell turtle could become established in Sandy Creek. Establishment of this species in Sandy Creek would probably not result in significant adverse effects to the aquatic ecosystem of Sandy Creek. Therefore, reptiles would not be significantly affected either by potential introductions or the proposed construction of the new channel reservoir.

A "low potential impact rating" for amphibians and reptiles was assigned because of the small area which would be affected by the proposed construction of the new channel reservoir adjacent to the Colorado River and the low potential of transfer and/or establishment of amphibian/reptilian species in Sandy Creek. Transfer of water from the Colorado River to Sandy Creek would cause an overall rise in water levels and potentially eliminate habitat for some amphibian and reptiles in Sandy Creek; however, these impacts cannot be assessed without hydrologic (i.e., water level) data and amphibian/reptilian surveys of Sandy Creek.

4.1.2.8 Fish

Proposed construction and operational activities could affect native fish populations in the Colorado River and Sandy Creek. Habitat alteration during and/or as a result of construction of the low head dam could potentially cause local non-significant reductions in some fish populations. Based on recent fish surveys, subadult blue suckers, a federal C2/state-listed threatened and a TOES "watch list" species (TOES 1995; TPWD 1995a; USFWS 1994, 1995b), is known to occur in the Egypt Reach of the Colorado River where the new channel reservoir is proposed to be located. Suitable habitat was not found for adult blue sucker in the Egypt Reach of the Colorado River (Mosier and Ray 1992). The blue sucker could be affected by the construction of the low head dam and new channel reservoir if the construction is located in an area currently being utilized as a nursery area. In addition, the potential transfer of larval or juvenile blue suckers from suitable habitat in the Colorado River to unsuitable breeding and nursery habitat in Sandy Creek could also potentially reduce the recruitment/survival rate of the Colorado River blue sucker population. In addition, the Guadalupe bass, a federal C2 and a TOES "watch list" species (TOES 1995; USFWS 1994, 1995b), is also present in the Egypt Reach of the Colorado River (Mosier and Ray 1992). Construction activities could affect adult Guadalupe bass if the species is currently utilizing the area as a breeding area. Larval and juvenile Guadalupe bass may be affected if the construction significantly disturbs a nursery area or if the species is transferred to unsuitable habitat in Sandy Creek.

A wide variety of fish species could potentially be introduced into Sandy Creek from the Colorado River. The historical fisheries data for Sandy Creek along with the recent survey data from nearby West Mustang Creek, which is similar to Sandy Creek in stream size, substrate, and current flow, was used to determine potential impacts from transfer species. Based on recent surveys of the Colorado River (Mosier and Ray 1992), 10 species of fish occur in the Egypt Reach of the Colorado River which are not present in West Mustang Creek or historically in Sandy Creek (see Tables III-18 and III-27). Based on known habitat requirements, three of the 10 fish species, gizzard shad, suckermouth minnow (*Phenacobius mirabilis*), and logperch (*Percina caprodes*) could potentially be transferred and become established during the transfer. Gizzard shad and suckermouth minnow have a low to moderate potential for becoming established in Sandy Creek due to marginal breeding/feeding habitat. The logperch is a highly adaptable species and has a moderate to high potential of becoming established in Sandy Creek. Due to its adaptive and competitive nature, logperch could potentially compete with native centrarchid and cyprinid populations for food (e.g., aquatic insects) and, therefore, may affect the diversity and abundance of some fish populations in Sandy Creek. The magnitude of these impacts would depend on the density of the introductions and the composition/density of current fish populations.

The increase in current flow would potentially alter the fish community of Sandy Creek. Recovery rates for the existing stream fishes would be strongly affected by factors such as: 1) persistence of the effects of disturbance, 2) species' differential abilities to survive disturbance and recovery, 3) presence of refugia, and 4) hydrologic conditions (Resh et al. 1988; Yount and Niemi 1990). In addition, fish species which utilize slower current flow could potentially decrease, while those which prefer faster current velocity could potentially increase in abundance (see Table III-19; Minckley 1963).

In addition, fish pathogens (such as fungi, protozoans, trematodes, cestodes, and parasitic copepods) (Hoffman and Meyer 1974) could be transferred (i.e., in the benthos, zooplankton, or fish) from the Colorado River to Sandy Creek. Few studies have been conducted on the potential effects from the introduction of fish pathogens. Less than two percent of the fish diseases are known and even for these the knowledge is incomplete (Stewart 1991). In one study, three forms of fish parasites present in the donor basin but not in the recipient basin were predicted to potentially cause problems for fish populations (Seagel 1987). Diseases can be destructive to aquatic species resulting in mass mortalities, jeopardizing economic enterprises, whole populations and sometimes resulting in the extinction of entire species (Bauer and Hoffman 1976). The potential effects from the introduction of fish pathogens cannot be addressed without extensive surveys. Therefore, the potential effects from the introduction of fish pathogens from the Colorado River to Sandy Creek are currently unknown.

A "moderate potential impact rating" was assigned for fish because of the potential presence of a federal C2/state-listed threatened, and TOES "watch list" fish species in the Colorado River, the potential introduction of several fish species and their pathogens from the Colorado River into Sandy Creek, and the potential alterations in the fish community of Sandy Creek due to the potential increase in current flow.

4.1.3 Summary

Moderate potential impacts could occur to endangered/threatened and/or candidate/sensitive benthic and fish species if they are present at the site or in the vicinity of the proposed low head dam/new channel reservoir sites. Potential impacts to these aquatic components of the Colorado River would be significantly less if these species are not present. Direct and indirect impacts could potentially occur to aquatic communities in Sandy Creek due to habitat alterations associated with the increase in current flow in Sandy Creek and the potential transfer of several adaptive native fish species. Several components of the aquatic environment could not be assessed due to the lack of current data on composition and abundance. An environmental assessment is necessary to accurately assess the potential impacts on endangered/threatened species in the Colorado River and the aquatic environment of Sandy Creek. The potential environmental impacts of the Colorado River to Sandy Creek interbasin water transfer are summarized in Table III-44.

4.2. Sandy Creek to Lake Texana

4.2.1 Abiotic Environment

Potential impacts to the abiotic environment of Sandy Creek as a result of the proposed interbasin transfer of water from the Colorado River have been discussed previously in Section 4.1. In summary, the abiotic environment of Sandy Creek would potentially be altered by an increase in flow and subsequent habitat changes. Regional water quality in the Colorado River and Sandy Creek is good; thus, the transfer of water from Sandy Creek to Lake Texana, a mesotrophic reservoir (i.e., based on Carlson's trophic state index), would not affect water quality in Lake Texana (TNRCC 1994b). Overall, significant impacts to the abiotic environment of Lake Texana would not occur as a result of the transfer of water from Sandy Creek to Lake Texana.

4.2.2 Biotic Environment

Potential aquatic biological impacts to the recipient system (i.e., Lake Texana) from the donor/conduit system (i.e., Colorado River/Sandy Creek) is discussed in this section. Based on the analysis of potential environmental impacts, a qualitative potential impact rating (i.e., low, moderate, high, unknown, or no effect) is subsequently assigned to each component of the aquatic environment.

Table III-44

Qualitative Rank of Potential Environmental Impacts
Colorado River to Sandy Creek

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	No significant increase in density	Low
Other Microbes	Unknown	No presence/absence or density data	High
Phytoplankton	Low	Continuous pumping and increase in flow would disperse potential algal blooms	Low
Periphyton	Low/Moderate	Little difference in species composition between Colorado River and Sandy Creek; in the long-term, potentially could cause abrasion and corrosion problems in pumps and/or pipeline	Moderate
Aquatic Plants	No Effect	Noxious species not present in the Colorado River; habitat in Sandy Creek not suitable for Colorado River macrophytes	Low
Zooplankton	Unknown	Composition/density data not available	Not Applicable
Benthic Invertebrate			
Mollusks	Moderate	Potential impacts on native mollusks; potential clogging/fouling problems from Asiatic clam	Moderate
Others	Unknown	Potential habitat alteration and subsequent change in benthic community of Sandy Creek due to an increase in flow (intermittent to permanent)	Not Applicable
Amphibians/Reptiles	Low	Potential local construction effects on Colorado River, increase in flow and change of status from intermittent to permanent in Sandy Creek; low chance of surviving transfer	Moderate
Fish	Moderate	Potential presence of federal C2/state-listed threatened/TOES fish species in Colorado River; potential introduction and/or establishment of non-native fish species and fish pathogens; potential alterations in the Sandy Creek fish community due to an increase in current flow	Moderate

4.2.2.1 Microbes

Under normal flow conditions, no significant increase in fecal coliforms would be expected from the Colorado River/Sandy Creek to Lake Texana transfer due to an increase in current flow and dispersal by the large volume of water in Lake Texana. Based on these analyses, a "no effect impact rating" was assigned for fecal coliforms. Although significant impacts are not expected due to dispersal in Lake Texana, an "unknown" rating was assigned to other microbes due to the lack of microbial presence/absence and density data for the donor/conduit system.

4.2.2.2 Phytoplankton

The increase in flow from Sandy Creek could alter the phytoplankton community in the northern section of Lake Texana. Roeder (1977) showed an inverse relationship between the rate of flow and the number of diatoms, while Philip (1981) reported that centric diatoms predominated during increased flows. The direct influence on the phytoplankton is not flow itself, but the increase in turbidity with higher velocities and the washout of algae from an area of a lake due to river inflow with lower phytoplankton densities. If the patterns for the rate of inflow are relatively constant in Lake Texana, then the high to low gradient in population densities from Stations 8 and 9 (lower Lake Texana) to Station 5 (upper Lake Texana) may reflect the decrease in flow (velocity) with distance from the Navidad River and Sandy Creek. With the anticipated increase in flow from Sandy Creek, it is expected that the flagellate-diatom community present in the northern section of Lake Texana could be altered and become a community dominated by centric diatoms (e.g., *Melosira*, *Cyclotella*).

Some phytoplankton would potentially be transferred from the Colorado River via Sandy Creek to Lake Texana during floods. However, survival of a significant concentration under normal conditions is unlikely due to dispersal and the length of the transfer. Transfer of phytoplankton from the new channel reservoir on the Colorado River to Sandy Creek during a bloom period could subsequently result in a slight increase in BOD levels in Lake Texana. Therefore, the transfer of these algae would not significantly impact the existing phytoplankton community or water quality in Colorado River/Lake Texana. Based on these assessments, a " low potential impact rating" was assigned to phytoplankton for the Colorado River/Sandy Creek to Lake Texana transfer.

4.2.2.3 Periphyton

The potential for periphyton to be transferred from the Colorado River/Sandy Creek transfer to Lake Texana under normal conditions is very low. However, during floods some species/individuals could potentially be transferred and survive. Establishment of transferred periphyton is not expected to occur or result in significant impacts since the potential for survival is low due to the differences between stream and lake habitats. Therefore, a "no effect rating" was assigned for periphyton.

4.2.2.4 Aquatic Plants

Several species of native aquatic plants and one introduced aquatic plant could potentially be transferred from the Colorado River via Sandy Creek to Lake Texana. The potential for establishment of native aquatic plants from the Colorado River in Sandy Creek with subsequent transfer to Lake Texana is low due to the differences in habitat between the Colorado River/Sandy Creek and Lake Texana. Floods could successfully transfer native plants and one introduced macrophyte, water feather, to Lake Texana. The potential for survival/establishment in Lake Texana is low, however, due to competition from noxious aquatic macrophyte populations in upper Lake Texana; therefore, a "no effect rating" was assigned to aquatic macrophytes.

4.2.2.5 Zooplankton

A "no effect rating" was assigned to zooplankton since the potential for survival and subsequent establishment in Lake Texana is highly unlikely due to the difference between habitats and in the ability of zooplankton to survive the transfer from the Colorado River/Sandy Creek (lotic) to Lake Texana (lentic).

4.2.2.6 Benthic Macroinvertebrates

Most benthic organisms would not survive the transfer from the Colorado River via Sandy Creek to Lake Texana due to the length of the transfer and the difference in habitats between Colorado River/Sandy Creek and Lake Texana. The Asiatic clam could survive the transfer to Sandy Creek from the Colorado River and in the long-term be introduced to Lake Texana by natural downstream movement or by floods.

As previously discussed, the potential for establishment in Sandy Creek is low because of its intolerance to high water temperatures (25-30°C) which occur in Sandy Creek during the summer (McMahon 1983; Armstrong et al. 1986; Gandara et al. 1995). If successfully transferred by floods into Lake Texana, the potential for establishment is low to moderate. Extensive noxious aquatic macrophyte communities, however, could be expected to hinder the establishment of the Asiatic clam in shallow littoral areas of Lake Texana (Howells 1995c).

Overall, significant effects would not be expected to occur from the potential transfer of most benthic macroinvertebrates. Based on these analyses, a " low to moderate potential impact rating" was assigned for benthic invertebrates.

4.2.2.7 Amphibians and Reptiles

Most of the amphibians and reptiles which potentially occur in Lake Texana would inhabit semiaquatic habitats along the edge of the lake or aquatic vegetated habitats in shallow bays of the littoral zone at Lake Texana. Some reptiles (e.g., common snapping turtle) may utilize deep water areas of the lake. Since the potential transfer, survival, and establishment of amphibians/reptiles from the Colorado River to Sandy Creek would not occur, transfer and establishment would not occur in Lake Texana. Therefore "a no effect rating" was assigned for amphibians and reptiles.

4.2.2.8 Fish

One fish species, logperch, has a moderate chance of being transferred from the Colorado River via Sandy Creek to Lake Texana either through establishment in Sandy Creek or by flood events. Habitat is present for this species in Lake Texana. This species is adaptable to a variety of environmental conditions and have a moderate long-term potential for survival/establishment in Lake Texana. If it becomes established, this species could cause population declines in native cyprinid and centrarchid populations, thereby altering the balance of the fish community in Lake Texana.

A "moderate potential impact rating" was assigned to fish because of the potential for establishment of a single fish species in Lake Texana. Impacts from the transfer of fish pathogens from the Colorado River via Sandy Creek cannot be assessed because of the lack of occurrence/infestation data for fish pathogens in the Colorado River. If non-native parasites become established due to the transfer, they could present significant long-term problems for the affected species in Lake Texana.

4.2.3 Summary

Two components of the aquatic environment would potentially be affected by the interbasin transfer of water from the Colorado River/Sandy Creek to Lake Texana. Low to moderate potential impacts could occur to benthic communities in Lake Texana from the potential introduction of the Asiatic clam. Moderate long-term impacts could occur to the fish community if two adaptable fish species present in the Colorado River basin are transferred and subsequently become established in Lake Texana. Other components of the aquatic environment would experience unknown or no significant effects from the proposed interbasin water transfer. Potential impacts are summarized in Table III-45.

4.3 Lake Texana to the O.N. Stevens Terminal Water Storage Reservoir

4.3.1 Abiotic Environment

Potential impacts to the abiotic environment of Lake Texana as a result of the proposed interbasin transfer of water from the Colorado River via Sandy Creek have been previously discussed in Section 4.2. In summary, no significant negative impacts to the abiotic environment of Lake Texana are expected from the proposed interbasin water transfer from the Colorado River to Lake Texana.

4.3.1.1 Hydrology

Local hydrologic changes would occur near the intake structure at Lake Texana. Water withdrawal would cause local currents to develop in the vicinity of the intake structure. Depending on the design of the intake, the current would potentially affect various levels (surface, mid-depth, bottom) of the water column.

Hydrologic flow patterns would not change in the terminal water storage reservoir at the O.N. Stevens Water Treatment Plant since current inflow and outflow structures would be used for the water transfer to the treatment system. Retention time in the storage reservoir would decrease and flushing of the

Table III-45

Qualitative Rank of Potential Environmental Impacts
Sandy Creek to Lake Texana

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	No significant increase in density	Low
Other Microbes	Unknown	No presence/absence data	High
Phytoplankton	Low	Potential for bloom after flood; slight increase in BOD due to bloom die-off after transfer from new channel reservoir on the Colorado River	Moderate
Periphyton	No Effect	Periphyton has low potential for transfer and/or survival if successfully transferred due to differences in habitat between Sandy Creek and Lake Texana	Low
Aquatic Plants	No Effect	Noxious aquatic plants not present in Colorado River/Sandy Creek	Low
Zooplankton	No Effect	Potential for survival is low due to differences in habitat between the Colorado River/Sandy Creek and Lake Texana	Low
Benthic Invertebrates			
Mollusks	Low	Potential introduciton of the Asiatic clam	Moderate
Other	Moderate	No site-specific data	High
Amphibians/Reptiles	No Effect	No transfer, survival, or establishment expected	Low
Fish	Moderate	Potential establishment of two fish species; unknown effects from fish pathogens	Moderate

system would be constant, since the proposed inflow would be continuous. Therefore, the water level in the terminal water storage reservoir would have to be managed carefully to prevent potential overflow and overflow-related problems.

4.3.1.2 Habitat Alteration

Local habitat alteration would occur in Lake Texana during the construction of the intake structure. Shoreline habitat may decrease temporarily if water levels are lowered in the lake to complete the construction of the intake. Depending on the engineering design, the construction would potentially disturb and possibly result in changes in the substrate. Scouring effects could occur on the bottom of Lake Texana depending on the location of the intake in the water column and the withdrawal rate of the water.

4.3.1.3 Physicochemical Characteristics

Water quality parameters may change due to construction and operational disturbances at the intake site. Construction activities may disturb the bottom and result in suspension of nutrients, increases in turbidity, and changes in concentrations in other chemical parameters.

Water quality in Lake Texana is generally satisfactory. The most important water quality concerns within Lake Texana are potentially undesirable levels of nutrients and herbicides in return flows from rice irrigation, the threat of surface water pollution from spills and illegal dumping of petroleum wastes, especially oil field brine, and periodically low levels of dissolved oxygen in the bottom layers (TWC 1992a).

The O.N. Stevens Water Treatment Plant currently obtains water from the Nueces River Basin. The quality of water within this basin is good. Potential areas of concern in the basin are fecal coliforms, dissolved oxygen, and copper concentrations (TWC 1992a). From below Lake Corpus Christi to the Calallen Dam (Segment 2102), fecal coliform levels in the Nueces River have exceeded the criterion for contact recreation (18 out of 99 times), thus, this segment is ranked as partially supporting for contact recreation. The maximum fecal coliform level was 2,590 colonies/100 mℓ and the minimum was 1 colony/100 mℓ. Elevated levels of orthophosphorus also exist in this segment (TNRCC 1994b).

4.3.2 Biotic Environment

Potential aquatic biological impacts to the donor system (i.e., Lake Texana) and the recipient system (i.e., O.N. Stevens Water Treatment Plant) are discussed in this section. Based on the analysis of potential environmental impacts, a qualitative potential impact rating (i.e., low, moderate, high, unknown, or no effect) is subsequently assigned to each component of the aquatic environment.

4.3.2.1 Microbes

Fecal coliforms (colonies per 100 mℓ) reported for Segment 1604 (Lake Texana) from January 1989 through December 1992 were well below the screening level of 400 colonies/100 mℓ. Levels of fecal coliforms ranged from a minimum of 3 colonies/100 mℓ, with a mean of 31 colonies/100 mℓ, to a maximum of 286 colonies/100 mℓ from 13 samples (TNRCC 1994b). Since fecal coliform levels are consistently low, a "no effect rating" was assigned for fecal coliforms.

The potential also exists for the transfer of other microbes (excluding heterotrophic microorganisms) to the O.N. Stevens Water Treatment Plant from the proposed interbasin water transfer. Some microbes are pathogenic, either producing diseases directly through infection or producing toxins which bring on illness, paralysis, or death. *Cryptosporidium parvum*, along with *Microsporidium* and *Giardia lambia* are important emerging microbial threats to the general human population, especially to high-risk groups (i.e., individuals with suppressed immune systems; malnourished infants) (Lederberg et al. 1992).

The *Cryptosporidium* parasite is widespread in the environment and has been found in animal (i.e., cattle, sheep, dogs, deer, foxes) and human waste (Bellamy et al. 1993). High concentrations have been reported in raw sewage (up to 14,000 oocysts per liter [oocysts/ℓ]) and treated sewage (up to 4,000 oocysts/ℓ) (Pontius 1993). Oocysts have also been found in rivers, streams, lakes, and reservoirs with the highest concentrations occurring during the spring and summer and during periods of high rainfall (Ongerth and Stibbs 1987; Rose 1988; LeChevallier et al. 1991a). Although treatment and filtration of water lowers the numbers of water-borne organisms, *C. parvum* oocysts can often be found in low levels in treated drinking water (LeChevallier et al. 1991b). *Cryptosporidium* oocysts are not killed by disinfectants and/or chlorination, and can survive for 18 months in a moist environment. The lesser known *Microsporidium* also produces similar chronic gastroenteritis in immunosuppressed individuals.

Spores of this species can survive up to four months in the environment. Control and prevention of *Microsporidium* is unknown at this time, whereas effective water treatment (e.g., flocculation, sedimentation, filtering - one micron porosity pressure filter, turbidity goal of 0.1 Nephelometric Turbidity Units [NTU]) can control *Cryptosporidium*. Additional protection is offered when ozone is used as a disinfectant (American Water Works Association [AWWA] 1994a; Fox 1994; DuPont et al. 1995). Water officials in Texas urban areas (i.e., Dallas, Houston, Austin) routinely check for *Cryptosporidium*, but not *Microsporidium* (Mitchell 1995).

Giardia lambia, a flagellated protozoan, is found in animal populations (i.e., beavers [*Castor canadensis*], nutria [*Myocastor coypus*]), and can also produce gastrointestinal problems in human populations. In the past two decades, there have been more than 95 outbreaks of waterborne giardiasis in the United States. *Giardia* oocysts are known to survive at a pumping station along the Central Arizona Project (CAP) canal in Arizona and in springs at Uvalde, Texas (DeCook and Waterstone 1987; Dallas Morning News 1995a; Mitchell 1995). *Giardia* oocysts are capable of surviving in water supply systems. Treatment for *Giardia* involves properly functioning conventional rapid sand filters in addition to effective pretreatment by coagulation, flocculation, and settling (Bergan et al. n.d.; Ampy and Gupta 1988; Lederberg et al. 1992; Fox 1994; DuPont et al. 1995; Mitchell 1995).

The majority of organisms associated with outbreaks of waterborne disease are monitored and controlled by water-purification plants. However, recent contamination of municipal water sources (i.e., Milwaukee, Wisconsin; Oxfordshire, Scotland) has resulted in large community outbreaks of cryptosporidiosis (*Cryptosporidium*) even when the quality of the water met water treatment standards. *Cryptosporidium* has been found in approximately 95 percent of the surface waters in the United States. It is present in water treatment facilities in urban areas (e.g., Las Vegas, Nevada; Phoenix and Mesa, Arizona), surface water supplies (e.g., Verde and Salt rivers, Oak Creek, Arizona), rural areas (Carollton; Georgia; Jackson County, Oregon), and near the intake of the CAP at Lake Havasu, Arizona (Moore et al. 1994; Dallas Morning News 1995b). *Cryptosporidium* has been detected in untreated waters in Texas, such as the Bosque River above Lake Waco in 1993, a dairy farming community, and in the Dallas area. The apparent *Cryptosporidium* outbreak in 1984 in the groundwater at Braun Station, a suburb of San Antonio, was attributed to the Norwalk virus (Pontius 1993; Mitchell 1995).

As a result of these concerns, a new and expensive monitoring program began in approximately 2,000 communities around the United States in October 1994, under the Information Collection Rule (ICR), developed by the Disinfectants/Disinfection Byproducts Rule (D/DBPR) negotiated rulemaking committee of the USEPA. The ICR is intended to provide surface water treatment to determine the level of and criteria for Enhanced Surface Water Treatment Rule (ESWTR) in order to prevent increased microbial risk as a result of the proposed D/DBPR. In addition, the AWWA has also developed a 12-point plan to protect the public from the threat of *Cryptosporidium* in drinking water (AWWA 1994b; Bingham and Langstaff 1994).

The ICR will require systems that serve populations greater than 100,000 to conduct monitoring for *Giardia*, *Cryptosporidium*, enteroviruses, total coliforms, and fecal coliforms or *Escheria coli* on a monthly basis at the intake of each plant. When a concentration of one or more pathogens per liter is detected in the source water during the first 12 months, finished water must also be monitored for all five parameters. For systems serving 10,000 to 100,000, monitoring for *Giardia*, *Cryptosporidium*, enteroviruses, total coliforms, and fecal coliforms or *Escheria coli* in the source water only must be conducted once every two months for one year. Systems serving fewer than 10,000 will be required to provide treatment data concerning pre-sedimentation processes, clarification/sedimentation processes, filtration processes, and disinfection processes. Some surface water systems serving greater than 100,000 must complete bench- or pilot-scale studies of disinfection byproduct precursor removal by activated carbon or membranes by September 1995. These data, in addition to concurrent health effects and technology research, will be used to develop Stage 2 of the D/DBPR and the ESWTR (USEPA 1994a).

Under the proposed two-stage D/DBPR, communities would be required to meet new standards for disinfectants and disinfection by-products. The proposed Stage 1 D/DBPR would lower the existing maximum contaminant level (MCL) for total trihalomethanes from 0.10 mg/ℓ-0.080 mg/ℓ and extend the MCL to all system sizes, establish six new MCLs and maximum residual disinfection levels (MRDL), and require enhanced coagulation or enhanced precipitative softening for certain systems. Stage 2 will incorporate ICR data and new research data. In addition, the proposed Stage 1 would require systems using surface water and conventional filtration to meet a treatment technique for removal of disinfection by-product precursors (compounds that react with disinfectants to form DBPs) measured as percent removal of total organic carbon, unless they meet specified avoidance criteria (USEPA 1994a, 1994b).

The proposed Interim ESWTR will include options to be refined based on ICR microbial data. Generally, these include: (1) requiring surface water systems with poorer quality source waters remove microbiological contaminants above the levels currently required by the Surface Water Treatment Rule (SWTR) of 99.9 percent for *Giardia* and 99.9 percent for viruses; and (2) making no changes if the current SWTR is determined adequate. In addition, the systems will be subject to sanitary surveys every five years and may be required to treat for *Cryptosporidium*. A long-term ESWTR will be developed for systems serving less than 10,000 and may include revisions to the interim ESWTR for systems greater than 10,000 (USEPA 1994a, 1994b).

Heterotrophic microorganisms could also increase BOD levels depending on the abundance or density of decomposing organisms transported within the 104-mi enclosed pipeline, and subsequently result in water taste/odor problems. The transfer water could contain dormant oocysts of the protozoan parasite *Cryptosporidium*, and, other waterborne diseases which could potentially be transferred to the water treatment plant. A "low to moderate potential impact rating" from other microbes was assigned based on the potential increase in BOD from microbial populations and the potential presence of a protozoan parasite.

4.3.2.2 Phytoplankton

Local changes in phytoplankton composition and abundance near the intake site at Lake Texana could occur as a result of construction and operational activities. An increase in turbidity from construction or scouring of the bottom from the intake current could shade phytoplankton communities and cause local decreases in population densities. Suspension of nutrients from these activities could result in temporary local population increases, if turbidity is not a limiting factor. These changes would only be local and would not significantly impact the phytoplankton community in Lake Texana.

Taste/odor problems could also result from the transfer of blue-green algae to the O.N. Stevens Terminal Water Storage Reservoir. Blue-green algae are among the major groups in Lake Texana which could cause taste and odor problems. Using Palmer's list (1962) and index (1969) to estimate the degree of taste and odor, it was observed that Station 8 in July and October and Station 9 in October could cause severe taste and odor problems. These stations which are near the proposed intake structure were dominated by *Oscillatoria subtlissima*. According to Palmer (1964), filamentous algae (e.g., *Oscillatoria*) produced taste and odor problems when counts reached 850 or more cells/mℓ. In August and October 1981, the population densities of *Oscillatoria* were 8,712 cells/ml and 6,263 cells/ml, respectively, in Lake Texana. Therefore, taste and odor problems could occur during August and October (Maeng 1983).

Based on this data, the water transferred from Lake Texana could potentially have increased taste and odor problems during the summer and fall months. High population densities of blue-green algae can also cause gastrointestinal, respiratory, and dermatologic problems in humans, ichthyosarcotoxicosis in fish and acute liver toxicosis/rapid neurotoxicosis in wild/domestic animal populations (Schwimmer and Schwimmer 1964, 1968; Gorham and Carmichael 1988; Carmichael 1992). *Oscillatoria*, the dominant species in Lake Texana during the summer and fall, has also been reported as causing taste and odor problems as well as corrosion in steel (Palmer 1964) and concrete equipment (van Zon 1982). A "low to moderate potential impact rating" was assigned to phytoplankton based on the potential increase in taste and odor problems during algal blooms and possible long-term structural damage to the intake pumps and pipeline.

4.3.2.3 Periphyton

Construction and operational activities would potentially influence the periphyton community at and in the vicinity of the intake site in Lake Texana. Temporary local and/or permanent changes in the substrate, current, and water quality would occur. Depending on the magnitude of these changes, the local periphyton community could be altered permanently or seasonally. An "unknown rating" was assigned to periphyton due to the absence of site-specific data for Lake Texana. However, some periphyton (i.e., benthic algal communities) would be present in the phytoplankton community as individual cells that were displaced due to natural perpetrations (e.g., heavy rains, wave action, etc.) (Hutchinson 1975). These cells would occur in the transfer water and could potentially add to the BOD levels, and subsequently, result in water taste and/or odor problems.

4.3.2.4 Aquatic Plants

The negative impacts associated with aquatic plants can be divided into direct and indirect impacts. The direct impacts include: (1) impeding transport of irrigation and drainage water in canals and ditches; (2) hindering navigation; (3) interfering with hydroelectric schemes; (4) increasing sedimentation by trapping silt particles; (5) decreasing human food production in aquatic habitats (e.g., fisheries, crops); (6) decreasing the possibilities for human hygiene (washing and bathing); and (7) adversely affecting recreation (e.g., swimming, waterskiing, angling). Indirect negative impacts from aquatic plants include: (1) water loss by means of evapotranspiration (transpiration via plants) and (2) an increase of health hazards by the formation of habitats which are favorable for the development of vectors of human diseases, such as malaria and schistosomiasis (bilharzia) (Pieterse and Murphy 1990).

Hydrilla and water hyacinth could be transferred from Lake Texana and become established in the terminal water storage reservoir. The floating water hyacinth and hydrilla are listed as harmful or potentially harmful aquatic plants by the State of Texas and are essentially the primary colonizers of the aquatic ecosystem (Howells 1992). These plants are restricted as follows: water hyacinth - blocks navigation, limits water access and recreation, shades and competes with more desirable aquatic plants, provides more habitat for mosquitos, and increases water loss from the system through transpiration; and hydrilla - tolerates low light and salinity, and grows so rapidly that it crowds or shades more desirable aquatic plants. Vegetative reproduction is the principal method by which floating aquatic weeds over-winter and colonize new locations, and submerged aquatic plants regrow and infest new areas. Water hyacinth produces many ramets or daughter plants from meristematic areas on rhizomes of parent plants. The new ramets in turn can produce additional ramets throughout the growing season. These floating weeds can double the number of ramets every three to 10 days under optimal growth conditions. Although vegetative reproduction is most important in water hyacinth, seeds are produced which remain viable for five to seven years, and possibly up to 15 years. The most prevalent method of dispersal in hydrilla is fragmentation, in which small fragments of two or more nodes of allochthonous or autochthonous origin are carried by wind, water, animals, or humans into an uninfected area. If conditions and substrate are appropriate, the fragments produce roots and become established in the new area. In addition to fragmentation, hydrilla also reproduces by seeds, turions (winter buds), or from stolons and rhizomes (Spencer and Bowes 1990; van Vierssen 1990; Joye and Cofrancesco 1991).

The potential for hydrilla and water hyacinth to be transferred from Lake Texana to the terminal water storage reservoir adjacent to the O.N. Stevens Water Treatment Plant would depend upon the removal/fragmentation of their reproductive structures from the littoral population into the open-water zone by natural perpetrations (i.e., windstorms, heavy rains, etc.). The potential for these species to survive the 104-mi enclosed pipeline is relatively high due their tolerance of adverse conditions (especially hydrilla).

A "moderate potential impact rating" was assigned to aquatic plants based on the potential establishment of two state-prohibited nuisance aquatic plants (Howells 1992). Various reproductive structures of both water hyacinth and hydrilla could survive the 104-mi enclosed pipeline transfer due to their ability (especially hydrilla) to withstand unfavorable conditions. If the essential nutrients and habitat are available to promote growth, one or both of these species could potentially cover the surface area of the terminal water storage reservoir and eventually could cause clogging of the intake structure of the water treatment plant.

4.3.2.5 Zooplankton

The "unknown rating" assigned to zooplankton was based on the absence of site-specific data for Lake Texana. However, the pelagic forms of zooplankton expected to be found in Lake Texana, such as rotifers, nauplii, microcrustaceans (i.e., postnaupliar free-living copepods and cladocerans), and protozoans (Pennak 1957), would be found in the transfer water and could potentially add to the BOD level of water transferred to the terminal water storage reservoir.

4.3.2.6 Benthic Macroinvertebrates

If the intake structure is designed to remove water from either the surface or mid-depth, most benthic organisms, with the exception of phantom midge (*Chaoborus*) and emerging aquatic insects (e.g., burrowing mayfly), would not be present in the water diverted from Lake Texana. Phantom midge larvae are nekobenthic organisms which migrate from the bottom toward the surface at night to feed on plankton. Phantom midge fly larvae and emerging aquatic insects could potentially be transported from Lake Texana to the terminal water storage reservoir. Death during the transfer or at the terminal water storage reservoir could result in an increase in the BOD level. Other life stages (eggs, juveniles) could survive. Since the terminal water storage reservoir is not a natural habitat, introduction would probably not result in establishment of benthic macroinvertebrates.

If the intake flow is withdrawn from near the bottom of the water column, the effects to benthic macroinvertebrates would potentially be greater. The bottom would initially be scoured by the current during the withdrawal. This would result in the temporary suspension and subsequent impingement/entrainment and transport of an unknown density of benthic organisms. The magnitude of this effect would depend on the velocity of the withdrawal and the composition and abundance of benthic macroinvertebrates at and in the vicinity of the intake. A "low potential impact rating" was assigned to benthic invertebrates based on the assumption that withdrawal would occur either at the surface or mid-depth and would, therefore, not disturb the benthic community in Lake Texana or result in a significant increase in the BOD level at the terminal water storage reservoir.

4.3.2.7 Amphibians/Reptiles

Amphibians and reptiles are not expected to occur in open, deep waters (18 ft) near the proposed site for the intake structure at the Palmetto Bend Dam on Lake Texana. Therefore, amphibians and reptiles would not be affected by the proposed operation of the intake structure. A "no effect rating" was assigned to amphibians and reptiles since transfer to the terminal water storage reservoir is unlikely.

4.3.2.8 Fish

Construction and operational impacts would potentially occur to the fish population in Lake Texana. Fish nesting success would potentially decrease for a variety of shallow water spawners (especially minnows and sunfishes) since suitable spawning habitat may not be available if the water level is lowered for construction of the intake during the spawning season. Withdrawal operations during the water transfer would potentially affect populations of pelagic fish due to impingement and/or entrainment. The operation of the water transfer would also potentially impact egg, larval, juvenile, and some small adult phases of native fishes in the donor basin (Lake Texana) into the conduit system (the pipeline). The transfer may result in mortality due to abrasion/collision, velocity changes, turbulence, and sheer stress from pumping, impingement on screens, or entrainment (Miracle and Gardner 1979; Cada 1990). Cambray and Jubb (1977) reported damage from pressure (70 meter [m] static head), irrespective of age, when fish were transferred through the "pepper-pot valves" in the Orange-Fish Tunnel, South Africa.

Several pelagic fish species would be expected to occur at or in the vicinity of the proposed intake structure on Lake Texana. Gizzard shad, threadfin shad (*Dorosoma pretense*), white bass (*Morone chrysops*), and possibly striped bass (*Morone saxatilis*) could be impinged or entrained during the proposed water transfer. Larval and juvenile life stages would potentially be affected more than adults due to their lack of mobility. The impact on these fish populations in Lake Texana would depend on: (1) abundance of each species in the vicinity of the intake; (2) day/night depth distribution of the species; (3) design of the intake structure (i.e., surface, mid-depth, or bottom withdrawal); (4) area affected around the intake structure; (5) hours of operation (24 hours versus 12 daylight hours); and (6) variable abiotic factors which would affect the depth distribution of the species. If significant, impingement and/or entrainment could reduce survival and recruitment of pelagic fish populations in Lake Texana. If not impinged, gizzard or threadfin shad would have a very low chance of surviving the transfer due to their sensitivity to environmental changes (Robison and Buchanan 1992). If either white or striped bass survive, the potential that they would become established is not likely due to the absence of suitable habitat in the terminal water storage reservoir. Therefore, the aquatic environment at the terminal water storage reservoir would not be directly affected by the potential transfer of fish from Lake Texana. Death during impingement has the potential for increasing the BOD levels at the terminal water storage reservoir and could indirectly affect water quality (i.e., taste and odor).

A "moderate potential impact rating" was assigned to fish populations due to the potential effects from impingement and/or entrainment of fish in the intake structure at Lake Texana and potential subsequent increases in BOD at the terminal water storage reservoir.

4.3.3 Summary

Four components of the aquatic environment could potentially be affected or could impact the conduit system and/or operations at the O.N. Stevens Water Treatment Plant due to the proposed interbasin transfer of water from Lake Texana to the terminal water storage reservoir. Low to moderate impacts could potentially occur from the transfer of microbes, phytoplankton, aquatic plants, and fish. The transfer of microbes could introduce a protozoan parasite into water used for human consumption. Taste/odor problems could result from the water transfer during blue-green algal blooms. Two noxious plants present in Lake Texana could become established in the terminal water storage reservoir and result in clogging problems. Pelagic fish populations could be impinged and/or entrained, thereby potentially reducing survival, recruitment, and population size. In addition, the death of all of these components during transfer would potentially increase BOD levels at the treatment plant. The potential impacts on the other aquatic components are either rated or ranked as unknown, or no effect, or low. Potential aquatic environmental impacts are summarized in Table III-46.

5.0 SUMMARY

In general, the open segments of the proposed interbasin water transfer (i.e., Colorado River to Sandy Creek transfer segment) would be expected to have a higher potential for significant impacts because of the lack of controls to prevent potential introduction, and establishment of introduced native fishes (Table III-47), and federal candidate/state threatened/TOES species and exotic aquatic organisms (Table III-48). The closed segment of the transfer (i.e., Lake Texana to the O.N. Stevens Terminal Water Storage Reservoir) would probably result in a lower potential for significant impacts since engineering/ environmental controls can often be utilized to lessen or mitigate impacts.

Based on the abiotic and biotic data available, several potential impacts to or from aquatic components of the ecosystems involved in the proposed transfer were identified. An environmental assessment which evaluates potential site-specific impacts is needed to determine if the potential impacts would significantly affect the aquatic environment of the study area.

6.0 RECOMMENDATIONS AND MITIGATIONS

6.1 Recommendations

6.1.1 Colorado River to Sandy Creek

- Conduct an aquatic environmental assessment to determine the potential impacts of the proposed Colorado River to Sandy Creek transfer

As discussed in the previous section on impacts, potentially significant impacts could occur to the benthic community in Sandy Creek due to the increase in current flow and the potential introduction of the non-native Asiatic clam. The environmental assessment should establish baseline benthic data for the

Table III-46

Qualitative Rank of Potential Environmental Impacts
Sandy Creek to Lake Texana

Environmental Component	Impact Rank	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	No Effect	Coliform densities below criteria level in Lake Texana	Low
Other Microbes	Low-Moderate	Potential presence of a protozoan parasite, *Cryptosporidium parvum*	High
Phytoplankton	Low-Moderate	Potential taste/odor problems from blue-green algal blooms; potential long-term structural damage to pumps/pipeline	Moderate
Periphyton	Unknown	Absense of site-specific data	Not Applicable
Aquatic Plants	Moderate	Potential establishment of two state-listed noxious plant species (water hyacinth and hydrilla) at the terminal water storage reservoir; potential clogging of water intake at the treatment plant	Moderate
Zooplankton	Unknown	Absense of site-specific data	Not Applicable
Benthic Invertebrates	Low	Transfer potential low if intake is located at surface or mid-depth	Moderate
Amphibians/Reptiles	No Effect	Habitat does not exist at intake site	Low
Fish	Moderate	Impingement/entrainment at intake and potential reduction in survival/recruitment of pelagic species; increase in BOD due to impingement	Moderate

Table III-47

List of Fish Species with the Potential to be Introduced by the Proposed Interbasin Water Transfer from the Colorado River to the Lavaca-Navidad River Basin

Taxa	Colorado	Lavaca-Navidad*	Transfer
BOWFINS			
Bowfin	N		No
HERRINGS			
Skipjack herring	N		No
Gizzard shad	N[0]	N[1]	Yes[2]
CARPS/MINNOWS			
Grass carp		I[+1]	No
Ribbon shiner	N		No
Silverband shiner	N		No
Suckermouth minnow	N[0]		Yes[2]
SUCKERS			
Blue sucker	N[0]	N	Yes[3]
SUNFISHES			
Guadalupe bass	N[0]	N	Yes[3]
PERCHES			
Logperch	N[0]		Yes[4]
CICHLIDS			
Rio Grande cichlid	I	I	NA[5]
Blue tilapia	I	I	NA[5]

[+]Triploid
*Includes species in Sandy Creek and Lake Texana
[0] Fishes collected in the Egypt Study reach (intake area) of the Colorado River
[1]Lake Texana
[2]Low to moderate potential for establishment
[3]Unlikely to become established; maybe affected by construction/transfer
[4]Moderate to high potential for establishment
[5]Occurs only below proposed intake area

Legend: N = Native
I = Introduced
NA = Not Applicable

Source: USDI 1974; Conner and Suttkus 1986; Hubbs et al. 1991; Robbins et al. 1991; Morales 1991; Bayer et al. 1992; Mosier and Ray 1992; Patek 1994; Chilton 1995; Jons 1995

Table III-48

List of Aquatic Federal/State/TOES Threatened, Candidate, and Watch List and Exotic Species Potentially Occurring in the Colorado/Lavaca-Navidad River Basins

		Lavaca-Navidad	
Common/Scientific Name	Colorado	Sandy Creek	Lake Texana
REPTILES			
American alligator			
Alligator mississippiensis	TWL		
FISH			
Blue sucker[1]			
Cycleptus elongatus	C2,ST,TWL		
Guadalupe bass[1]			
Micropterus treculi	C2,TWL		
EXOTIC SHELLFISH			
Asiatic clam[1]			
Corbicula fluminea	X		
EXOTIC FISH			
Blue tilapia			
Tilapia aurea	X		
Rio Grande cichlid			
Cichlasoma cyanoguttatum	X		

[1]Known to occur in the reach where the intake site is proposed to be constructed

Legend: C2 = Candidate Category 2
TWL = TOES Watch List
ST = State Threatened
X = Exotic

Source: McMahon 1983; Hubbs et al. 1991; TOES 1995; TPWD 1995a, 1995b; USFWS 1995b, 1995c

Colorado River and Sandy Creek and subsequently assess if: (1) the Asiatic clam could potentially clog the intake structure; (2) the introduction of the Asiatic clam to Sandy Creek could result in a significant negative impact to aquatic communities in Sandy Creek; and (3) the potential changes (i.e., current flow rate, etc.) resulting from the interbasin water transfer could benefit or negatively impact the benthic community and associated aquatic communities in Sandy Creek.

Effects on amphibian and reptile populations which utilize Sandy Creek should also be assessed since changes in hydrology (i.e., current flow rate) could result in a decrease in suitable breeding habitat (e.g., loss of intermittent pools). The blue sucker (state-listed threatened species) and the Guadalupe bass (federal C2 and TOES "watch list" species) could be affected by the proposed project if: (1) the low head dam/new channel reservoir and intake structure is constructed at a location currently being utilized as a nursery area for juvenile and/or subadult blue sucker/Guadalupe bass, and/or (2) results in the transfer and/or mortality of larval or juvenile blue sucker/Guadalupe bass from suitable breeding/nursery habitat in the Colorado River to unsuitable breeding/nursery habitat in Sandy Creek (i.e., potential reduction in the recruitment to the Colorado River blue sucker/Guadalupe bass populations). In addition, several Colorado River fish species which are not present in Sandy Creek could be transferred to and become established in Sandy Creek. This may affect the existing fish community in Sandy Creek and potentially, through time and/or physical effects (i.e., flooding), Lake Texana.

In addition, only limited information is available on the composition and abundance of aquatic communities in Sandy Creek or from the proposed location of the new channel reservoir/intake site on the Colorado River. Aquatic biological field surveys are needed to provide, at a minimum, biological data of sufficient detail and quality to allow accurate analysis of the potential effects from the proposed interbasin water transfer.

The field survey methodology for determining potential impacts on aquatic communities in the Colorado River and Sandy Creek should be designed to provide sufficient data for the assessment of all of the previously identified environmental issues. A minimum of five transects with at least three sampling points per transect should be established on the Colorado River and Sandy Creek. One transect should be at the intake/outflow location. Two transects above and two transects below the intake/outflow structure should be established in order to determine the potential from drift (benthos) and upstream movements of fish.

The field survey methodology to determine the presence or absence of the blue sucker at or in the vicinity of the proposed intake site on the Colorado River will have to be carefully designed since blue sucker larvae, juveniles, and at times adults are difficult to collect even where they are relatively common (Kay et al. 1994). It should be noted that larval fish light traps have been successful in collecting hard-to-capture species (Snyder 1995; Tyberghein 1995). Although other ichthyoplankton sampling gear should be evaluated and subsequently used during the study, larval fish light traps deserve strong consideration during the sampling design phase of the project.

Meador (1992) recommended a series of pre-operational/post-operational environmental assessments and studies to evaluate potential impacts, develop mitigations, and monitor the effects of interbasin water transfers (Figure III-9). These recommendations should be reviewed and considered when the environmental assessment for the proposed transfer is being planned.

- Conduct extensive site-specific water quality tests

Although water quality of the Egypt Reach of the Colorado River (Segment 1402) meets all state standards, water quality at the proposed intake site is currently unknown. Water quality surveys are needed to determine if potential water quality problems exist at the proposed intake site.

6.1.2 Lake Texana to O.N. Stevens Terminal Water Storage Reservoir

- Conduct a monitoring program to determine if *Cryptosporidium* is present in the Nueces River and Lake Texana waters

The ICR, developed by the D/DBPR negotiated rulemaking committee of the USEPA, could determine if *Cryptosporidium* was present in either of the two source waters (e.g., Nueces River and Lake Texana) which would supply water to the treatment plant. This rule is intended to provide and determine the level of and criteria for enhanced surface water treatment to prevent increased microbial risk as a result of D/DBPR. The ICR will require systems serving populations greater than 100,000 (i.e., Corpus Christi - 364,314; Ramos 1995) to conduct monitoring for not only *Cryptosporidium*, but also for *Giardia*, enteroviruses, total coliforms, fecal coliforms, or *Escheria coli*, on a monthly basis at the intake of the plant. When a concentration of one or more pathogens per liter in the source water during the first 12

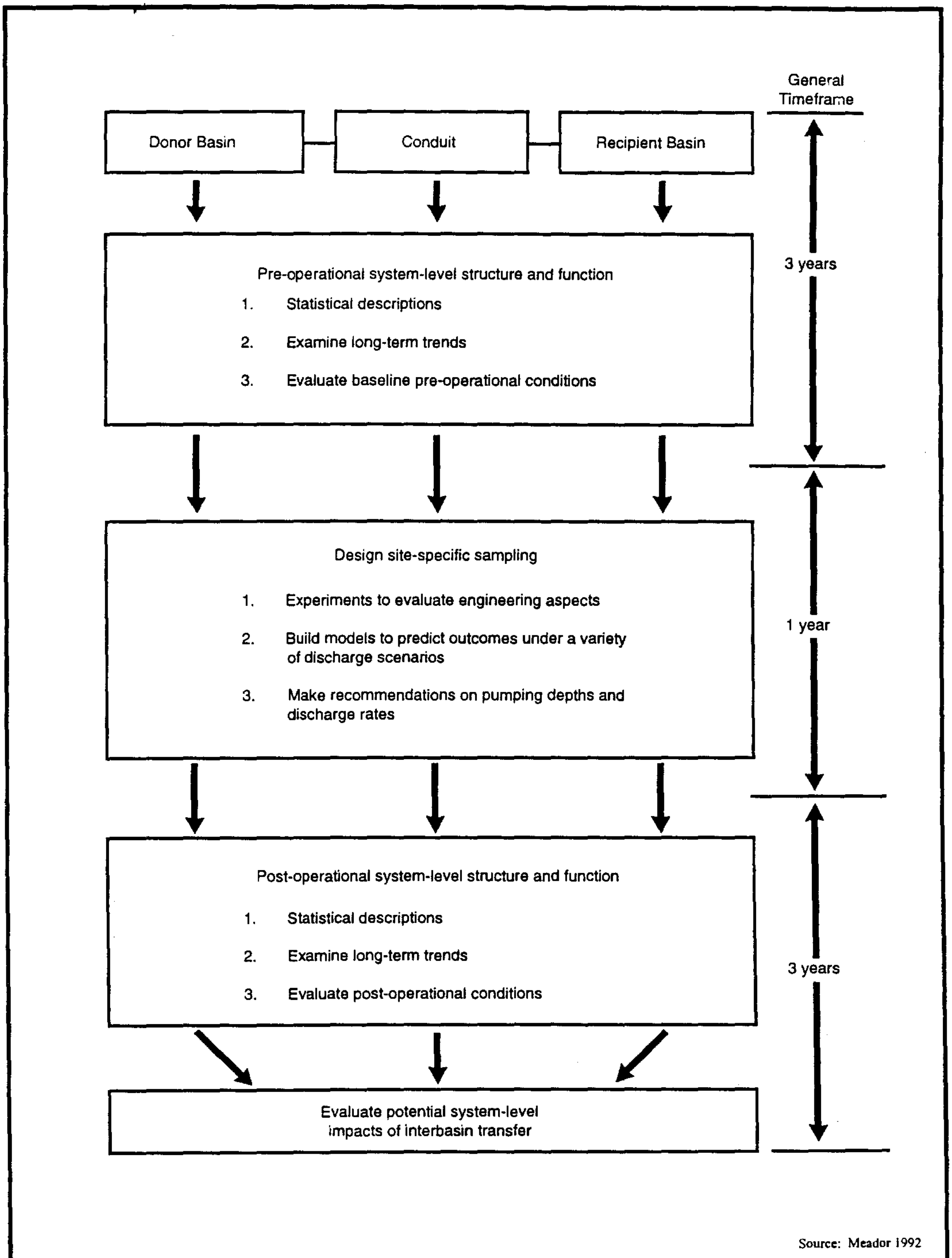


Figure III-9. Recommendations for Pre-operational/Post-operational Environmental Assessments for Interbasin Water Transfers.

months is found, finished water must also be monitored for all five parameters. The AWWA also advises water utilities to adopt its 12-Point Plan to safeguard consumers against illness from *Cryptosporidium* (Bingham and Langstaff 1994).

- Conduct an environmental study to determine the potential effects of intake operational effects on pelagic fish populations in Lake Texana

This study should be designed to determine potential impacts on the fish populations in Lake Texana and to develop mitigations, if necessary, to ensure that no significant effects to the fish community would occur as a result of the proposed interbasin water transfer.

- Conduct extensive site-specific water quality tests

Lake Texana (Segment 1604) has had several recent exceedances of screening levels. Extensive water quality tests should be conducted at and in the vicinity of the proposed intake site (surface, mid-depth, and bottom) to determine if any potential water quality problems exist.

6.2 Mitigations

Specific engineering/environmental mitigations for the proposed interbasin water transfer are discussed in this sub-section. Mitigations for the open/closed segments of the transfer including the new channel reservoir (i.e., Colorado River to Sandy Creek; Sandy Creek to Lake Texana) are:

- If necessary, treat the new channel reservoir with algicides prior to or during pumping to prevent long-term damage to pumps from algae
- If the Asiatic clam is present, schedule periodic 30-day water level drawdowns (initial design must allow concurrent operation) or design the new channel reservoir with steep sides to limit its establishment
- Design the intake structure to impinge a minimal number of fish utilizing surface to mid-water withdrawal, horizontal screens, and deflectors
- Use a series of progressively smaller screens to help eliminate the transfer of aquatic organisms (if engineering alternatives are feasible)

Mitigations for the closed segment of the transfer (e.g., pipelines) include:

- Use materials in pipelines (e.g., mortar lining) which will resist damage from aquatic organisms (e.g., algae, bacteria)
- If necessary, use algicides inside the dam intake structure and/or in the terminal water storage reservoir prior to water withdrawal to prevent algal taste/odor problems
- Use screens with mesh size of less than 0.08 centimeters (cm), remove shells manually, use mechanical traps, and/or periodically chlorinate at the intake site to control problems with the Asiatic clam
- Develop surface/mid-depth intake structures which will minimize impingement of fish
- Design and plan to use horizontal screens in the intake structure to reduce fish impingement
- Use bar screens (one inch diameter) to prevent entrainment of fish
- Schedule any lake drawdowns associated with the construction of the intake structure on the Palmetto Bend Dam during winter to lessen potential impacts on spawning fish
- Use aeration devices along the pipeline route to reduce potential water taste/odor problems from decaying entrained aquatic organisms (e.g., BOD, algal blooms)

Mitigations for the terminal water storage reservoirs include:

- design the terminal water storage reservoir to hold maximum long-term water storage capacity and/or design an overflow system to ensure that noxious/exotic organisms which may survive the transfer do not escape into nearby water bodies;
- design the terminal water storage reservoir to prevent establishment of noxious aquatic plants;
- utilize aeration devices during operation if odor/taste problems result from algal blooms and/or high BOD levels.

Mitigations for the water treatment facility include:

- conduct pre-construction and/or pre-treatment surveys to determine the presence or absence of pathogenic organisms (i.e., *Cryptosporidium parvum*, *Giardia*, *Escheri coli*, enterovirsuses, total/fecal coliforms) in the recipient system, as specified by the USEPA's (1994) ICR, D/DBPR, ESWTR, and if necessary, add additional water devices (e.g., micron porosity pressure filters, ozone) in the treatment plant to ensure a safe water supply.

In summary, open systems have a higher potential for significant adverse environmental impacts because of the lack of available controls to prevent potential dispersal, introduction, and establishment of introduced and exotic aquatic organisms. Although significant environmental impacts could occur in closed transfers, detrimental environmental impacts are more likely to occur in open systems. Closed transfer systems which involve the transfer of water from the donor system directly to a water treatment facility are recommended for interbasin water transfers since the transfer of aquatic organisms can be controlled to a greater degree than transfers through open or open/closed systems. If environmental problems are identified which are unavoidable, mitigation plans should be developed to lessen or alleviate the impacts. If mitigation plans are unacceptable to regulators, the design should be changed or the site should be relocated to the best alternative location.

SECTION IV

SOUTHEAST STUDY AREA

1.0 PROJECT DESCRIPTION

During Phase I of the Trans-Texas Water Program, 28 proposed transfer routes were identified for the Southeast Study Area (Figure IV-1). These transfer routes were subdivided by segments and labeled according to the river basins of origin and destination (e.g., Sabine River to Neches River - SN). A total of five distinct segments synonymous with their perspective river basin comprises the study area: (1) six separate transfer corridors between the Sabine River and the Neches River; (2) eight transfer routes between the Neches River and the Trinity River; (3) eight transfer segments between the Trinity River and the San Jacinto River; (4) five transfer segments from the San Jacinto River to the Brazos River; and (5) one transfer segment extending from the Trinity River to the Brazos River (Table IV-1). Water transfers between these river basins would utilize existing streams, lakes, reservoirs, and new conveyance (e.g., pipelines, tunnels) or existing conveyance (i.e., raw water system pipelines, canals, or pump stations) structures (Sabine River Authority [SRA] 1994).

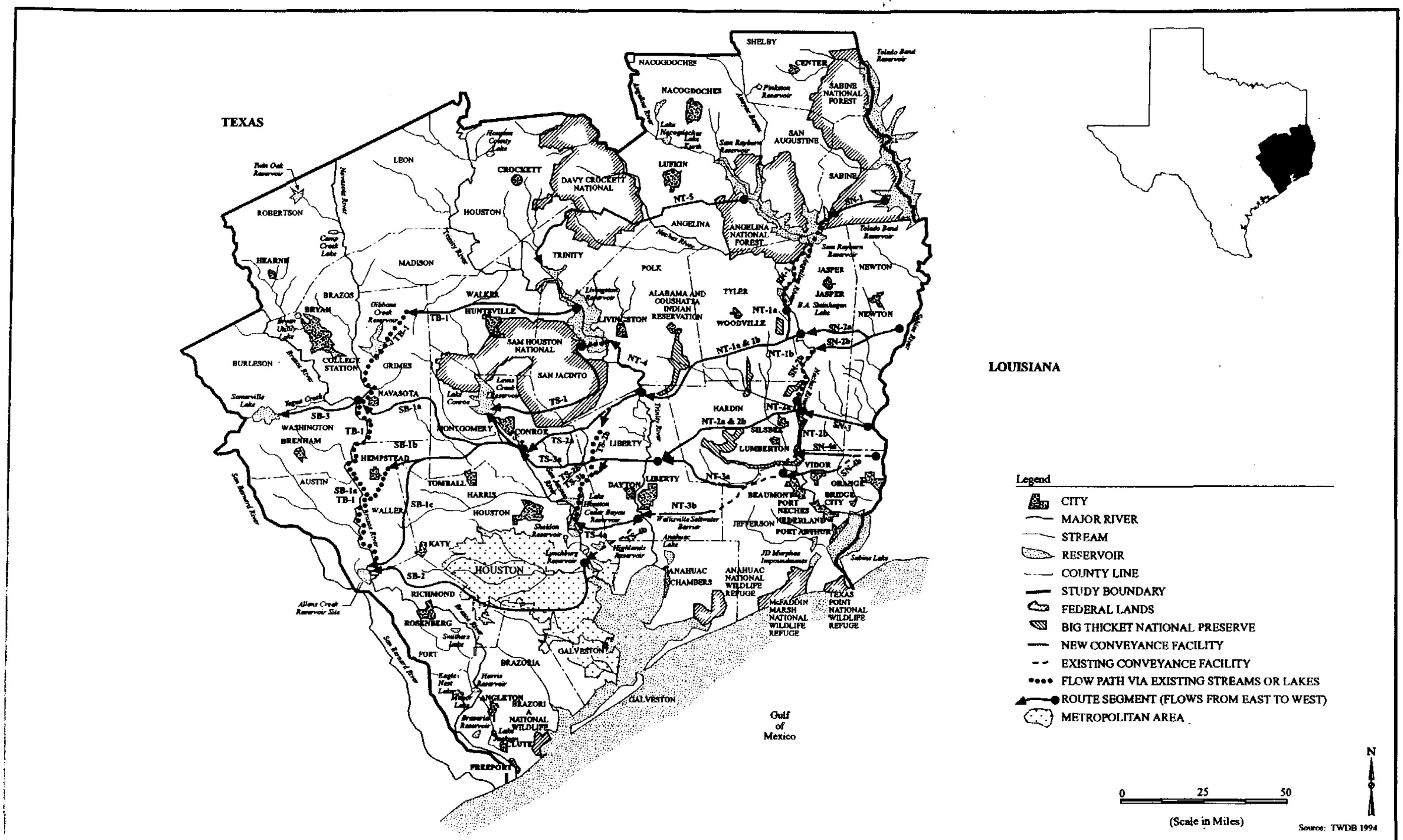
2.0 METHODOLOGY

A general qualitative aquatic impact assessment methodology was developed to analyze the proposed interbasin water transfers in the Southeast Study Area. The two basic components of the assessment methodology were: (1) a comparison of species composition between the donor and conduit/recipient basins based on historic and current literature, and (2) an evaluation and assessment of the potential environmental impacts from the introduction of aquatic organisms between basins based on their distribution and known habitat requirements.

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

3.1 General Overview

The Southeast Study Area extends along the Texas Gulf Coastal Plain from the Louisiana border in the east to the Brazos River in the west. Thirty-two counties, which contain the major cities of Houston, Galveston, Beaumont, Port Arthur, and Orange, lie within the area drained by the Sabine, Neches, Trinity, San Jacinto, and Brazos river basins (see Figure IV-1). This area encompasses a major portion of the South Central Plains and the Western Gulf Coastal Plain ecoregions with a smaller section lying



igure IV-1. Southeast Study Area : Trans-Texas Water Program Alternate Routes

Table IV-1

Proposed Transfer Routes, Southeast Study Area, Trans-Texas Water Program

Name	Basin Source	Basin Destination	Source of Diversion	Destination	Description
SN-1	Sabine	Neches	Toledo Bend Reservoir	B.A. Steinhagen Lake	Travels Angelina R.
SN-2a	Sabine	Neches	Sabine R. at Bon Wier	Neches R. at Mount Union	Canal
SN-2b	Sabine	Neches	Sabine R. at Bon Wier	Neches R., South of Mount Union	Travel in Neches R. to diversion points
SN-3	Sabine	Neches	Sabine R. at Deweyville	East side of Neches R. at Evadale	Canal
SN-4a	Sabine	Neches	SRA pump station	LNVA Neches First Lift pump station	Utilizes SRA canal and Lakeview canal
SN-4b	Sabine	Neches	SRA pump station	LNVA Neches First Lift pump station	Utilizes SRA canal; links directly with LNVA station
NT-1a	Neches	Trinity	B.A. Steinhagen Lake	East of Trinity R. at Romayor	Connects with SN-1
NT-1b	Neches	Trinity	East Side of Neches R.	East of Trinity R. at Romayor	Connects with SN-2a, tunnel under Neches R. and Big Thicket
NT-2a	Neches	Trinity	Neches R. near Evadale	East of Trinity between Moss Hill and Hardin	
NT-2b	Neches	Trinity	Terminus of SN-3	East of Trinity between Moss Hill and Hardin	Tunnel under Neches R. and Big Thicket
NT-3a	Neches	Trinity	LNVA Neches First Lift pump station	East of Trinity between Moss Hill and Hardin	Travels 11 miles in LNVA's Neches main canal
NT-3b	Neches	Trinity	LNVA Neches First Lift pump station	Trinity R. south of Liberty	Travels 23 miles in LNVA's Neches main canal
NT-4	Neches	Trinity	NT-1a or NT-1b	Lake Livingston	Continuation of NT-1a, NT-1b
NT-5	Neches	Trinity	Sam Rayburn Reservoir	Lake Livingston	Crosses Neches R. by inverted siphon, crosses Alabama Creek, uses Little Rock Creek and channel
TS-1	Trinity	San Jacinto	Lake Livingston	Lake Conroe	

Table IV-1 (Continued)

Proposed Transfer Routes, Southeast Study Area, Trans-Texas Water Program

Name	Basin Source	Basin Destination	Source of Diversion	Destination	Description
TS-2a	Trinity	San Jacinto	East of Trinity R. near San Jacinto	East of San Jacinto R. southeast of Conroe	
TS-2b	Trinity	San Jacinto	East of Trinity R. near Romayor	Lake Houston	Utilizes Marsh Branch and Luce Bayou
TS-3a	Trinity	San Jacinto	East of Trinity between Moss Hill and Hardin	East of San Jacinto R. below Conroe	Canal
TS-3b	Trinity	San Jacinto	East of Trinity between Moss Hill and Hardin	Lake Houston	Utilizes Luce Bayou
TS-4a	Trinity	San Jacinto	East of Trinity R. south of Liberty	Lake Houston	Utilizes part of Dayton Canal
TS-4b	Trinity	San Jacinto	West of Trinity R. south of Liberty	Lynchburg Reservoir	Utilizes 22 miles of CWA canal
TS-5	Trinity	San Jacinto	Terminus of TS-1a and TS-3a	Lake Conroe	
SB-1a	San Jacinto	Brazos	East of San Jacinto south of Conroe	East of Brazos near Navasota	
SB-1b	San Jacinto	Brazos	East of San Jacinto south of Conroe	Natural channel east of Hempstead	
SB-1c	San Jacinto	Brazos	San Jacinto near Conroe	Proposed Allen's Creek Reservoir	
SB-2	San Jacinto	Brazos	Lynchburg Reservoir	Proposed Allen's Creek Reservoir	Crosses Brazos R.
SB-3	San Jacinto	Brazos	San Jacinto near Navasota	Somerville Lake Dam	Follows the valley of Yegua Creek
TB-1	Trinity	Brazos	Lake Livingston	Gibbons Creek Reservoir	

Legend: SRA = Sabine River Authority LNVA = Lower Neches Valley Authority CWA = Coastal Water Authority R. = River

Source: Brown & Root, Inc. 1994

in the East Central Texas Plains and the Texas Blackland Prairies ecoregions (Omernik and Gallant 1987; SRA 1994).

3.2 Abiotic Environment

3.2.1 Physical Setting

Five major river basins (Sabine, Neches, Trinity, San Jacinto, and Brazos) basins are present in the Southeast Study Area. Stream flow of these rivers varies as a function of precipitation level, gradient, evapotranspiration rates, size of the drainage basin, runoff and infiltration rates, water consumption, and general runoff characteristics. Physical alterations (e.g., dams, dredged channels) and freshwater diversions (e.g., reservoirs, canals) have modified many of these rivers. Peak discharge in these rivers tends to occur in winter and spring months, while low flows often occur during summer-late fall periods (Livingston 1992).

The geographic distribution of man-made reservoirs in the Southeast Study Area reflects a complex interaction between topography, climate, economics, and the need to regulate or modify the movement of water in the major river basins. Reservoirs in the Western Gulf Drainage of southeast Texas are relatively large (median surface area = 20 square miles [mi^2]) and deep (mean depth = 25 feet [ft], range = 4.3 - 134.5 ft), are morphologically complex (dendritic [tree-like] shape), have irregular shorelines with numerous coves, islands, and embayments), and consist of two types: mainstem (e.g., Toledo Bend, Sam Rayburn) and tributary (e.g., Lake Conroe, Gibbons Creek) (Soballe et al. 1992). Mainstem reservoirs are located lower in the drainage basin of larger rivers (stream order greater than 7-8, drainage area greater than 3,861 mi^2), are influenced more by river inflows, have less dramatic (9.8 to 13.1 ft) water level fluctuations (often due to river regulation), have short residence time (less than 30 days), contribute greater nutrient loads, and have expanded riverine and transitional longitudinal zones. Tributary reservoirs are located higher in the drainage basin of low-order streams (less than 7-8, drainage area less than 3,861 mi^2) and often are in areas of greater topographic relief. They usually have higher depth:surface area ratios, longer residence times (greater than 100 days), lower nutrient loading rates (per unit area), and more pronounced (49.2. to 52.8 ft) water level fluctuations as a result of flood control, hydroelectric generation, or flow augmentation operations. There are strong connections between water residence time, reservoir location, and operational practices (quantity, timing, and depth(s) from which the water is released) because their hydrology (e.g., stream size, flow volume, and basin morphometry) is interrelated (Leopold et al. 1964).

Along the Texas Gulf Coastal Plain, the river basins of Southeast Texas are largely confined or entirely confined to the humid subtropical zone. There is little or no water deficiency during any season along the coast, while farther inland there tends to be a winter surplus and summer deficiency of moisture (Carr 1967).

3.2.2 Physicochemical Characteristics

Salient chemical characteristics of these river basins are compared in Table IV-2. Instead of presenting long-term averages, a single water year (1966) was selected during which the mean annual discharge was intermediate with respect to extremes observed over several decades. The eastern streams, confined to the Texas Gulf Coastal Plain, are soft to moderately hard and usually are slightly acidic. From the Trinity River westward (excluding the San Jacinto system, which is similar to eastern streams), the waters are hard to very hard and typically basic (Conner and Suttkus 1986). Texas Gulf Coastal Plain rivers in general tend to have higher ion concentrations (e.g., chloride and sodium) than the "average river water" (Livingston 1963). A summary of differences in limnological parameters characteristic of mainstem and tributary reservoirs in the study is are listed in Table IV-3.

Water quality in these river basins has undergone changes in various locations due to man-made uses (i.e., impoundments, diversions, recycling, etc.). Although local violations of water quality standards (e.g., water quality/effluent limited) occur due to human influences (Table IV-4), the water quality in each of these basins is suitable for its designated uses (i.e., contact recreation, high quality aquatic habitat, public water supply). Primary sources of contaminants include domestic wastewater effluents and pastureland/rangeland runoff. Major reservoirs in the Southeast Study Area have been evaluated and ranked by the Texas Natural Resource Conservation Commission (TNRCC) using Carlson's Trophic State Index (TSI) (Carlson 1977). Carlson's TSI is used to score reservoirs according to trophic conditions based on secchi disk transparency, total phosphorus levels, and chlorophyll A levels. Chlorophyll A was given priority by the state as the primary trophic indicator, because it is best for estimating algal biomass in most reservoirs. Based on this assessment which was an average calculated from 10 years of data (September 1983-August 1992), Toledo Bend, Sam Rayburn, B.A. Steinhagen, and Lake Houston are

Table IV-2

Salient Physicochemical Characteristics of Major Rivers in the Southeast Study Area

Physicochemical Characteristics	Major Rivers				
	Sabine	Neches	Trinity	San Jacinto	Brazos
Drainage (km^2)	25,123	25,900	46,620	10,360	116,550
Discharge/km^2 (m^3)	0.0088	0.0046	0.0056	0.0058	0.0022
Ionic Concentrations (mg/ℓ)[1]					
Silica (SiO_2)	12.0	12.0	10.0	19.0	8.3
Calcium (Ca)	9.5	9.7	42.0	31.0	61.0
Magnesium (Mg)	3.0	3.1	4.2	3.2	10.0
Sodium (Na)	30.0	18.0	60.0	27.0	56.0
Bicarbonate (HCO_3)	32.0	32.0	123.0	88.0	170.0
Sulfate (SO_4)	15.0	15.0	45.0	9.1	61.0
Chloride (Cl)	43.0	25.0	61.0	60.0	82.0
Nitrate (NO_3)	0.6	0.8	4.6	0.4	1.3
Total Dissolved Solids[1]	130	103	282	185	367
Hardness as $CaCO_3$,[1]					
Ca, Mg	36	37	124	91	194
Noncarbonate	10	11	23	19	55
Specific Conductance[1] (μmhos at 25°C)	237	178	503	329	658
pH[1]					
Maximum	7.1	7.1	8.1	7.5	8.0
Minimum	5.6	5.7	6.7	6.3	6.8

[1] Time-weighted means or extremes for lowermost mainstem location where continuous records were kept for Water Year 1966 (USGS 1971); drainage area used for discharge/km^2 is that for the sampling station rather than the total presented at first entry.

Legend:

km^2	= square kilometers	°C	= degrees Celsius
m^3	= cubic meters	pH	= hydrogen-ion
mg/ℓ	= milligrams per liter	$CaCO_3$	= calcium carbonate
μmhos	= micromhos	USGS	= U.S. Geological Survey

Source: Conner and Suttkus 1986

Table IV-3

Summary of Differences in Limnological Characteristics of Mainstem and Tributary Reservoirs in the Southeast Study Area

Limnological Characteristics	Mainstem	Tributary
Annual Runoff (cm)	43.9	51.6
Drawdown (m)	2.2	5.6
Water Residence Time (years)	0.14	0.72
Secchi Depth (m)	1.3	1.8
Mean Surface (m)	9.1	12.0
Surface Area (km^2)	110.5	97.4
Volume (x 10^6 m^3)	1153.7	1061.8
Inorganic Nitrogen (mg/ℓ)	0.352	0.173
Total Nitrogen (mg/ℓ)	0.672	0.559
Total Nitrogen Load	164.1	26.4
Organic Nitrogen Load (percentage of total nitrogen load)	52.0	65.0
Total Phosphorus (mg/ℓ)	0.052	0.037
Total Phosphorus Load (g/m^2 $year^{-1}$)	16.6	2.3
Chlorophyll A ($\mu g/\ell$)	5.9	7.7

Legend:
cm = centimeter
m = meter
km^2 = square kilometers
m^3 = cubic meters
mg/ℓ = milligrams per liter
$\mu g/\ell$ = micrograms per liter
g/m^2 = grams per square meter

Source: Soballe et al. 1992

Table IV-4

Summary of Water Quality Problems in Individual River Basin Segments of the Southeast Study Area

River	Segment		Water Quality Problems
Sabine	0503	Sabine River below Toledo Bend Reservoir	lower 80 miles has elevated fecal coliform levels
	0504	Toledo Bend Reservoir	elevated levels of lead, DDE, and mercury in sediments
Neches	0602	Neches River below B.A. Steinhagen Lake	elevated manganese in sediments; dioxin in fish tissues
	0609	Angelina River	low DO levels during periods of hypolimnetic releases from Sam Rayburn Reservoir
	0610	Sam Rayburn Reservoir	depressed DO levels in upper reservoir caused by organic pollutants in Paper Mill Creek; elevated arsenic, zinc, and mercury levels in sediments
Trinity	0801	Trinity River Tidal	inorganic nitrogen concentrations exceed screening levels; elevated fecal coliform bacteria levels
	0802	Trinity River below Lake Livinston	dissolved cadmium concentration exceeds chronic criterion; elevated orthophosphorus concentrations; PCB levels in fish tissue exceeded screening criterion; lower 54 mile reach has elevated fecal coliform bacteria levels
	0803	Lake Livingston	elevated nutrient levels; DDE sediment samples exceed screening levels; elevated PCB levels in fish tissue
San Jacinto	1001	San Jacinto River Tidal	nitrite plus nitrate nitrogen and orthohosphorus levels elevated
	1002	Lake Houston	total phosphorus and orthphosphorus levels elevated
	1004	West Fork San Jacinto River	total phosphorus and orthphosphorus levels elevated
Brazos	1202	Brazos River below Navosta River	elevated orthophosphorus and total phosphorus levels; upper portion has elevated fecal coliform densities
	1209	Navosta River below Lake Limestone	elevated phosphorus and nitrogen levels
	1211	Yegua Creek	average elevated chloride and sulfate levels are elevated; phosphorus levels above screening criteria in lower portion
	1212	Somerville Lake	average total dissolved solids levels greater than stream criterion

Legend: DDE = Dichlorodiphenylethylene
DO = Dissolved Oxygen
PCB = Polychlorinated Biphenyl

Source: TNRCC 1994b

considered mesotrophic, while Lake Livingston and Somerville Lake show signs of eutrophication. Somerville Lake was classified as hypertrophic due to its large algal counts (963,000 cells per liter [cells/ℓ in August) and very high nitrogen and phosphorus concentrations (Brazos River Authority 1995). No trophic status was given to Gibbons Creek Reservoir, a power plant cooling lake, or Lynchburg Reservoir (TNRCC 1994b).

3.3 Biotic Environment

3.3.1 Rivers

The microalgal components of the Texas Gulf Coastal Plain rivers are not well studied or understood. However, microalgae of various types contribute to the biota of the relatively slow-moving rivers and streams of the Texas Gulf Coastal Plain. These rivers also harbor a rich diversity of epiphytic macrophytes (Sheath and Cole 1992) and microphytes (Livingston et al. 1991). Aquatic flora is often dominated by green algae (*Cladophora, Microspora*; Sheath and Cole 1992) and pennate (*Navicula, Nitzschia*: Davis and Buzan 1981) and/or centric (*Melosira granulata*: Fisher et al. 1974) diatoms and is well developed in areas where the water currents are not swift. In acidic dystrophic waters, the microalgal flora is often specialized, with some species being aerophilous. Current characteristics have a strong influence on the diatom composition. In fast-moving streams, rheophilic types predominate. Usually plankton development is scarce in open-water situations or in streams and rivers of even moderate current strength, with benthic flora limited to the edges, stream bed, or associated pools. Muddy or highly turbid rivers are often associated with relatively impoverished diatom development. Large rivers, however, may have a well-developed plankton flora consisting of diatom blooms (e.g., *Melosira distans* var. *alpigena* -Sabine River) in the spring or early summer, and green algae, blue-green algae, and diatom blooms (e.g., *Cyclotella meneghianiana* - Sabine River) in late summer and fall (Williams 1972). Such associations are often developed along specific stretches of the river and are often derived from benthic or epiphytic populations. Overall, the microflora of the slow-moving Texas Gulf Coastal Plain rivers, though not well studied in terms of distribution and ecology, may contribute an extremely important dimension to the biological organization of such areas (Livingston 1992).

The composition and distribution of aquatic macrophytes in coastal plain river systems are dependent on complex interactions of various factors: climate, hydroperiod, water quality, soils/sediment characteristic, watershed properties, and biological interactions. The meandering Texas Gulf Coastal Plain rivers and streams are a product of gentle slopes, sediment deposition patterns, precipitation, and evapotranspiration conditions (Wharton et al. 1982). Aquatic macrophytes associated with the coastal plain river systems (e.g., Angelina River) include emergent forms dominated by narrow- and broad-leaved plants, such as narrowleaf cattail (*Typha angustifolia*), smartweed (*Polygonum punctatum*), spikerush (*Eleocharis* spp.), and duck potato (*Sagittaria* sp.); floating plants such as water hyacinth (*Eichornia crassipes*); and submergent types like waterweed (*Anacharis* sp.), pondweed (*Potamogeton* sp.), water milfoil (*Myriophyllum* sp.), and coontail (*Ceratophyllum* sp.) (Durocher 1986). These types of emergent, floating, and submergent aquatic plants contribute to the productivity of the river basins of the Texas Gulf Coastal Plain.

Within the Texas Gulf Coastal Plain drainage systems, there is considerable variation in the animal assemblages depending on species diversity and variability and specific changes in key ecological features in time and space. Planktonic forms include protozoans (*Difflugia* sp.) and rotifers (i.e., *Keratella* spp.), which feed primarily on the microorganisms (blue-green and green algae, diatoms, and flagellates), and crustaceans (e.g., cladocerans - *Bosmina* and copepods - *Tropocyclops prasinus*: Trinity River - Fisher et al. 1974). Benthic macroinvertebrates found in the substrate, depending upon habitat and water quality, include chironomid larvae, annelid worms, mollusks, and aquatic insects.

Thirty-four species of unionid clams comprise the mollusk fauna of the Sabine Subprovince (Sabine, Neches, Trinity, and San Jacinto rivers) of freshwater clams (Appendix A-3). Indicative of this subprovince are sandbank pocketbook (*Lampsilis satura*), *Proptera amphichaena*, and the problematic species in the genera *Fusconaria* and *Pleurobema*. The Brazos River falls into the Central Texas Subprovince and has a considerably smaller unionid population (24 species - Appendix A-3) (Neck 1982; Howells 1995a 1995c).

Developmental stages of aquatic insects are dominant forms in numerical abundance and species richness at various trophic levels (Resh and Rosenberg 1984). These organisms are representative of types found in the major river basins of Southeast Texas (Wurtz and Roback 1955; Hendricks et al. 1969, 1974; Harrell et al. 1973; Fisher et al. 1974; Cox 1976; Davis and Buzan 1981; Wood et al. 1994). Nektonic forms include various vertebrates (i.e., reptiles and amphibians), with fishes taking a predominant role.

Certain forms remain in specific habitats through their life history, whereas others may be migratory, making use of various parts of the river system as a function of life history stages.

The diversity of the Texas Gulf Coastal Plain ichthyofauna is dominated by minnows (Cyprinidae), suckers (Catostomidae), catfishes (Ictaluridae), sunfishes (Centrarchidae), and perches (Percidae). Compared with the central and eastern portions of North America, the Texas Gulf Coastal Plain ichthyofauna is depauperate (118 freshwater species; Appendix A-4). The richest diversity occurs in the Sabine River Basin, than gradually decreases westward. Minnows, suckers, and catfishes contribute around 50 percent of the faunal diversity with sunfishes, perches, killifishes (Cyprinodontidae), and livebearers (Poeciliidae) comprising the rest (Conner and Suttkus 1986). Anderson et al. (1995) reported a downward shift in the fish faunal diversity of southeast Texas over the last three decades. Most notable is a trend in a reduction of lotic adapted taxa with narrow habitat requirements (darters, minnows, suckers, and catfish) and an increase in opportunistic species (mosquito fish and silversides) tolerant of variable habitat conditions and able to respond quickly to habitat disturbances (e.g., alteration of instream flow, eutrophication, and exotic species introduction).

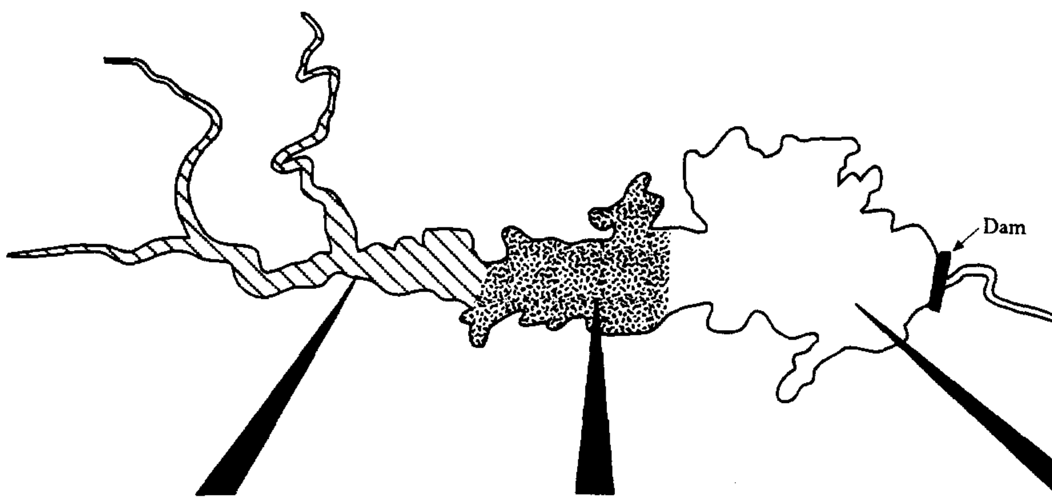
Systematic multidisciplinary and comparative studies of Texas Gulf Coastal Plain rivers are lacking, so precise associations of habitat and animal distributions are not well developed. Outside of specific faunal distributions, few generalizations can be made concerning process-orientated functions in such stream and river systems. The various rivers of Southeast Texas remain poorly studied from the standpoint of ecosystem ecology. River management, based on ecosystem-level research, is largely lacking (Livingston 1992).

3.3.2 Reservoirs

Primary productivity of reservoirs in Southeast Texas is dependent upon physical, chemical, and biological variables which relate to climate, size, topography, geology, land use of the watershed, shape of the reservoir basin, inflow characteristics, water residence time, and operational practices. Reservoirs in Southeast Texas are relatively nutrient-rich and moderately productive. Nutrient loads (a product of inflow volume and concentration) and concentrations in mainstem impoundments are significantly higher than tributary reservoirs. These differences are attributable to the larger drainage areas of mainstem reservoirs, and to more numerous point and non-point nutrient sources along the larger streams which flow into mainstem reservoirs. High turbidity and light limitation are also major determinations of productivity and abundance by eliminating or severely reducing littoral communities (Soballe et al. 1992). Longitudinal changes in reservoir morphology and flow velocity result in longitudinal differences in the factors that determine the relative concentrations of phytoplankton, periphyton, and macrophytes to total ecosystem production (Figure IV-2; Kimmel and George 1984).

Autochthonous production and the overall standing crop of photosynthetic organisms (primary producers) in reservoirs are governed by light availability, nutrient concentrations, substrate (for rooted or attached plants), water level fluctuations, and water residence time (especially for phytoplankton). These environmental factors, operating in concert, also determine the relative contributions of the various producers (suspended algae [phytoplankton], attached algae [periphyton], and macrophytes [macroscopic algae and aquatic vascular plants]) to overall system production. Phytoplankton production dominates in most reservoirs because changing water levels inhibit the development of littoral macrophyte and periphyton communities. The predominant types of algae occurring in these reservoirs are green algae, blue-green algae, and, to a certain extent, flagellates and diatoms with maximum densities occurring in late winter/early spring or late summer/early fall (Silvey and Wyatt 1969). Although geographically close and under the same basic environmental conditions, the reservoirs in the Southeast Study Area may show considerable individuality with regard to dominant species during the peak periods (i.e., Sam Rayburn Reservoir: green algae - *Groenbladia neglecta*/blue-green algae - *Aphanocaspa delicatissima*; Livingston Reservoir: centric diatoms - *Cyclotella* sp./blue-green algae - *Dactylococcopsis* sp.; Lake Conroe: blue-green algae - *Raphidiopsis* sp.; Lake Houston: centric diatoms - *Melosira distans*/flagellates - *Chroomonas* sp./*Cryptomonas erosa*; Gibbons Creek Reservoir: green algae/flagellates - *Ankistrodesmus falcatus*/*Cryptomonas erosa* and *Chroomonas acuta*; blue-green algae - *Lynbgya* sp. and *Oscillatoria geminata*; and Somerville Lake: green algae - *Cateria klebsii*/blue-green algae - *Microcystis* sp.). However, in reservoirs having relatively stable water levels, expanding stands of rooted and floating macrophytes (e.g., Eurasian watermilfoil, *Myriophyllum spicatum* - 2,644 acres (ac) [Toledo Bend]; or hydrilla, *Hydrilla verticillata* - 8,859 ac [Toledo Bend] and 15,760 ac [Sam Rayburn Reservoir]) can become a nuisance (Rudy 1978; Morris et al. 1978; Environmental Science and Engineering, Inc. [ESE] 1984; Bettoli et al. 1985; Soballe et al. 1992; Helton and Hartmann 1993, 1994; Gandara et al. 1995a; Brazos River Authority 1995).

RIVER IMPOUNDMENT/RESERVOIR



RIVERINE ZONE	TRANSITIONAL ZONE	LACUSTRINE ZONE
Narrow, channelized basin (small basin cross-section)	Broader, deeper basin	Broad, deep, lake-like basin (large basin cross-section)
Relatively high flow	Reduced flow	Little flow
High suspended soils, turbid, low light available, $Zp < Zm$	Reduced suspended solids, less turbid, light availability increased	Relatively clear, light more available at depth, $Zp > Zm$
Nutrient supply by advection, relatively high nutrients	Advective nutrient supply reduced	Nutrient supply by internal recycling, relative low nutrients
Light-limited phytoplankton production	Phytoplankton production/m^3 relatively high	Nutrient-limited phytoplankton production
Cell losses primarily by sedimentation	Cell losses by sedimentation and grazing	Cell losses primarily by grazing
Organic matter supply primarily allochthonous, $P < R$	Intermediate	Organic matter supply primarily autochthonous, $P > R$
More "eutrophic"	Intermediate	More "oligotrophic"

Legend

Zp = Photic layer
Zm = Mixed layer
P = Photosynthesis
R = Respiration

Source: Kimmel and Groeger 1984

Figure IV-2. Longitudinal Zonation of a River Impoundment/Reservoir

The periphyton community of reservoirs in the Southeast Study Area are dominated by diatoms, green algae, and blue-green algae during the summer and diatoms in the winter. Although attached plants are an important producer component of many aquatic systems, water-level fluctuations and high turbidity restrict periphyton and macrophyte growth in many reservoirs. Substrates located below the one percent light level are generally unsuitable for periphyton colonization. Likewise, many rooted macrophytes cannot tolerate short-term fluctuations in water depth. Attached algae and aquatic macrophytes attain maximum abundance in reservoirs that have clear water and stable water levels. Shallow embayment areas of reservoirs maintained at a relatively constant level are often infested with American lotus (*Nelumbo lutea* - B.A. Steinhagen Lake), Eurasian watermilfoil (Toledo Bend), coontail (*Ceratophyllum demersum* - Toledo Bend), hydrilla (Toledo Bend, Sam Rayburn, B.A. Steinhagen), and floating algal mats composed of green algae (*Oedogonium*, *Mougeotia*), and blue-green algae (*Lyngbya*). Only in the most plant-infested reservoirs do attached plants cover more than 15 percent of the water surface (i.e., B.A. Steinhagen - 45 percent of lake is vegetated: 6 percent by hydrilla and 39 percent by native species). Since their areal extent is restricted, attached plants in the Southeast Study Area are generally minor contributors to overall ecosystem production (ESE 1984; Ploskey 1986; Soballe et al. 1992; Helton and Hartmann 1993, 1994).

The structure of the consumer community in reservoirs is shaped by direct effects of physical and chemical factors on the consumer organisms themselves and indirectly by the effects of reservoir conditions on resource availability, predation, and competition. Reservoir consumer organisms can be categorized into three groups: (1) zooplankton (drifting and weakly swimming animals), (2) benthos (bottom dwellers), and (3) nekton (strongly swimming animals - fish) (Soballe et al. 1992).

The animal component of the plankton is composed primarily of protozoans (Protozoa), rotifers (Rotatoria), cladocerans (Cladocera), and copepods (Copepoda). These animals are mostly microscopic and tend to be cosmopolitan in their distribution (Pennak 1978). Zooplankton species found in Southeast Texas reservoirs are generally typical of North American lakes. In Southeast Texas, the limnetic zooplankton communities were dominated by various components as is indicated within the different impoundments (Toledo Bend: rotifers - *Asplanchna* sp., *Chromogaster* sp.; Sam Rayburn Reservoir and Livingston Reservoir: rotifers - *Keratella*, *Brachionus*/*Polyarthra* and the copepod/*Acanthocyclops*; Lake Conroe: rotifers - *Asplanchna* and *Conochilus* spp. and cladocerans - *Bosmina longirostis*; and Gibbons Creek Reservoir: rotifers - *Polyarthra vulgaris*, *Synchaeta* sp., cladocerans - *Diaphanosoma* *leuchtenbergianum*, and copepods) (Allard 1974; Inglis et al. 1976; ESE 1984; Cichra et al. 1985; Moore 1993). The submerged plants and substrate of the littoral regions are inhabited by microcrustacean fauna (e.g., cladocerans - *Camptocercus* sp., *Chydorus brevilabris*, *Ceriodaphnia* spp., and *Diaphanosoma brachyurum*: Lake Conroe) distinctly different qualitatively and quantitatively from that found in the limnetic zone (Pennak 1966; Campbell et al. 1985).

The zooplankton assemblage of turbid reservoirs may differ slightly from that of most natural lakes in that these organisms may sustain themselves by feeding more on detritus and detrital aggregates than on phytoplankton (Goldman and Kimmel 1978; Arruda et al. 1983). In addition, reservoir zooplankton must contend with changing patterns of stratification, horizontal transport, and predation. The spatial distribution of reservoir zooplankton reflects the longitudinal zonation of physical and chemical characteristics within a reservoir (see Figure IV-2). Typically, the maximum abundance of zooplankton occurs downstream of the transition zone. The longitudinal patterns of zooplankton abundance and composition in the Southeast Texas reservoirs typically vary with time (Threlkeld 1983). Direct effects of water level fluctuations on zooplankton are not likely to be significant, but modification or elimination of littoral zone vegetation and habitat that results from water level changes may have important indirect effects. The zooplankton assemblage in reservoirs is influenced strongly by flushing rate, as well as by longitudinal and vertical changes in water velocity (Threlkeld 1982; Dirnberger and Threlkeld 1986).

The abundance and species composition of the benthos is closely tied to three major factors: (1) characteristics of the substrate, (2) physical-chemical characteristics of the water, and (3) the food supply. All of these factors can be strongly influenced by reservoir operation. The most important effects of reservoirs on benthic organisms are related to (1) siltation and/or scouring, (2) anoxia, (3) water-level fluctuations, (4) altered flow, (5) changes in temperature regimen, and (6) trapping and discharge or organic matter. Fluctuating reservoir water levels continually affect the benthos community by (1) stranding and resulting desiccation of benthic invertebrates in the littoral zone, (2) burial of deep bottom-dwelling (profundal) organisms by erosion and redeposition of littoral sediments, and (3) loss or lack of habitat and food sources due to changes in substrate particle size and absence of littoral macrophytes. Hale and Bayne (1980) documented the effects of a 9.8 ft water-level fluctuation in West Point Reservoir (Alabama-Georgia) and indicated that recolonization of exposed-areas benthic organisms required two-months of continuous inundation.

Abundance, composition, and spatial distribution of benthic organisms within a reservoir is determined by a variety of factors (e.g., water depth, substrate type, frequency and duration of anoxia). Therefore, the benthic fauna of reservoirs should exhibit patterns of longitudinal zonation. Baxter (1977) reported considerable longitudinal variation in reservoir benthos, and a common trend is for maximum abundance to occur near the river inflow (see Figure IV-2). This may be explained by the relatively high concentration of organic matter (presumably, of allochthonous origin) in the riverine zone sediments of some impoundments (James et al. 1987). There is frequently a tremendous increase in the abundance of some benthic macroinvertebrates (e.g., true midges [chironomids] and earthworms [oligochaetes]) in the years following inundation, while other groups (e.g., mayflies [ephemeropterans], caddisflies [trichopterans], and stoneflies [plecopterans]) typically decrease (Baxter 1977). This is reflected in the dominant benthic communities found in reservoirs in the Southeast Study Area (i.e., Toledo Bend: aquatic worms, midges [chironomids], and phantom midges [*Chaoborus*]; Gibbons Creek: *Chaoborus*, midges, and aquatic oligochaetes [Tubificidae and Naididae]) (Inglis et al. 1976; Howard 1982; ESE 1984).

The trophic relations of reservoir fish are complex, but the standing crop and production of fish depend on reservoir morphology, water residence time, nutrient levels, and operating characteristics. Many of the abundant species are food generalists (Keast 1978), and their feeding behavior can typically span several trophic levels (e.g., from periphyton grazing to piscivory) and can vary with season and with fish age. For example, a top predator might progress from planktivore to insectivore to piscivore during its growth and development. Spatial heterogeneity in fish communities follows the pattern observed in abiotic components and in other biotic components of river-reservoir ecosystems. Siler et al. (1986) showed that the abundance of threadfin shad (*Dorosoma petenense*) and harvest of sport fish in Lake Norman, North Carolina, were lowest in the near-dam area and increased steadily upstream into the river zone. The effects of water-level fluctuations on reservoir fish populations and fisheries were reviewed by Ploskey (1986). In general, reservoir fisheries are most affected by water-level fluctuations that (1) are large (i.e., several feet), (2) last several months, (3) occur during the growing season, and (4) inundate or eliminate productive areas of littoral or terrestrial vegetation. Rapidly rising waters that inundate terrestrial areas can temporarily increase supplies of invertebrate foods; likewise, large drawdowns that concentrate prey fish for two or three months at temperatures above 13°C can increase predator foraging and growth (Aggus 1979). Loss of habitat by drawdown can negatively affect spawning success and egg mortality, but because year-class strength depends on factors beyond spawning success, drawdown may still have a net positive effect on recruitment in some species.

Dolman (1990) classified some of the reservoir types in the Southeast Study Area according to fish community associations. Lakes and reservoirs like Conroe, Sam Rayburn, B.A. Steinhagen, and Toledo Bend typically have high densities of redear sunfish (*Lepomis microlophus*), largemouth bass (*Micropterus salmoides*), and bluegill (*Lepomis macrochirus*) and lower densities of gizzard shad (*Dorosoma cepedianum*), channel catfish (*Ictalurus punctatus*), and freshwater drum (*Aplodinotus grunniens*). Lake Livingston fish communities are characterized by combinations of longear sunfish (*Lepomis megalotis*), bullhead minnow (*Pimephales promelas*), freshwater drum, logperch (*Percina caprodes*), and orangespotted sunfish (*Lepomis humilis*), while Gibbons Creek, a power plant cooling lake, has a fish assemblage dominated by blue tilapia (*Tilapia aurea*) and threadfin shad.

In summary, the ecological structure and functioning of biotic communities in Southeast Texas reservoirs are linked to water residence time, both because of the direct effects of water renewal on the plankton and other components of the biota and because water residence time correlates with other important limnological variables (e.g., nutrient loading, water depth, watershed size, turbidity, and mixing regime). The biotic communities of Southeast Texas impoundments exhibit longitudinal zonation within reservoirs that coincides with the longitudinal zonation of physical and chemical variables. Reservoir primary productivity usually is dominated by phytoplankton and is often maximal in the zone of transition from riverine to lacustrine conditions. The irregular shorelines of Southeast Texas impoundments provide extensive areas for littoral vegetation, but water-level fluctuations may impede macrophyte and periphyton growth. Coves and embayments of Southeast Texas reservoirs create tremendous spatial heterogeneity. Water exchange between the open area of the reservoir and these shallow bays is often restricted, and nutrients, organic material, and planktonic biomass can accumulate in these areas. As a consequence, reservoir embayments are often more productive and have more diverse biota than the main body of the reservoir (Soballe et al. 1992).

3.3.3 Threatened, Endangered, and Candidate Species

Fourteen aquatic/semi-aquatic species are listed for the river basins of the Southeast Study Area (Table IV-5). Four of the federally listed Candidate Category 2 (C2) species (mollusk, reptile and two fish), one state threatened fish species, and one Texas Organization For Endangered Species (TOES) "watch list" reptilian species occur in the Sabine through the San Jacinto river basins. The remaining four C2 species (invertebrate, fish and two plants) are found in the Sabine, Neches, Trinity, and Brazos rivers.

Table IV-5

List of Federal/State/TOES Endangered, Threatened, Candidate, Watch List, and Special Concern Aquatic Species Potentially Occurring in River Basins of the Southeast Study Area

Common/Scientific Name	Sabine			Neches			Trinity			San Jacinto			Brazos		
	F	S	TO	F	S	TO	F	S	TO	F	S	TO	F	S	TO
PLANTS															
Tissue sedge															
Carex hyalina							C2		W						
Neches River rosemallow															
Hisbiscus dasycalyx				C2	E										
Grass-of-Parnassus															
Parnassia asarifolia					T										
INVERTEBRATES															
Big Thicket emerald dragonfly															
Somatochlora margarita	C2														
MOLLUSKS															
Texas heelsplitter															
Potamilus amphichaenus	C2		SC	C2		SC	C2		SC	C2		SC			
REPTILES															
Alligator snapping turtle															
Macroclemys temmincki	C2	T	T	C2	T	T	C2	T	T	C2	T	T			
American alligator															
Alligator mississippiensis			WL			WL			WL			WL			
FISH															
Paddlefish															
Polyodon spathula	C2	E	T	C2	E	T	C2	E	T	C2	E	T			
Ironcolor shiner															
Notropis chalybaeus			WL			WL									
Sharpnose shiner															
Notropis oxyrhyncus													C2		T
Blue sucker															
Cycleptus elongatus	C2	T	WL	C2	T	WL	C2	T	WL	C2	T	WL			
Creek chubsucker															
Erimyzon oblongatus		T			T			T			T				
Western sand darter															
Ammocrypta clara			T												
Blackside darter															
Percina maculata		T	T												

Legend:			
F = Federal		E = Endangered	
S = State		T = Threatened	
TO = TOES		C2 = Candidate Category 2	
WL = Watch List		SC = Special Concern	

Source: TOES 1993, 1995; TPWD 1995c; USFWS 1994, 1995b

One "watch list" fish species is found in both the Sabine and Neches rivers, while one state threatened and one TOES threatened fish species are confined to the Sabine River. Another state threatened plant species is found in the Neches River (TOES 1993, 1995; TPWD 1995c; USFWS 1995b).

TOES has also identified an aquatic invertebrate species of special concern (also listed as a C2 species; USFWS 1994), disjunct water beetle, which may occur in the project area. The distribution of this species in Texas has not been determined (TOES 1988). Two species of freshwater mollusks, Texas heelsplitter (*Potamilus amphichaenus*), a recently listed federal C2 species (USFWS 1994), and false spike (*Quincuncina mitchilli*), which was proposed as candidate for federal protection (Neves 1993), are listed as species of special concern by TOES (1988). Texas heelsplitter occurs in the Sabine, Neches, and Trinity River basins. False spike occurs only in the Brazos River Basin (Howells 1995a).

Native mollusks of the United States and Canada were recently evaluated and ranked as endangered, threatened, or as special concern species. These rankings are not legally binding but do provide an insight to species of mollusks which could potentially be listed in the near future. One endangered, three threatened, and seven special concern species of mollusks are listed for the Southeast Study Area (Williams et al. 1993; Howells 1995a). The only listed endangered species is Texas fawnsfoot (*Truncilla macrodon*). Threatened species include Texas pimpleback (*Quadrula petrina*), smooth pimpleback (*Quadrula houstonensis*), and Texas heelsplitter. Special concern species are Texas pigtoe (*Fusconia askewi*), triangle pigtoe (*Fusconia lananesis*), Texas fatmucket (*Lamsilis bracteata*), sandback pocketbook (*Lampsilis satura*), southern hickorynut (*Obovaria jacksoniana*), and Louisiana pigtoe (*Pleurobema riddelli*). The distribution of these species within the study area is presented in Table IV-6.

4.0 ANALYSIS OF POTENTIAL ECOLOGICAL IMPACTS

General qualitative assessments of the potential environmental impacts which could result from the transfer of water between river basins in the Southeast Study Area are discussed in this section. All assessments are based on available current and/or historic abiotic/biotic data. Overall, current data on aquatic communities, with the exception of macroinvertebrate and fish communities, are not available for rivers and reservoirs in the study area. Potential impacts from water withdrawal on instream/estuarine flows are not addressed in this section since the volume of water to be diverted for the proposed transfers

Table IV-6

Distribution of Listed Native and Special Concern Unionid Mollusks
in River Basins of Southeast Study Area

Unionidae	River Basins				
	Sabine	Neches	Trinity	San Jacinto	Brazos
Texas pigtoe *Fusconaia askewi*	X	X	?	?	
Triangle pigtoe *Fusconaia lananensis*		X		X	
Texas fatmucket *Lampsilis bracteata*					X
Sandbank pocketbook *Lampsilis satura*	X	X	?	?	
Southern hickorynut *Obovaria jacksoniana*	X	X			
Louisiana pigtoe *Pleurobema riddelli*	X	X	X	X	
Texas heelsplitter *Potamilus amphichaenus*	X	X	X		
Smooth pimpleback *Quadrula houstonensis*			?	?	X
Texas pimpleback *Quadrula petrina*					X
False spike *Quincuncina mitchelli*					X
Texas fawnsfoot *Truncilla macrodon*				X	X

? Distribution is questionable

Source: Neck 1984; Howells 1995a

is unknown. Instream/estuarine flow requirements should be addressed as soon as flow diversion rates can be projected.

4.1 Microbes

Fecal coliform levels vary widely within river segments and between river basins in the Southeast Study Area. Fecal coliform levels are reported as elevated in segments of the Sabine, Trinity, and Brazos rivers (TNRCC 1994b). Potential impacts would depend on the concentration of fecal coliforms at the intake and outfall and if municipalities utilize the recipient system for water. In general, interbasin water transfers from a basin which involve transport from areas (reservoirs/rivers) of elevated fecal coliform levels to conduit and recipient basins with low fecal coliform levels could potentially be impacted by the proposed transfers (e.g., Sabine to Neches River Basin). Data on presence and abundance of other microbes which could potentially affect humans (i.e., *Cryptosporidium*) are not available for river basins in the study area. An "unknown impact rating" was assigned to fecal coliforms and other microbes since current site-specific data are not available for the proposed water transfers.

4.2 Algae

Native algal communities in lotic/lentic habitats of the study area are fairly consistent in composition (diatoms, green algae, blue-green algae) with variations occurring in dominant forms due to a variety of physicochemical/environmental factors. Multiple interacting physical, chemical, and biotic factors, in proper combination, may lead to the development and persistence of nuisance algal blooms (i.e., blue-green algae). Massive blue-green algal blooms occurring in late summer and fall could potentially be transferred between donor (reservoir/lake) systems causing increased taste, odor, and health (e.g., gastrointestinal, respiratory, dermatologic) and wildlife (e.g. ichthysarcotoxicosis - fish and acute liver toxicosis/rapid neurotoxicosis - wild/domestic animal impacts) in the recipient basins (Palmer 1964; Schwimmer and Schwimmer 1964, 1968; Carmichael 1992). Different algal species, like *Cladophora glomerata*, could potentially cause increased wear on the intake's water pumps from abrasion, or *Oscillatoria* sp. could cause corrosion in steel (pitting) and concrete equipment (van Zon 1982; Anderson 1990). Moderate impacts would potentially occur if the intake structure is designed and located in an area which regularly produces phytoplankton blooms. Based on these concerns, a "low to moderate potential impact" rating was assigned to algae.

4.3 Aquatic Plants

Several state-listed noxious aquatic plants could potentially be transferred by the operations associated with some of the proposed interbasin water transfers (Howells 1992). Helton and Hartmann (1995) reported that eight exotic plant species, giant duckweed (*Spirodela oligorhiza*), salvinia (*Salvania* spp.), water hyacinth, egeria (*Egeria densa)*, hydrilla (*Hydrilla verticullata*), alligatorweed (*Alternanthera philoxeroides*), water lettuce (*Pistia stratiotes*), and water fern (*Azolla* sp.), are established in the river basins and reservoirs of the Southeast Study Area (Table IV-7). All of these species could potentially be transferred via existing rivers/reservoirs or enclosed conveyance facilities between lake/reservoir ecosystems (e.g., B.A. Steinhagen Lake to Livingston Reservoir) and cause alterations in the ecosystems (i.e., shade and competition with more desirable aquatic plants, etc.). Individual species (i.e., water hyacinth) could be transported by the same methods (e.g., Livingston Reservoir to Gibbons Creek Reservoir, a cooling reservoir) resulting in detrimental economic/environmental effects ranging from clogging waterways, which would limit access and recreation, to providing microhabitats for various human disease vectors and disruption of wildlife habitats (Pieterse and Murphy 1990). Low impacts would generally occur during river-to-river transfers. Impacts from the transfer of noxious aquatic macrophytes could occur during some of the proposed reservoir-to-reservoir transfers or reservoir-conduit-reservoir transfers. Depending on the presence and abundance of the noxious aquatic plants, moderate to high impacts could occur in reservoir-to-reservoir transfers. Therefore, a "low to high potential impact rating" was assigned to aquatic plants.

4.4 Zooplankton

Riverine and reservoir zooplankton communities can differ greatly in composition. In general, river zooplankton populations and biomass would be lower than reservoir biomass due to flushing by the current flow. River-to-river water transfers would generally have a lower potential for impacts due to the similarity of riverine environments in the study area. Construction of the intake structure in the productive upper bays of reservoirs and subsequent operational activities could result in negative local impacts to littoral zone zooplankton populations. Decreases in zooplankton populations could potentially impact early life stage fish consumers (larval and juvenile fish) and subsequently adult fish populations. In addition, potential impacts from the introduction of non-native zooplankton has not been thoroughly

Table IV-7

Known Occurrence of Exotic Organisms by River Basin/Man-Made Impoundment
(Southeast Study Area)

Common/Scientific Name	River Basin: Sabine	Neches	Trinity	San Jacinto	Brazos
EXOTIC PLANTS					
Giant duckweed/*Spirodela oligorhiza*		X[2]			
Salvinia/*Salvinia* spp.	X	X[2]			
Water hyacinth/*Eichhornia crassipes*	X	X	X	X[5]	X
Water lettuce/*Pistia stratiotes*					X
Hydrilla/*Hydrilla verticillata*	X[1]	X[3]	X[4]	X[6]	X[7]
Egeria/*Egeria densa*	X	X[3]			
Alligatorweed/*Alternanthera philoxeroides*	X	X	X	X[5]	
Water Fern/*Azolla* spp.	X	X[3]			
EXOTIC SHELLFISH					
Asiatic clam/*Corbicula fluminea*	X	X	X	X	X
EXOTIC FISH					
Grass carp/*Ctenopharyngodon idella*	X	X	X	X	
Rudd/*Scardinius erythrophthalmus*					X
Blue tilapia/*Tilapia aurea*			X	X	
Rio Grande cichlid/*Cichlasoma cyanoguttatum*					X

[1]Only Toledo Bend Reservoir
[2]Only B.A. Steinhagen Lake
[3]Only Sam Rayburn Reservoir and B.A. Steinhagen Lake
[4]Only Livingston Reservoir
[5]Only Lake Conroe and Lake Houston
[6]Only Lake Conroe
[7]Only Gibbons Creek Reservoir and Somerville Lake

Legend: spp. = species

Source: McMahon 1983; Howells et al. 1991; Hubbs et al. 1991; Bushek and Cameron 1992; Howells 1992; Helton and Harmon 1995 researched. Therefore, there is a unknown potential for impacts from the proposed water transfer. Based on these concerns, a "low to moderate potential impact rating" was assigned to zooplankton.

4.5 Benthic Invertebrates

Populations of benthic invertebrates could potentially be affected during the interbasin water transfers. Potential increases in flow, changes in water quality, and possible physical alterations of habitat associated with the interbasin waters could significantly affect composition, diversity, and abundance of aquatic invertebrates in the donor basin, conduit system, and/or recipient basin. The potential impact to and from most invertebrates, with the exception of native mollusks and introduced exotic mollusks cannot be accurately assessed at this time due to the lack of recent data on the composition of benthic macroinvertebrates in the Southeast Study Area.

4.5.1 Native Mollusks

Introduction of freshwater unionid mussels (Unionidae) are not expected to have negative impacts since no significant effects as yet have been reported from other introductions (Howells 1995a). Construction of the intake structure and/or new channel reservoirs for the proposed interbasin water transfers could result in significantly negative effects if construction disturbs or destroys the habitat for an existing population. The larval or glochidial phase, which drifts/swims in the current in search of a host (fish), could be diverted from an area of suitable habitat in its native river basin(s) to potentially unsuitable habitat in the open/closed conduit system and/or the recipient basin, where the species may or may not occur. In addition, survival of the glochidial phase is unlikely in long transfers. This could potentially reduce survival/recruitment rate of the species, decrease the population, and potentially result in the listing of the species. Significant direct negative impacts to native listed mussels would only occur if the intake is located in or immediately downstream from a population of the species. Negative indirect effects could also occur if the number of potential fish host species decreases since most mussels require a specific host or hosts to transform into the juvenile phase.

4.5.2 Exotic Mollusks

One state-listed harmful mollusk, the introduced Asiatic clam (*Corbicula fluminea*), is present in all of the major drainage basins in eastern Texas (McMahon 1983; see Table IV-7). Population levels are unknown in the study area due to the lack of recent riverine aquatic ecological studies in the area. If present, the Asiatic clam may directly affect operational aspects of the interbasin water transfers since it is known to reduce flow by clogging/fouling water intake and conveyance structures (i.e., valves, canals, pipelines). Dead and/or decaying Asiatic clams could indirectly cause drinking water odor/taste problems. It has also been postulated that the Asiatic clam could outcompete native mollusk species due to its ability to achieve high densities. Some studies have indicated severe reductions in numbers and elimination of native mollusk populations after the introduction of the Asiatic clam, while other studies found no significant impact on native populations after the introduction. Therefore, some researchers hypothesize that the Asiatic clam cannot outcompete native mollusks unless the affected environment is significantly impacted by human activities (i.e., dredging, channelization, etc.) (McMahon 1983).

The introduced zebra mussel (*Driessena polymorpha*) has spread rapidly throughout North America but is not yet known to occur in Texas. The potential for introduction and establishment of this species into the reservoirs/rivers in Southeast Texas is considered to be very low since this species does not tolerate the acidic water (calcium [Ca^{2+}] levels lower than 12 mg/ℓ and pH below 7.3) which is present in the region (Strayer 1991; Howells 1995b; Whittier et al. 1995) and high mean annual air temperatures (greater than 26°C) of the region (Strayer 1991).

4.5.3 Summary

Based on these general analyses, transfer of the Asiatic clam could result in "moderate to high potential impacts" when present in the donor system. Depending on the location of the intake structure and/or new channel reservoirs, native mollusks could experience "low to high potential impacts". Depending on the transfer location, a "moderate potential impact rating" was assigned to mollusks. As previously discussed, potential impacts from or to other benthic invertebrates cannot be assessed because of the lack of current data on these communities in the study area.

4.6 Amphibians/Reptiles

Amphibian and reptilian communities are diverse in Southeast Texas and could be affected by some of the proposed interbasin water transfers. Construction would potentially disturb and or destroy littoral and shoreline habitats. Operation may result in impingement/entrainment and thus a decrease in recruitment and survival of local populations. In addition, interbasin water transfers from large rivers to smaller rivers/creeks could significantly alter semiaquatic and riparian habitat by increasing the water level in the receiving system. Depending upon the habitat, higher water levels from an increase in current flow could result in an increase or decrease in habitat for amphibians and reptiles. Regionally, introduction of non-native amphibians and reptiles through transfer is not a major concern since most species occur throughout the study area. A local concern would be the transfer of the bullfrog (*Rana catesbeiana*), an amphibian species which preys on other amphibians, to an area where it does not occur.

In general, river-to-river transfers would have low potential impacts to amphibians and reptiles due to the small area affected. However, if located in a nursery area (bayou or backwater area), construction could potentially result in moderate impacts. Reservoir-to-reservoir transfers, which have intake structures in the productive upper end and/or coves of reservoirs, would potentially result in moderate local impacts to amphibians and some reptiles. Based on these analyses, a "low to moderate potential impact rating" was assigned to amphibians and reptiles.

4.7 Fish

4.7.1 Native Populations

Although some differences exist in native fish populations between the eastern river basins (Sabine/Neches/Angelina) and the western river basins (San Jacinto/Trinity/Brazos River) in the Southeast Study Area, the species composition of most Southeast Texas river basins is similar (Appendix A-4). Based on known distribution and general qualitative habitat requirements (Robison and Buchanan 1992), the following native species could be introduced and potentially become established in other basins within the Southeast Study Area if they survive the transfer: chestnut lamprey (*Ichthyomyzon casteneus*), emerald shiner (*Notropis atherinodes*), bigmouth buffalo (*Ictiobus cyprinellus*), black buffalo (*Ictiobus niger*), chain pickerel (*Esox niger*), and mud darter (*Etheostoma asprigene*) (Table IV-8).

Table IV-8

List of Fish Species with the Potential for Transfer in the Various River Basins and Man-Made Impoundments/Southeast Study Area

Taxa	Sabine/Neches/Angelina	Trinity/San Jacinto	Brazos	Transfer
LAMPREYS				
Chestnut lamprey	N			Yes
Southern Brook lamprey	N	N		No
PADDLEFISHES				
Paddlefish	N[1]	N[1]		No
CARPS/MINNOWS				
Grass carp	I	I[2]		Yes
Cypress minnow	N			No
Redfin shiner	N	N		No
Speckled chub	N		N	No
Emerald shiner	N	N		No
Ironcolor shiner	N			No
Taillight shiner	N			No
Sabine shiner	N	N		No
Suckermouth minnow	N	N		No
Creek chub	N	N		No
Rudd			I	No
SUCKERS				
Bigmouth buffalo	N			Yes
Black buffalo	N		NI	Yes
Blacktail redhorse	N	N		No
BULLHEADS/CATFISHES				
Freckled madtom	N	N		No
PIKES				
Chain pickerel	N			Yes
SILVERSIDES				
Brook silversides	N	N		No
TEMPERATE BASSES				
Yellow bass	N	N		No
PERCHES				
Western sand darter	N			No
Scaly sand darter	N	N		No
Mud darter	N			Yes
Harlequin darter	N	N		No
Cypress darter	N	N		No
River darter	N			No
CICHLIDS				
Blue tilapia		I		Yes
Rio Grande Cichlid			I	No

[1]Found only in riverine systems below most downstream dams
[2]Reproducing population in the Trinity River and Galveston Bay

Legend: N = Native I = Introduced NI = Considered native but possibly introduced

Source: Conner and Suttkus 1986; Trimm et al. 1989; Hubbs et al. 1991; Pitman 1991; Robbins et al. 1991; Whiteside and Berkhouse 1992; Webb 1995

Establishment of any introduced native species would be determined by multiple factors. These include but are not limited to: (1) survival during the transfer, (2) presence of suitable habitat at the intake/outfall site for the potential transfer species, (3) availability of trophic position (pelagic piscivore, benthic insectivore, adaptable omnivore, etc.) in the vicinity of the outfall site; (4) adaptability to a trophic assemblage and physicochemical environment of the recipient basin; and (5) species-specific characteristics (abiotic/biotic adaptability versus specificity in habitat requirements). Fish are less likely to survive long, closed transfers due to the potential for impingement, abrasion, and the lack of food resources. Open transfers increase the chance of survival by potentially providing suitable feeding/resting habitat and low physical stress (i.e, less potential for immediate/long-term death from impingement/abrasion and more natural physicochemical characteristics [temperature, oxygen concentrations, etc.]). Site-specific abiotic and biotic fisheries data (composition, numbers, condition factors) are needed from the intake/outfall site and immediate vicinity to determine or predict the possibility of the introduction/establishment. Since these data are not available, only a general qualitative assessment can be made regarding the potential for introduction/establishment of the transfer species. The chance for establishment for most of the potential transfer species would be low in a long, closed transfer and, at best, moderate in an open transfer.

Native fish populations could also be affected by construction of new channel reservoirs/intake structures and/or the operation associated with the transfer of water. If construction occurs in an area utilized for spawning, the subsequent alteration to the habitat could result in a local decrease in the population of the species. However, the negative impact would be local and would not significantly affect species with stable populations.

The operation of the water transfer would also potentially impact egg, larval, juvenile, and potentially some small adult phases of native fishes in the donor basin by diverting these phases into the conduit system. The transfer may result in mortality due to abrasion/collision, velocity changes, turbulence, and sheer stress from pumping, impingement on screens, or entrainment (i.e., especially from long closed pipelines) (Miracle and Gardner 1979; Cada 1990). Significant water withdrawals/additions during the proposed interbasin water transfers could also alter physicochemical parameters and affect riverine and estuarine fish populations.

4.7.2 Exotic Species

Two potentially harmful introduced exotic species, the grass carp (*Ctenopharyngodon idella*) and the blue tilapia (*Tilapia aurea*), occur in the San Jacinto/Trinity River basins and could be introduced and become established in the Brazos River by several of the proposed interbasin water transfers (see Table IV-7). Successful establishment of exotic fishes varies widely between geographic regions (from 38 to 77 percent), but is generally greater in areas either altered by man or depauperate in native species. Detailed ecological analyses documenting the effects of fish introductions are scarce, however, the majority (31) of those which have been completed show a 77 percent decline in native fish populations after the introduction of exotic or non-native fish. Biotic interactions are important in structuring the impacted fish assemblage with competition and predation being cited as the two most important factors (Ross 1991). Competitive interactions may lead to: (1) the extinction of the species, (2) fluctuating coexistence as the environment alternately favors one species or the other, and (3) nich shifts (Molye and Vondracek 1985).

The establishment of the grass carp would depend primarily on the availability of food (aquatic vegetation). Other important factors would be survival during the transfer and the presence of spawning habitat. Although environmental impacts appear to vary with location and stocking density, negative impacts from grass carp may include decline in bluegill populations and failure of largemouth bass to spawn, and decreases in benthic and attached invertebrates. Positive impacts reported included increases in sunfish productivity and decreases in aquatic macrophytes (Luedke 1987). In addition, grass carp more than two years old can survive in salinities up to 17.5 parts per thousand (ppt) (Trimm et al. 1989). Therefore, establishment, followed by downstream dispersal, may result in significant impact to estuarine aquatic floral (e.g., widgeon grass - *Ruppia maritima*)/faunal communities.

The establishment of blue tilapia would probably depend on the availability and suitability of habitat (e.g., relatively high temperatures, backwaters/oxbows habitat for spawning and feeding). Introduction and establishment of the blue tilapia generally results in a steady decline of native fish species and long-term decreases in recreational fisheries due to competition for spawning sites and food resources and higher reproductive survival rates (Hanifen 1981; Muoneke 1988).

In addition, exotic fishes could be hosts for parasites which can devastate other fish populations (e.g., grass carp introduced a non-native cestode parasite, the Asian tapeworm [*Bothriocephalus acheilognathi*] via the red shiner [*Cyprinella lutrensis*] which caused reduction of a native cyprinid, woundfin - *Plagopterus argentissimus* [Deacon 1988]). Based on the concerns stated above, introduction of the grass carp and the blue tilapia into the Brazos River should be avoided.

A "low-high potential impact rating" was assigned for fish because of the potential presence of a federal C2, state-listed endangered/threatened, and TOES threatened/watch list fish species in the river basins, the potential introduction of several native and exotic fish species, and the potential alterations in the fish communities due to the potential increase in current flow.

4.7.3 Endangered and Threatened Species

Eight federally listed C2 species, three state-threatened species, and three TOES species (one threatened and two "watch list") could potentially be affected by construction of the intake structure and operational activities during the proposed interbasin water transfers (see Table IV-5). The three listed plant species and one mollusk could potentially be affected if water withdrawal results in insufficient water levels for these aquatic/semi-aquatic plants to grow. As previously stated, potential impacts related to water withdrawal cannot be addressed since the proposed rates are unknown.

The Big Thicket emerald dragonfly (*Somatochloa margarita*) occurs in clear, sandy streams and, therefore, would not occur in any of the proposed reservoir/river donor, conduit, and recipient basins. The alligator snapping turtle and the American alligator would be able to avoid most construction and operational impacts due to its mobility and would not be impacted. The sharpnose shiner (*Notropis oxyrhyncus*) occurs only in the Brazos River Basin and the ironcolor shiner (*Notropis chalybaeus*) in the Sabine/Neches river system. The paddlefish (*Polyodon spathula*), blue sucker (*Cycleptus elongatus*), and the sharpnose and ironcolor shiners could be affected by the construction/operational activities of the new channel reservoirs and/or intake structures associated with the proposed interbasin water transfers if the construction/operational activities occur in habitat currently being utilized by the species as spawning or nursery habitat. In addition, the potential transfer of larval or juvenile phases of these species may result in mortality due to abrasion/collision, velocity changes, turbulence, and sheer stress from pumping, impingement on screens, or entrainment (i.e., especially from long closed pipelines). If either of these effects occur, the recruitment/survival rate could decrease and potentially reduce the population of the paddlefish, blue sucker, and sharpnose and ironcolor shiners.

The creek chubsucker (*Erimyzon oblongus*) occurs in creeks and smaller streams and would not be affected since it would not occur at the proposed intake sites on larger rivers. However, if small streams are used for conveyance and the creek chubsucker is present, it could be affected by changes in current flow, habitat, and water quality. The blackside and western sand darters, which inhabits smaller creeks/rivers in the Sabine River Basin, would not be affected since it is not expected to occur at proposed transfer intake sites on the mainstem of the Sabine River. One TOES (1988) aquatic invertebrate species of special concern (also listed as federal C2 species - USFWS 1994), disjunct crawling water beetle could occur in the study area. If present, this aquatic invertebrate could be affected by construction/operational activities associated with the proposed interbasin water transfers.

5.0 SUMMARY

In general, open transfer systems (e.g., canals, reservoirs, rivers) proposed for the Southeast Study Area have a higher potential for significant impacts because of the lack of controls to prevent potential dispersal, introduction, and establishment of introduced native fishes (see Table IV-8), federal C2/state endangered and threatened/TOES threatened, special concern, and "watch list" species (see Table IV-5), and exotic aquatic organisms (see Table IV-7). Although closed systems can result in significant aquatic environmental impacts, closed transfer systems (e.g., pipelines) generally have lower impact potential since engineering/environmental controls can often be utilized to lessen or mitigate impacts.

Potential impacts to and from aquatic communities for the proposed interbasin water transfers are difficult to assess due to the lack of recent aquatic biotic data on rivers and some of the reservoirs in the Southeast Study Area. However, some general qualitative impacts to aquatic communities can be postulated. Depending on the location and design of the proposed transfer (i.e., river-to-river, reservoir-to-reservoir, reservoir-to-river), impacts would potentially vary from low to high (Table IV-9). However, the uncertainty of analysis for most aquatic components is moderate to high. Therefore, site-specific environmental assessments need to be conducted to determine impacts for each proposed transfer.

Table IV-9

Qualitative Rank of Potential Environmental Impacts
Southeast Study Area

Environmental Component	Rank Impact	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	Unknown	Future municipal use of conduit and/or recipient systems unknown; lack of site-specific data	Not Applicable
Other Microbes	Unknown		
Algae	Low-Moderate	Potential taste-odor problems from algal blooms; potential long-term damage to pumps/pipelines	Moderate
Aquatic Plants	Low-High	Potential transfer of water hyacinth and hydrilla, clogging of intakes	Low
Zooplankton	Low-Moderate	Construction/operation of intake structures may result in local impacts to zooplankton populations and subsequently consumer (fish) populations	High
Benthic Invertebrates			
Mollusks	Low-High	Potential clogging of intake structure by the Asiatic clam and potential impacts of construction/operational activities on native mollusk populations in rivers	Moderate
Other	Unknown	No site specific data	Not Applicable
Amphibians/Reptiles	Low-Moderate	Potential local construction impacts on habitat; alteration/destruction of semi-aquatic and riparian habitat from increases in current flow (river to stream/creek)	High
Fish	Low-High	Potential impacts on threatened, endangered, and indigenous species from construction/operational activities (impingement, entrainment, etc.) and introduction of non-indigenous/native forms	High

6.0 RECOMMENDATIONS AND MITIGATIONS

During the site selection process, several alternative locations and alternative intake sites at each location should be proposed. An environmental assessment should be conducted at each location and proposed intake site to ensure that the best alternative for the environment (i.e., the least affected site for native mollusks/fishes, threatened/endangered species, exotic/nuisance organisms) and the proposed project can ultimately be selected. Comprehensive water quality studies should be conducted for the assessment to determine if the overall water quality at the proposed intake site(s) is suitable for its designated uses (i.e., contact recreation, high quality aquatic habitat, and public water supply). Multi-year environmental studies are recommended due to the current lack of abiotic/biotic aquatic data from river/reservoir ecosystems in the study areas and the variability in the population due to fluctuations in the abiotic environment (e.g., droughts, floods).

Engineering and environmental mitigations which can be utilized during the engineering design and operational phases of the project to alleviate or lessen impacts to or from aquatic components of the ecosystem can be categorized by the type of transfer (i.e., open or closed). Open transfers utilize existing rivers, reservoirs, or canals to complete the transfer. Closed transfers use new or existing conveyance facilities (e.g., pipelines, tunnels) which terminate into another body of water. General mitigations for each of these transfer types and associated facilities for the Southeast Study Area are listed below:

(1) open transfers from reservoirs/rivers:

- the intake site should be located in the middle (transitional zone) or (lower lacustrine zone) section of the reservoir to reduce impacts on aquatic biological communities (e.g., aquatic plants, fishes, amphibians, reptiles);
- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).

(2) new channel reservoirs (open/closed transfers):

- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).
- if necessary, treat the intake area with algicides prior or during pumping to alleviate potential long-term pump damage;
- design the reservoir with steep sides or schedule periodic 30-day water level drawdowns (initial design must allow this to occur concurrently with operation) to limit the establishment of the Asiatic clam.

(3) conveyance structures in closed transfers:

- design or plan to use horizontal screens in intake structures to reduce the impact of fish impingement;
- utilize screens with mesh size of less than 0.08 centimeters (cm), remove shells manually, or use mechanical clam traps at appropriate points in the system, and/or conduct periodic chlorination at the intake site to control the Asiatic clam in the system;
- use materials in pipelines (i.e., mortar lining) that will resist damage from transferred aquatic organisms (e.g., algae, bacteria);
- use bar screens (one inch diameter) to prevent the entrainment of fish;
- use aeration devices along the conveyance route to reduce Biological Oxygen Demand (BOD) from decaying aquatic organisms.

In summary, open systems have a higher potential for significant adverse environmental impacts because of the lack of available controls to prevent potential dispersal, introduction, and establishment of introduced and exotic aquatic organisms. Although significant environmental impacts could occur in closed transfers, detrimental environmental impacts are more likely to occur in open systems. Closed transfer systems which involve the transfer of water from the donor system directly to a water treatment facility are recommended for interbasin water transfers since the transfer of aquatic organisms can be controlled to a greater degree than transfers through open or open/closed systems. If environmental problems are identified which are unavoidable, mitigation plans should be developed to lessen or alleviate the impacts. If mitigation plans are unacceptable to regulators, the design should be changed or the site should be relocated to the best alternative location.

SECTION V

WEST-CENTRAL/SOUTH-CENTRAL STUDY AREA

1.0 PROJECT DESCRIPTION

During Phase I of the Trans-Texas Water Program, 15 proposed interbasin water transfers were identified for the West-Central Study Area (Figure V-1) and the South-Central Study Area (Figure V-2). These transfers were subdivided by segments and labeled according to the river basins of origin and destination (i.e., Guadalupe River to San Antonio River: G-13, Brazos River to San Antonio: B-10, etc.) except for L-14 and L-20 (Table V-1). A total of five segments synonymous with their respective river basin comprises the study area: (1) two separate transfer corridors between the San Antonio River and the Nueces and Guadalupe rivers and one transfer corridor between the Guadalupe River and the San Antonio River; (2) five transfer routes between the Guadalupe River and the San Antonio River; (3) three transfer segments between the Colorado River and the San Antonio River; (4) one transfer segment from the Brazos River to the San Antonio River; and (5) two individual transfer segments extending from the Sabine River to the San Antonio River and one separate transfer segment between the Brazos River and the San Antonio River (see Table V-1) (San Antonio River Authority [SARA] 1994a).

All of the potential transfer alternatives listed in Table V-1, with the exception of L-14, could be used for recharge to the Edwards Aquifer. With the exception of G-13, G-14, and G-15, all transfers would require some level of treatment prior to recharging (i.e., through natural stream beds and other recharge features without any mechanical or chemical treatment). Phase II would involve water transfers from other river basins to a terminal water storage reservoir in the San Antonio or Guadalupe river basins. The terminal water storage reservoir would probably be located on a stream where local inflows and releases could be made (SARA 1994a).

2.0 METHODOLOGY

A general qualitative aquatic impact assessment methodology was developed to analyze the proposed interbasin water transfers in the West-Central and the South-Central study areas. The two basic components of the assessment methodology were: (1) a comparison of species composition between the donor and conduit/recipient basins based on historic and current literature and (2) an evaluation and assessment of the potential environmental impacts from the introduction of aquatic organisms between basins based on their distribution and known habitat requirements.

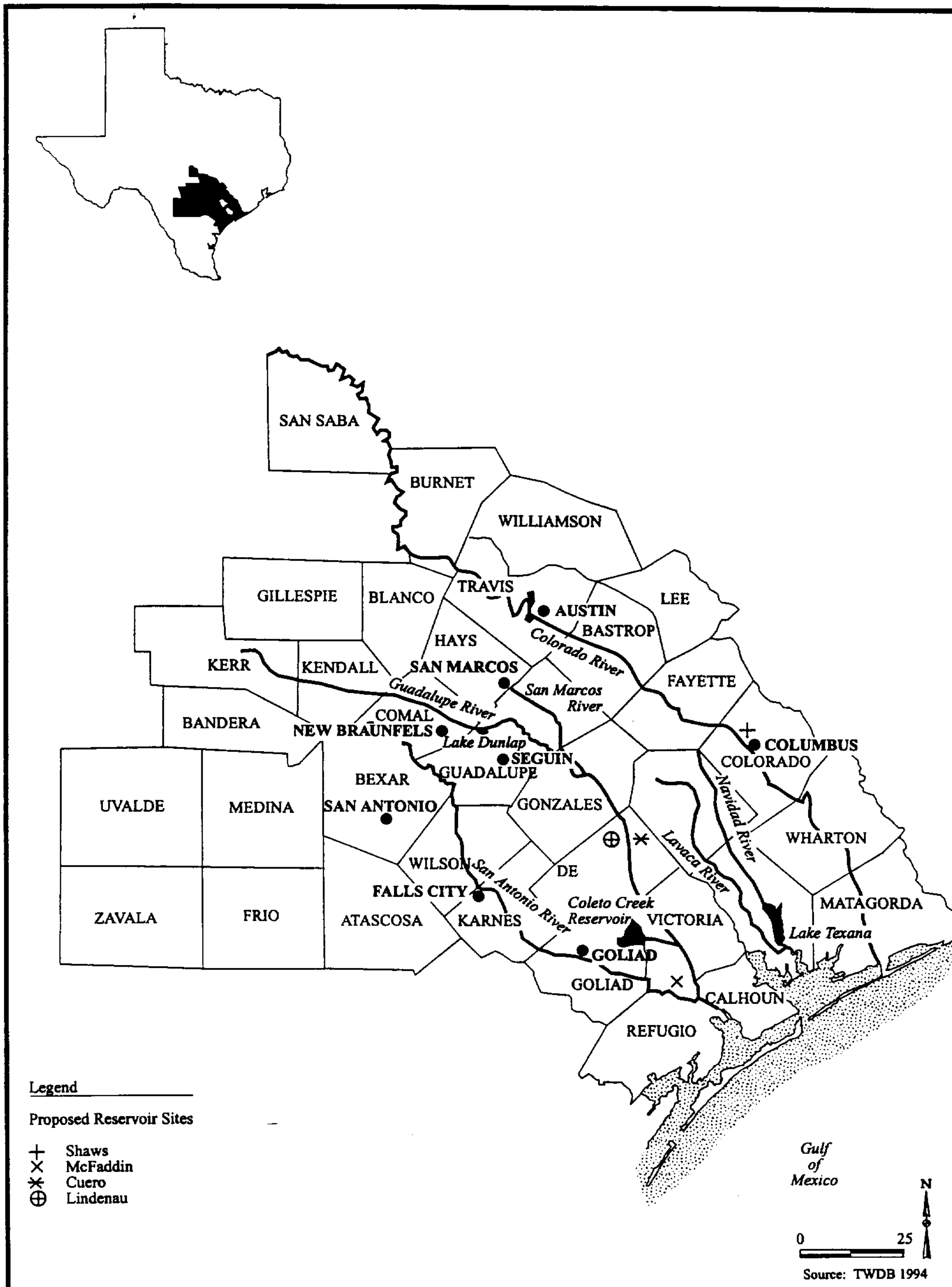


Figure V-1. West-Central Study Area: Trans-Texas Water Program

Figure V-2. South-Central Study Area : Trans-Texas Water Program

Table V-1

Proposed Trans-Basin Diversions, West-Central Study Area, Trans-Texas Water Program

Name	Basin Source	Basin Destination	Source of Diversion	Destination	Description
L-14	San Antonio	Nueces	San Antonio R. at Falls City	Choke Canyon Reservior	Transfer of Reclaimed Water to Corpus Christi
L-20	Guadalupe	San Antonio	Guadalupe R.	Water Treatment Plant	Guadalupe R./ San Antonio R./ Coleto Creek Diversion
	San Antonio	Guadalupe	San Antonio R. at Goliad	Coleto Creek Reservoir	
G-13	Guadalupe	San Antonio	San Marcos R.	Water Treatment Plant	San Marcos R.
G-14, 15	Guadalupe	San Antonio	Lake Dunlap	Water Treatment Plant	Guadalupe R. at Lake Dunlap
G-16	Guadalupe	San Antonio	Cuero Reservoir	Water Treatment Plant	Cuero Reservoir
G-17	Guadalupe	San Antonio	Lindenau Reservoir	Water Treatment Plant	Lindenau Reservoir
G-18	Guadalupe	San Antonio	McFaddin Reservoir	Water Treatment Plant	McFaddin Reservoir
C-13	Colorado	San Antonio	Lake Austin	Water Treatment Plant	Lake Travis
C-17	Colorado	San Antonio	Colorado R. at Columbus	Water Treatment Plant	Colorado R. at Columbus
C-18	Colorado	San Antonio	Shaws Bend Reservoir	Water Treatment Plant	Shaws Bend Reservoir
B-10	Brazos	San Antonio	Allen's Creek Reservoir	Water Treatment Plant	Allen's Creek Reservoir
SB-10	Sabine	San Antonio	Toledo Bend Reservoir	Water Treatment Plant	Toledo Bend Reservoir
SBB-10	Sabine	Brazos	Toledo Bend Reservoir	Allen's Creek Reservoir	Toledo Bend/ Allen's Creek Reservoir
	Brazos	San Antonio	Allen's Creek Reservoir	Water Treatment Plant	

All of the above alternatives, with the exception of L-14, were also studied with the option of being used as recharge to the Edwards Aquifer. All alternatives with the exception of G-13, G-14, and G-15 required some level of treatment prior to recharging. Alternatives G-13, G-14, and G-15 involved recharge through natural stream beds and other recharge features without any mechanical or chemical treatment.

Phase II analysis could involve the use of a terminal reservoir in the San Antonio or Guadalupe River Basins which could receive water from other river basins prior to treatment in the water treatment plant. The terminal reservoir would likely be on a stream where it receives local inflows and would make releases.

Source: SARA 1994a

3.0 DESCRIPTION OF THE AFFECTED ENVIRONMENT

3.1 General Overview

The West-Central Study Area encompasses the region west of the Brazos River and includes the City of San Antonio and all other cities (e.g., San Marcos, New Braunfels, Seguin) that rely upon the Edwards Aquifer for their water supply. Thirty-three counties including parts of the Colorado and Lavaca-Navidad river drainage and all of the Guadalupe and San Antonio river basins form this study area (see Figure V-1). The South-Central Study Area also encompasses the region west of the Brazos River, including the cities of Corpus Christi and Austin. This area consists of 12 counties and the Nueces River Basin (see Figure V-2). The West-Central Study Area encompasses a major portion of the Western Gulf Coastal Plain along with the East Central Texas Plains, Texas Blackland Prairies, and Central Texas Plateau ecoregions; the South-Central Study Area lies mainly within the Western Gulf Coastal Plain, East Central Texas Plains, and Southern Texas Plains ecoregions (Omernik and Gallant 1987; TWDB 1994). The drainage basins of the Guadalupe and San Antonio rivers are largely confined or entirely confined to a subtropical humid zone with warm summers, whereas the Nueces River Basin lies mainly within the subtropical subhumid zone and is characterized by hot summers and dry winters (Larkin and Bomar 1983).

3.2 Abiotic Environment

3.2.1 Physical Setting

Four major drainage basins (Colorado, Lavaca-Navidad, Guadalupe, and San Antonio) lie within the West-Central Study Area. One major river basin, the Nueces, is present in the South-Central Study Area. Interbasin water transfers involving the Colorado and Lavaca-Navidad river basins have been discussed in Section III. The drainage basins of the Guadalupe, San Antonio, and Nueces rivers cover a large area of south and south-central Texas.

The Guadalupe River is spring-fed and originates in the Edwards Plateau as a swift, shallow, rocky stream. As the Guadalupe River enters the Gulf Coastal Plain, it meanders through a broad, flat valley to the Gulf of Mexico. Because of its springs and spring-fed tributaries (e.g., San Marcos, Comal), the

Guadalupe River has an annual runoff of more than one million acre feet (ac-ft) in its lower course. The San Antonio River has its source in large springs within and near the City of San Antonio. It flows across the coastal plain as a shallow, pool and riffle river to its junction with the Guadalupe River near the Texas Gulf Coast. Because of its limited and rather arid drainage area, the average runoff is relatively small, with an annual flow of 350,000 ac-ft near its mouth.

The Nueces River rises in Edwards County and flows through limestone canyons fed by numerous springs before entering the coastal plain where it forms long, narrow pools on its descent to Nueces Bay. The flow of the Nueces River, although highly erratic, is normally low (i.e., runoff about 620,000 acre feet per year [ac-ft/yr] in its lower course). Principal water conservation projects in its lower course are Choke Canyon Reservoir and Lake Corpus Christi (Young et al. 1973; Ramos 1995).

3.2.2 Physicochemical Characteristics

Salient chemical characteristics of the river basins in the study areas are compared in Table V-2. Instead of presenting long-term averages, a single water year (1966) was selected during which the mean annual discharge was intermediate with respect to extremes observed over several decades. The waters of the Guadalupe and the Nueces rivers are very hard in the upper half of the basin, while the stream sections confined to the coastal plain area are generally soft to moderately hard. In contrast, the waters of the San Antonio River are moderately hard to very hard (Young et al. 1973; Conner and Suttkus 1986).

Water quality in these river basins has undergone change in various locations due to man-made uses (e.g., impoundments). Although local violations of water quality standards (e.g., water quality/effluent limited) occur due to human influences (Table V-3), the water quality in each of these basins is suitable for its designated use (i.e., contact recreation, high quality aquatic habitat, public water supply). Primary sources of contaminants include domestic wastewater effluents, non-confined livestock operations, urban runoff, and storm water runoff. Carlson's Trophic State Index (TSI) was utilized by the Texas Natural Resource Conservation Commission (TNRCC) to evaluate and subsequently rank the trophic status of major reservoirs in the study areas (Carlson 1977). Carlson's TSI utilizes secchi disk transparency, total phosphorus levels, and chlorophyll A levels to determine the trophic level. Chlorophyll A was given

Table V-2

Salient Physicochemical Characteristics of Major Rivers in the West-Central and South-Central Study Areas

Physicochemical Characteristics	West-Central		South-Central
	Guadalupe	San Antonio	Nueces
Drainage (km^2)	15,540	10,619	43,253
Discharge/km^2 (m^3)	0.0033	0.0011	0.0003
Ionic Concentrations (mg/ℓ)[1]			
Silica (SiO_2)	11.0	17.0	19.0
Calcium (Ca)	61.0	86.0	56.0
Magnesium (Mg)	14.0	17.0	5.9
Sodium (Na)	25.0	76.0	35.0
Bicarbonate (HCO_3)	223.0	254.0	207.0
Sulfate (SO_4)	28.0	88.0	24.0
Chloride (Cl)	36.0	101.0	33.0
Nitrate (NO_3)	2.5	9.3	0.5
Total Dissolved Solids[1]	289	527	279
Hardness as $CaCO_3$,[1]			
Ca, Mg	208	284	160
Noncarbonate	26	76	0
Specific Conductance[1] (µmhos at 25°C)	513	904	474
pH[1]			
Maximum	8.2	8.2	8.1
Minimum	6.9	7.2	7.0

[1] Time-weighted means or extremes for lowermost mainstem location where continuous records were kept for Water Year 1966 (USGS 1971); drainage area used for discharge/km^2 is that for the sampling station rather than the total presented at first entry.

Legend:

km^2	= square kilometers	°C	= degrees Celsius
m^3	= cubic meters	pH	= hydrogen-ion
mg/ℓ	= milligrams per liter	$CaCO_3$	= calcium carbonate
µmhos	= microhmos	USGS	= U.S. Geological Survey

Source: Conner and Suttkus 1986

Table V-3

Summary of Water Quality Problems in Individual River Basins
of the West-Central and South-Central Study Areas

River	Segment		Water Quality Problems
Guadalupe	1803	Guadalupe River below San Marcos River	elevated fecal coliform bacteria; elevated nitrite plus nitrate nitrogen, orthophosphorus and total phosphorus levels
	1804	Guadalupe River below	elevated fecal coliform bacteria
	1807	Coleto Creek	average total dissolved solids levels exceed segment criteria
	1808	Lower San Marcos River	nitrite plus nitrate nitrogen, orthophosphorus and total phosphorus levels elevated
San Antonio	1901	Lower San Antonio River	lower 69 mile reach downstream from the city of Goliad exhibits elevated fecal coliform bacteria levels; elevated nutrient levels
	1911	Upper San Antonio River	elevated fecal coliform levels and nutrient levels; lower 71 mile reach exhibits elevated PCB concentrations in fish tissues and concentrations of chromium, lead, silver, bis (2-ethyl-hexyl) phtalate, DDE, and PCBs in sediment have exceeded screening levels
Nueces	2103	Lake Corpus Christi	elevated levels of orthophosphorus
	2116	Choke Canyon Reservoir	chloride, sulfate, and total dissolved solids are higher than desired in upper end of reservoir; levels of fecal coliform exceed criterion

Legend: DDE = Dichlorodiphenylethylene
PCB(s) = Polychlorinated Biphenyl(s)

Source: TNRCC 1994b

priority by the state as the primary trophic state indicator because it is best for estimating algal biomass in most reservoirs. Based on this assessment, which is an average calculated from 10 years of data (September 1983-August 1992), Choke Canyon Reservoir is considered mesotrophic and Lake Corpus Christi shows signs of eutrophication (TNRCC 1994b).

3.3 Biotic Environment

Young et al. (1973) reported that the Guadalupe, San Antonio, and Nueces river basins were lacking sufficient information on the aquatic flora and fauna composition (i.e., except for fishes). The natural aquatic communities found in these river basins are of two major types, spring and stream. However, man-made lakes/reservoirs have altered community structure and composition in many parts of these drainages. Studies of protozoans and algae in these river basins have been very limited. The most comprehensive study of protozoans and algae on the Guadalupe River within the West-Central Study Area (New Braunfels to Bloomington) was conducted periodically by the Academy of Natural Sciences of Philadelphia from 1949 to 1973. These surveys recorded 124 species of protozoans dominated by Mastigophora (flagellates), Sarcodina, and Ciliata, and 220 species of periphytic algae dominated by diatoms (i.e., *Navicula* sp., *Synedra rumpens*, *Biddulphia laevis*) in addition to moderate growths of green algae (e.g., *Cladorpha glomerata*) and blue-green algae (e.g., *Oscillatoria* spp.) (Academy of Natural Sciences of Philadelphia 1974). Studies conducted between river miles (R.M.) 184 and 279 on the Guadalupe River indicate that the algal community was most influenced by changes in flow rate and to a lesser extent by temperature changes (Young et al. 1972). Few studies involving algae have been conducted on the San Antonio River Basin and none are known from the Nueces River Basin. Studies on the San Antonio River Basin have been conducted in lacustrine or creek habitats, all near San Antonio. None of these studies listed species, but included only total algal counts of chlorophyll concentrations (Young et al. 1973). Hynes (1970) and Round (1964) listed the types of common algal components indigenous to plankton and attached communities in lotic habitats that could be expected to occur in the San Antonio and Nueces rivers (see Table III-23).

Although geographically near one another and exhibiting similar chemical characteristics, the man-made impoundments in the West-Central Study Area may show differences with regard to dominant groups (e.g., Canyon Lake: green and yellow-brown algae; Braunig Reservoir: blue-green algae and diatoms) (Kubota 1970). Hannan et al. (1972) determined that the impoundments (e.g., Lake Dunlap) on the Guadalupe River between New Braunfels and Gonzales acted as nutrient traps and that nitrogen was the nutrient that limited algal growth. Listed as eutrophic by the TSI (TNRCC 1994b), Lake Corpus Christi exhibited an algal population dominated by diatoms (centric, pennate - *Diploneis* sp.) and blue-green algae (*Lyngbya*, *Oscillatoria*, and *Merismopedia minima*) (Morris et al. 1978).

The distribution of aquatic macrophytes in the Guadalupe, San Antonio, and Nueces river basins shows a general distributional pattern. Clear headwaters of the streams and springs exhibit a diverse and abundant flora. As the stream becomes more turbid downstream, the submerged vegetation disappears and nuisance growths of floating and emergent plants become common. The Guadalupe River between

New Braunfels and Gonzales has several stretches where reduced stream flow due to impoundment has created ideal habitats for spatterdock (*Nuphar* sp.), southern wildrice (*Zizaniopsis milacea*), cattails (*Typha* sp.), bulrushes (*Scirpus* sp.), water hyacinths (*Eichhornia crassipes*), and water planchon (*Egeria densa*). Hannan and Young (1970) concluded that the extensive aquatic macrophyte communities in this stretch of the Guadalupe River were due to the small riverine reservoirs (e.g., Lake Dunlap) that acted as nutrient traps. In the delta region of the lower Guadalupe River, large stands of cattails dominate the broad plains and water hyacinths have virtually blocked the main stream, bayous, and ditches (Young et al. 1973). Noxious aquatic vegetation (i.e., hydrilla [*Hydrilla verticullata*], water hyacinth, alligatorweed [*Alternanthera piloxeroides*], water lettuce [*Pistia stratoides*]) has been reported from the river reservoirs (i.e., Dunlap, McQueeney, Placid, and Woods) on the Guadalupe River and from Coleto Creek Reservoir (i.e., hydrilla) in the study area (Helton and Hartmann 1995).

In contrast, the headwaters of the San Marcos River contains a well-studied, extremely diverse, and rather unique aquatic flora (21 species including four exotic species and a variety of mosses) which has changed over the period from 1930 to 1991. Because of increased urbanization and commercial development of the headwater region, many plants present in the 1930s have been eliminated, new plants have been introduced, and habitat changes have occurred in the San Marcos River (Young et al. 1973; Staton 1992). A second unique ecosystem in the lower San Marcos River Basin is a series of six small marshes, or bogs, that occur just north of Ottine (adjacent to R.M. 24). The sphagnum vegetation of these bogs resembles that of East Texas and represents the most southwestern locality for this plant in the United States. Most of this unique vegetation is terrestrial with the wet sandy flats having stands of water hyssop (*Bacopa* sp.), water pennywort (*Hydrocotyle umbellata*), arrowhead (*Sagittaria falcata*), common cattail (*Typha latifolia*), and bushy beardgrass (*Andropogon glomeratus*) (Raun 1958).

Aquatic vegetation in the San Antonio River Basin, although less abundant, follows the same general distributional pattern as that described for the Guadalupe River Basin. It is either absent or very sparse throughout most of the lower San Antonio River Basin below the Medina River. High turbidity, the absence of riffles, and the occurrence of unstable substrates in this section of the river are not conducive to aquatic plant growth. Since these conditions persist in the lower reaches of the San Antonio River in Wilson, Karnes, and Goliad counties, aquatic vegetation in these reaches is not a problem nor is it likely to become one (Young et al. 1973). Aquatic macrophytes have been reported to be non-existent along the San Antonio River in Goliad County (Larry Larrade, M.S. thesis, in preparation, Southwest Texas State University).

The Nueces River and its tributaries are clear, spring-fed streams that possess a varied aquatic flora. In the upper Nueces River and its upper tributaries, aquatic plants are seldom abundant except in pools behind dams. The lower Nueces River from Calallen (R.M. 13) to 20 miles (mi) above Lake Corpus Christi (R.M. 67) has experienced severe overabundance of aquatic vegetation (particularly water hyacinth), and has successfully completed an aquatic plant eradication program (Young et al. 1973). However, Helton and Hartmann (1995) reported two noxious aquatic plant species, water hyacinth in Lake Corpus Christi and hydrilla in Choke Canyon Reservoir, respectively.

Extensive zooplankton data in these river basins (i.e., San Antonio, Nueces) are non-existent. The Academy of Natural Sciences of Philadelphia (1949) reported a variety of rotifers (i.e., *Cephalodella* spp., *Brachonius* sp.) and Cooper (1967) listed 36 crustacean taxa including cladocerans (i.e., *Diaphanosoma brachyurum*, *Ceriodaphnia reticulata*) and copepods (i.e., *Cyclops vernalis*) from the lower end of the Guadalupe River. These types of zooplankters (e.g., rotifers, cladocerans, copepods), listed as common components of lotic (Winner 1975) and lentic (Pennak 1957) ecosystems, could also occur in the San Antonio River and the Nueces River and associated man-made impoundments.

Twenty-five species of unionid clams occur in the Guadalupe River. In contrast, only 15 species of freshwater molluscs are known from the Nueces River Basin (Appendix A-3). These river basins are in the Central Texas Subprovince of freshwater clams. This subprovince is characterized by four species (Texas pimpleback [*Quadrula petrina*], golden orb [*Q. aurea*], Texas fatmucket [*Lampsis bracteata*], and *Sphenonaias mitchelli*) which comprise the only endemic freshwater community in Texas. In addition, one southern-derived species, Tampico pearly mussel (*Cyrtonaias tampicoensis*), occurs throughout the region (Neck 1982; Howell's 1995a, 1995c).

The aquatic insect fauna of the Guadalupe River Basin, although often studied, remains poorly known. Ephemeropterans (mayflies), odonates (dragonflies), coleopterans (beetles), and dipterans (true flies) were reported as common in the lower Guadalupe River (Academy of Natural Sciences of Philadelphia 1974). Recent information on the Guadalupe River near the City of Cuero reported mayflies and dipterans as abundant aquatic macroinvertebrates (Whiteside et al. 1991). Other than cave forms, very little work has been published concerning aquatic invertebrates in the San Antonio River Basin. Whiteside et al. (1993) reported mollusks (e.g., *Corbicula fluminea*), dipterans (chironomids), and mayflies (*Tricorythodes* sp.) as the most abundant invertebrate forms in Cibolo Creek near the San Antonio River at Karnes City. Members of only a few phyla of aquatic invertebrates (e.g., freshwater shrimp, dipterans) have been recorded from the Nueces River Basin (Young et al. 1973).

Despite the low occurrence of native fishes, the Guadalupe and San Antonio river basins are distinguished by a relatively high degree of endemism (six species) and by being the southwesternmost river drainage in which distinct populations of eastern lowland or Mississippi Valley fishes appear. A total of 87 freshwater species including 21 introduced forms has been reported from Guadalupe/San Antonio River Basin and its man-made lakes and reservoirs (e.g., Lake Dunlap, Coleto Creek Reservoir) (Appendix A-4). Whiteside et al. (1994) reported 52 fish species, dominated by minnows and sunfishes, in the San Marcos River. Fish collections in the Guadalupe River Basin were dominated by the omnivorous red shiner (*Cyprinella lutrensis*) and the western mosquitofish (*Gambusia affinis*) (Truett and Gallaway 1975). Espey, Huston and Associates (1983) reported that the most commonly collected ichthyofauna in the lower San Antonio River included the western mosquitofish, sailfin molly (*Poecilia latipinna*), red shiner, and bullhead minnow (*Pimephales vigilax*). The Nueces River Basin appears to mark the ultimate southwestward penetration for most, if not all, of the eastern lowland/Mississippi faunal elements. Despite its larger area and stream mileage than that of the adjacent San Antonio Bay Drainage, the Nueces River drainage has a very depauperate freshwater ichthyofauna. A total of 60 freshwater fish species including 11 introduced and two endemic forms is described for the Nueces River and its man-made impoundments (e.g., Choke Canyon Reservoir, Lake Corpus Christi) (Appendix A-4; Conner and Suttkus 1986; Hubbs et al. 1991). Young et al. (1973) reported minnows (e.g., *Notropis* spp.) to be the most abundant type of fishes in the Nueces River Basin.

3.4 Threatened, Endangered, and Candidate Species

Twelve aquatic/semi-aquatic species are listed for the river basins of the West-Central/South-Central study areas (Table V-4). Four federally listed endangered (2 fish, plant, and salamander), one threatened salamander, one Candidate Category 1 (C1) turtle, and two Candidate Category 2 (C2) blindcatfish species are found in the Guadalupe River basin. Two of the remaining C2 fish species along with a TOES "watch list" reptilian species occur in both the river basins of the West-Central/South-Central study

Table V-4

List of Aquatic Federal/State/TOES Endangered, Threatened, Candidate, and Watch List Species Potentially Occurring in River Basins of the West-Central/South-Central Study Areas

Common/Scientific Name	West-Central: Guadalupe F	Guadalupe S	Guadalupe TO	San Antonio F	San Antonio S	San Antonio TO	South-Central: Nueces F	Nueces S	Nueces TO
PLANTS									
Texas wild-rice									
Zizania texana	E	E	E						
AMPHIBIANS									
San Marcos salamander									
Eurycea nana	T	T	T						
Texas salamander									
Eurycea neotenes	C2			C2					
Texas blind salamander									
Typhlomoge rathbuni	E	E	T						
REPTILES									
Cagle's map turtle									
Graptemys caglei	C1								
American alligator									
Alligator mississippiensis			WL			WL			WL
FISH									
Blue sucker									
Cycleptus elongatus	C2	T	WL	C2	T	WL	C2	T	WL
Toothless blindcat									
Trogloglanis pattersoni	C2	T	E						
Widemouth blindcat									
Satan evrystomus	C2	T	E						
San Marcos gambusia									
Gambusia georgei	E	E	X						
Guadalupe bass									
Micropterus treculi	C2		WL	C2		WL	C2		WL
Fountain darter									
Etheostoma fonticola	E	E	E						

Legend: F = Federal; S = State; TO = TOES; WL = Watch List; T = Threatened; C1 = Candidate Category 1; C2 = Candidate Category 2; X = Extinct; E = Endangered

Source: TOES 1993, 1995; TPWD 1995a, 1995b; USFWS 1995c, 1995d areas. The remaining C2 salamander species is confined to the West-Central Study Area (TOES 1995; USFWS 1995c, 1995d; TPWD 1995a, 1995b). Two aquatic invertebrates of special concern which are also listed as C2 species (USFWS 1994), disjunct crawling water beetle (*Haliplus nitens*) and Flint's net-spinning caddisfly (*Cheumatopsyche flinti*) may occur in the study areas, however, the specific distribution in Texas is unknown (TOES 1988; Linam et al. 1994).

Federal endangered and threatened mollusks are not listed for the West-Central/South-Central study areas (USFWS 1995c, 1995d). However, false spike (*Quincuncina mitchelli*) has been proposed as a candidate for federal protection (Neves 1993) and is considered a species of concern by the Texas Organization for Endangered Species (TOES) (1988). This species is known to occur in the Guadalupe River Basin (Table V-5).

Table V-5

Distribution of Listed Native and Special Concern Unionid Mollusks
in River Basins of West-Central/South-Central Study Areas

	River Basins	
Unionidae	Guadalupe	Nueces
Texas fatmucket *Lampsilis bracteata*	X	X
Golden orb *Quadrula aurea*	X	X
Smooth pimpleback *Quadrula houstonensis*	X	
Texas pimpleback *Quadrula petrina*	X	
False spike *Quincuncina mitchelli*	X	

Source: Howells 1995a

Native mollusks of the United States and Canada were recently evaluated and ranked as endangered, threatened, or special concern species by Williams et al. (1993). These ranking are not legally binding but do provide an insight to species of mollusks which could potentially be listed in the near future. Two threatened and two special concern species of mollusks are present in the West-Central/South-Central study areas. Threatened species include Texas pimpleback (*Quadrula mortoni*) and smooth pimpleback

(*Quadrula houstonensis*). Special concern species are Texas fatmucket (*Lamsilis bracteata*) and golden horb (*Quadrula aurea*). These species are present in several river basins of the study areas (see Table V-5).

4.0 ANALYSIS OF POTENTIAL ECOLOGICAL IMPACTS

4.1 Microbes

Fecal coliform levels are elevated only in the Guadalupe and lower San Antonio river basins. Transfers from these basins could be a cause of concern if fecal coliform levels are lower in the conduit or recipient basin. However, since the majority of the proposed transfers would terminate at a water treatment facility, fecal coliform levels would not be a concern in most of the proposed water transfers. Based on this general qualitative analysis, a "low potential impact rating" was assigned to fecal coliforms.

Potential increases in Biological Oxygen Demand (BOD) from microbial populations and the potential presence of protozoan parasites could present problems for enclosed long-distance conveyances to a terminal water storage reservoir. Heterotrophic micro-organisms could increase BOD levels depending on the abundance/density of decomposing organisms transported within the enclosed conveyance and could result in water taste/odor problems. In addition, the transferred water could contain dormant environmentally resistant (18 months) oocysts of the protozoan parasite, *Cryptosporidium parvum*, a component of rivers and streams, lakes and reservoirs, raw and treated sewage, and treated surface water. This coccidian parasite, present in farm animal and human wastes, represents one of the recently defined, emerging microbial threats, especially to high-risk groups (i.e., individuals with suppressed immune systems, malnourished infants, etc.) to the general human population (Lederberg et al. 1992). As a component of surface waters (95 percent in the United States), it has recently caused waterborne disease outbreaks in municipal water supplies of urban areas (e.g., Milwaukee, Wisconsin) and rural areas (Carrollton, Georgia; Jackson County, Oregon) (Pontius 1993; Moore et al. 1994).

As a result of these concerns, a new and expense monitoring program began in approximately 2,000 communities around the United States in October 1994, under the Information Collection Rule (ICR), developed by the Disinfectants/Disinfection Byproducts Rule (D/DBPR) negotiated rulemaking committee of the USEPA. The ICR is intended to provide surface water treatment to determine the level of and criteria for Enhanced Surface Water Treatment Rule (ESWTR) in order to prevent increased microbial risk as result of the proposed D/DBPR. In addition, the American Water Works Association (AWWA) has also developed a 12 point plan to protect the public from the threat of *Cryptosporidium* in drinking water (AWWA 1994b; Bingham and Langstaff 1994). Based on these concerns, a "low to moderate potential impact rating" was assigned to other microbes.

4.2 Algae

Native lotic and lentic algal communities are fairly consistent in composition (diatoms, green algae, blue-green algae) within the study areas with changes occurring in dominant forms in response to a variety of physicochemical/environmental factors. Multiple interacting physical, chemical, and biotic factors, in proper sequence, may lead to the development and persistence of nuisance algal blooms (i.e., blue-green algae). Massive blue-green blooms occurring in late summer and fall could potentially be transferred between systems utilizing short conveyances. Increased taste and odor as well as various health (e.g., gastrointestinal, respiratory, dermatologic) and wildlife (e.g., ichthyotoxic) effects could occur in the recipient basins (Palmer 1964; Gorhmam and Carmichael 1988). As previously discussed, some algal species could potentially cause increased wear on the intake's water pumps or cause corrosion in steel (pitting) and concrete machinery (Anderson 1990; van Zon 1992). Algae was assigned a "low to moderate impact rating" due to these concerns.

4.3 Aquatic Macrophytes

Noxious aquatic plants could potentially be transferred by the operations associated with some of the proposed interbasin water transfers (Howells 1992). Helton and Hartmann (1995) reported that five exotic plant species, water hyacinth, hydrilla, water lettuce, alligatorweed and Eurasian watermilfoil (*Myriophyllum spicatum*), are established in the river basins and reservoirs of the West-Central and South-Central study areas (Table V-6). These species could potentially be transferred via existing streams/lakes or enclosed conveyance facilities between lacustrine habitats. These species could cause alterations in the ecosystems (i.e., outcompetes native aquatic plant species) and detrimental economic/environmental effects ranging from impeding navigation, clogging drainage and irrigation canals, to reducing recreational activities and disrupting wildlife habitats (Pieterse and Murphy 1990). Therefore, aquatic macrophytes were assigned a "low to moderate impact rating".

Table V-6

Known Occurrence of Exotic Organisms by River Basin/Man-Made Impoundment
(West-Central/South-Central Study Areas)

Common/Scientific Name	West-Central		South-Central
	Guadalupe	San Antonio	Nueces
EXOTIC PLANTS			
Water hyacinth/*Eichhornia crassipes*	X[1]		X[4]
Water lettuce/*Pistia stratiotes*	X[2]		
Hydrilla/*Hydrilla verticillata*	X[3]		X[5]
Eurasian watermilfoil/*Myriophyllum spicatum**			
Alligatorweed/*Alternanthera philoxeroides*	X[2]		
EXOTIC SHELLFISH			
Giant Ram's-horn snail/*Marisa cornuarietis*	X		
Asiatic clam/*Corbicula fluminea*	X	X	X
EXOTIC FISH			
Grass carp/*Ctenopharyngodon idella*	X		
Rudd/*Scardinius erythrophthalmus*	X		
Africa lake cichlid/*Pseudotropheus* sp.	X	X	
Convict cichlid/*Cichlasoma nigrofasciatum*	X	X	
Rio Grande cichlid/*Cichlasoma cyanoguttatum*	X	X	X
Blue tilapia/*Tilapia aurea*	X	X	
Mozambigue tilapia/*Tilapia mossambica*	X	X	
Redbelly tilapia/*Tilapia zilli*		X	

* Occurs in Lake Austin
[1]Only Lake Dunlap and Guadalupe River
[2]Only Lake Dunlap
[3]Only Coleto Creek Reservior, Lake Dunlap, and San Marcos River
[4]Only Lake Corpus Christi
[5]Only Choke Canyon Reservior

Legend: sp. = species

Source: McMahon 1983; Howells et al. 1991; Hubbs et al. 1991; Horne et al. 1992; Howells 1992; Helton and Harmon 1995

4.4 Zooplankton

Historic and/or recent data on zooplankton communities in the study areas are almost non-existent. As a result, a potential impact rating cannot be assigned to zooplankton at this time.

4.5 Benthic Invertebrates

Differences in water quality and possible physical alterations of habitat from construction and/or operational activities could significantly affect composition, diversity, and abundance of aquatic invertebrates in the donor basin, conduit system, and/or recipient basin. The transfer of benthic macroinvertebrates could also occur during the interbasin water transfers. With the exception of some native/exotic mollusks, potential impacts to benthic invertebrates are unknown due to the lack of macroinvertebrate studies documenting the results of similar transfers in the United States and the lack of recent benthic macroinvertebrate data from the river basins in the West-Central/South-Central study areas.

4.5.1 Native Mollusks

Introduction of freshwater unionid mussels (Unionidae) would not be expected to have negative impacts since no significant effects as yet have been reported from other introductions (Howells 1995a). As previously discussed, construction of the intake structure and/or new channel reservoir for the proposed interbasin water transfers could result in significantly negative impacts if construction disturbs or destroys the habitat of the native mollusks. This would potentially reduce the survival/recruitment rate of the species, decrease the species population, and could potentially, in the future, result in the listing of the species. However, significant direct negative impacts to native listed mussels would only occur if the intake is located in or immediately downstream from a population of the listed species (Neves 1993). Negative indirect effects could also occur if the number of potential fish host species decreases since most mussels require a specific host or hosts to transform into the juvenile phase.

4.5.2 Exotic Mollusks

Two state-listed harmful mollusks, the introduced Asiatic clam and the Giant Ram's-horn snail (*Marisa* spp.), are present in all of the major drainage basins along the Texas coast and the Comal/San Marcos rivers, respectively (Table V-6; McMahon 1983; Horne et al. 1992). Impacts similar to those described for the Asiatic clam in the Southeast Study Area (i.e., clogging of intake structures, potential decreases in native mollusk populations) would potentially occur. It has been postulated that the Asiatic clam could outcompete native mollusk species due to its ability to achieve high densities. Some studies have indicated severe reductions in numbers and elimination of native mollusk populations after the introduction of the Asiatic clam, while other studies found no significant impact on native populations after the introduction. Therefore, some researchers hypothesize that the Asiatic clam cannot outcompete native mollusks unless the affected environment is significantly impacted by human activities (i.e., dredging, channelization, etc.) (McMahon 1983). If the Giant Ram's-horn snail is transferred to a suitable habitat (i.e., a population of aquatic macrophytes), it could become established. Long-term detrimental impacts would potentially occur to aquatic macrophytes and associated attached invertebrate fauna.

The introduced zebra mussel (*Driessena polymorpha*) has spread rapidly throughout North America but is not yet known to occur in Texas. The potential for introduction and establishment of this species into the reservoirs/rivers in South-Central/West Central Texas is considered to be very low since this species would not tolerate the high mean annual air temperatures (greater than 26°C) of the region (Strayer 1991).

4.5.3 Summary

Depending on the origin of the water transfer and the design of the project, native mollusks could experience "low to moderate potential impacts" due to and/or construction operational activities. Exotic mollusks (e.g., the Asiatic clam) could clog intake structures and therefore cause operational impacts. Generalizations relative to the potential impact to or from other benthic invertebrates cannot be accurately assessed at this time due to lack of recent data on the composition of benthic macroinvertebrates in the West-Central/South-Central study areas.

4.6 Amphibians and Reptiles

Amphibian/reptilian communities in the study areas could potentially be impacted by some of the proposed interbasin water transfers. In general, most of the potential impacts would be related to construction of the intake structure and/or new channel reservoir since most of the transfers would be closed and would empty into a terminal water storage reservoir where impacts can usually be controlled. However, if the intake or new channel reservoir is located in a nursery area (bay or backwater area), construction and operational impacts could result.

Construction would potentially disturb or destroy littoral and/or shoreline habitats. Operational activities may result in impingement/entrainment and thus a decrease in recruitment/survival of local populations. In addition, interbasin water transfers from large rivers to small intermittent creeks could significantly alter semiaquatic and riparian habitat by increasing water levels in the recipient system. Higher water levels could result in decreases or increases in amphibian/reptilian habitat. Introduction of non-native amphibians and reptiles is not a major concern since most species occur in both study areas. A local concern would be the transfer of the bullfrog (*Rana catesbeina*), an amphibian species which consumes other amphibians, potentially resulting in a decrease in native amphibian populations. Based on these analyses, a "low to moderate potential impact rating" was assigned to amphibians and reptiles.

4.7 Fish

Significant differences exist in the fish populations between some basins within the West-Central and South-Central study areas. The potential effects from interregional (i.e., between a basin in one study area to another study area [West-Central to South-Central]) water transfers are discussed in this section.

4.7.1 Native Populations

Establishment of any introduced native species would be detrimental by multiple factors. These include but are not limited to : (1) survival during the transfer, (2) presence of suitable habitat a the intake/outfall site for the potential transfer species, (3) availability of trophic position (pelagic piscivore, benthic insectivore, adaptable omnivore, etc.) in the vicinity of the outfall site; (4) adaptability to a trophic assemblage and physicochemical environment of the recipient basin; and (5) species-specific characteristics (abiotic/biotic adaptability versus specificity in habitat requirements). Fish are less likely to survive long, closed transfers due to the potential for impingement, abrasion, and the lack of food resources. Site-specific abiotic and biotic fisheries data (composition, numbers, condition factors) are needed from the intake/outfall site and immediate vicinity to determine or predict the possibility of the introduction/establishment. Since these data are not available, only a general qualitative assessment can be made regarding the potential for introduction/establishment of the transfer species. The chance for establishment for most of the potential transfer species would be low in a long, closed transfer and, at best, moderate in an open transfer.

Native fish populations could also be affected by construction of new channel reservoirs/intake structures and/or the operation associated with the transfer of water. If construction occurs in an area utilized for spawning, the subsequent alteration to the habitat could result in a local decrease in the population of the species. However, the negative impact would be local and would not significantly affect species with stable populations.

The operation of the water transfer would also potentially impact egg, larval, juvenile, and potentially some small adult phases of native fishes in the donor basin by diverting these phases into the conduit system. The transfer may result in mortality due to abrasion/collision, velocity changes, turbulence, and sheer stress from pumping, impingement on screens, or entrainment (i.e., especially from long closed pipelines) (Miracle and Gardner 1979; Cada 1990). Significant water withdrawals/additions during the proposed interbasin water transfers could also alter physicochemical parameters and affect riverine and estuarine fish populations.

Based on known distribution and general habitat requirements, two native species and three native introduced species in the Guadalupe/San Antonio river basins could potentially be transferred and become established in the South-Central Texas Study Area (e.g., San Antonio River to Choke Canyon Reservoir). The pallid shiner (*Notropis amnis*) and the bigscale logperch (*Percina macrolepidum*) are native species; rock bass (*Ambloplites rupestris*), smallmouth bass (*Micropterus dolomieui*), and the spotted bass (*Micropterus punctulatus*) are the native introduced species (Table V-7).

As previously discussed, establishment would depend on survival during the transfer, availability of food, and spawning habitat. The pallid shiner and the spotted bass, which occasionally becomes established

Table V-7

List of Fish Species with the Potential for Transfer in the Various River Basins and Man-Made Impoundments West-Central to South-Central Study Areas

Taxa	West-Central Guadalupe/San Antonio	South-Central Nueces	Transfer
CARPS/MINNOWS			
Grass carp	I[1]		Yes
Nueces roundnose minnow	E		No
Ribbon shiner	N		No
Pallid shiner	N		Yes
Sand shiner	N		No
Rudd	I		Yes
SUCKERS			
Lake chubsucker	N		No
BULLHEADS/CATFISHES			
Widemouth blindcat	E		NA[2]
Toothless blindcat	E		NA[2]
SUCKERMOUTH CATFISHES			
Suckermouth catfish	I		Yes
KILLIFISHES			
Golden topminnow	N		No
Blackstripe topminnow	N		No
LIVEBEARERS			
Largespring gambusia	E		No
San Marcos gambusia	E		No
Guppy	I		Yes
SUNFISHES			
Rock bass	I		Yes
Smallmouth bass	I		No
Spotted bass	NI		Yes
PERCHES			
Bluntnose darter	N		No
Fountain darter	E		No
Bigscale logperch	N		Yes
Dusky darter	N		No
CICHLIDS			
African lake cichlid	I		Yes
Convict cichlid	I		Yes
Blue tilapia	I		Yes
Mozambique tilapia	I		Yes
Redbelly tilapia	I		Yes

[1]Introduced radio-tracked specimens in Guadalupe River below the City of Sequin
[2]Subterranean fishes

Legend:
N = Native
I = Introduced
NI = Considered native but possibly introduced
E = Endemic
NA = Not Applicable

Source: Conner and Suttkus 1986; Howells et al. 1991; Hubbs et al. 1991; Robbins et al. 1991; Whiteside and Berkhouse 1992; SARA 1994b in reservoirs, would have a moderate to high potential for establishment due to its adaptability to slow current/turbidity and warm water (Robison and Buchanan 1992). The bigscale logperch, generally prefers streams or rivers, but it can become common in lakes when it is the only percid (Lee et al. 1980). In the long-term, the bigscale logperch has a low to moderate chance of transfer and subsequent establishment. The smallmouth bass would have a very low chance of survival due to their preference for cooler waters than would be present in either during the transfer or in summer at Choke Canyon Reservoir. The rock bass would have at least a moderate chance for survival since it is more adaptable to temperature.

4.7.2 Exotic Species

Nine introduced exotic species could potentially be introduced from the West-Central Study Area to the South-Central Study Area by interbasin water transfers. Two exotic species, the grass carp and rudd (*Scardinius erythrophthalmus*), could potentially be introduced from one of the proposed water transfers (see Tables V-6 and V-7). Other introduced exotic species (i.e., convict cichlid [*Cichlasoma nigrofasciatum*], African lake cichlid (*Pseudotropheus* sp.), blue tilapia [*Tilapia aurea*]), Mozambique tilapia (*mossambica*], redbelly tilapia [*T. zilli*], suckermouth catfish [*Hypostomus pleucostomus*] and guppy [*Poecilia reticulata*]) could also be introduced in another transfer (i.e., San Antonio River to Choke Canyon Reservoir).

Spawning habitat and food resources are available for grass carp; thus, if survival occurs during the transfer, the grass carp has a moderate to high chance of establishment. If rudd are transferred, its establishment is likely due to its wide range in environmental tolerances, adaptable feeding habits (i.e., can be carnivorous and/or herbivorous), and ability to hybridize with golden shiners (*Notemigonus crysoleucas*) (Howells et al. 1991). Detrimental effects may occur if either one or both of these species become established. Reservoir fish populations could be significantly impacted if any cichlid becomes established due to competitive habits and high reproduction/survival rates. Other introduced exotic species which could be introduced include suckermouth catfish and guppy. These species could also be detrimental if populations become established.

In addition, various fish pathogens (i.e., fungi, protozoans, trematodes, cestodes, and parasitic copepods) (Hoffman and Meyer 1974) could be tranferred (i.e., in the benthos, zooplankton, or fish) between river basins between the West-Central to the South-Central Study Area. Few studies have been conducted on the potential effects from the introduction of fish pathogens. Less than two percent of fish diseases are known and even for these the knowledge is incomplete (Stewart 1991). Diseases can be destructive to aquatic species and may result in mass mortalities, thereby jeopardizing economic enterprises, whole populations, and sometimes resulting in the extinction of the species (Bauer and Hoffman 1976). The potential effects from the introduction of fish pathogens can not be addressed without extensive surveys. Therefore the potential effects from the introduction of fish pathogens between river basins are currently unknown.

A "low-moderate potential impact rating" was assigned for fish because of the potential presence of federal endangered/C2, state-listed endangered/threatened, and TOES "watch list" species, the potential introduction of several native/exotic fish species and their pathogens, and the alterations in the fish communities to the potential increase in current flow.

4.7.3 Endangered and Threatened Species

Four federally listed endangered, one threatened, one C1, five C2 species and one TOES "watch list" species could potentially be affected by construction of the intake structure and operational activities during the proposed interbasin water transfers. As previously stated, potential impacts related to water withdrawal cannot be addressed since the proposed rates are unknown.

Texas wild-rice, San Marcos salamander, and San Marcos gambusia are known from the upper reaches of the spring-fed San Marcos River. The Texas salamander is confined to springs, springruns, and subterranean waters in the Edwards Plateau, while the fountain darter occurs only in San Marcos Springs and Comal Springs in Hays and Comal counties, respectively. Guadalupe bass are found primarily in Edwards Plateau rivers, while the blind catfishes and Texas blind salamander occur only in deep underground caves in Bexar County.

The fountain darter, San Marcos gambusia, Texas wild-rice, San Marcos and Texas salamanders and Guadalupe bass would not be affected as long as the intake structure was located a safe distance downstream from the habitat of these species. Both the blind catfishes and Texas blind salamander would not be affected by the proposed interbasin water transfers since surface water withdrawals would occur outside of the Edwards Aquifer recharge zone southeast of San Antonio. Beneficial impacts would occur to the blindcatfish/salamanders and cave invertebrates (e.g., several federally listed candidate amphipods, beetles, spiders, and shrimp species [USFWS 1994, 1995d]); if any of the recharge alternatives are selected, since water levels would potentially increase in the Edwards Aquifer.

Cagle's map turtle is endemic to the Guadalupe river system with robust populations between Victoria and Sequin (Linam et al. 1994), while the blue catfish occurs in large rivers of the West-Central/South-Central study areas. The blue sucker and the Cagle's map turtle could be affected by the construction/operational activities of the new channel reservoirs and/or intake structures associated with the proposed interbasin water transfers if the construction/operational activities occur in habitat currently being utilized by the species as spawning or nursery habitat. In addition, the potential transfer of larval or juvenile phases of the blue sucker may result in mortality due to abrasion/collision, velocity changes, turbulence, and sheer stress from pumping, impingement on screens, or entrainment (i.e., especially from long closed pipelines). If either of these effects occur, the recruitment/survival rate could decrease and potentially reduce the population of the blue sucker. The American alligator would be able to avoid most construction and operational impacts due to its mobility and would not be impacted.

Two aquatic invertebrates of special concern (also listed as federal C2 species - USFWS 1994), disjunct crawling water beetle and Flint's net spinning caddisfly may occur in the study area; however, the specific distribution in Texas is unknown (TOES 1988; Linam et al. 1994). If present, these aquatic invertebrates could be affected by construction/operational activities associated with the proposed interbasin water transfers.

5.0 SUMMARY

In general, open transfer systems (e.g., reservoirs, rivers) have a higher potential for significant impacts because of the lack of controls to prevent potential dispersal, introduction, and establishment of introduced native fishes (see Table V-7), federal endangered/threatened/candidate and state endangered and threatened/TOES "watch list" species (see Table V-4), and exotic aquatic organisms (see Table V-6). Although closed systems (e.g., pipelines) can result in significant environmental impacts, closed systems generally have lower impact potential since engineering and environmental controls can often be designed and/or utilized to lessen or mitigate impacts.

Potential impacts to and from aquatic communities for the proposed interbasin water transfers are difficult to assess due to the lack of recent aquatic biotic data for the West-Central and South-Central study areas. However, some general qualitative impacts to aquatic communities can be postulated. Overall, impacts would potentially vary from low to moderate (Table V-8). However, the uncertainty of analysis for most aquatic components is moderate to high. Therefore, site-specific environmental assessments are necessary to determine impacts for each proposed transfer.

6.0 RECOMMENDATIONS AND MITIGATIONS

During the site selection process, several alternative locations and alternative intake sites at each location should be proposed. An environmental assessment should be conducted at each location and proposed intake site to ensure that the best alternative for the environment (i.e., the least affected site for native mollusks/fishes, threatened/endangered species, exotic/nuisance organisms) and the proposed project can ultimately be selected. Comprehensive water quality studies should be conducted for the assessment to determine if the overall water quality at the proposed intake site(s) is suitable for its designated uses (i.e., contact recreation, high quality aquatic habitat, and public water supply). Multi-year environmental studies are recommended due to the current lack of abiotic/biotic aquatic data from river/reservoir ecosystems in the study areas and the variability in the population due to fluctuations in the abiotic environment (e.g., droughts, floods).

Engineering and environmental mitigations which can be utilized during the engineering design and operational phases of the project to alleviate or lessen impacts to or from aquatic components of the ecosystem can be categorized by the type of transfer (i.e., open or closed). Open transfers utilize existing rivers, reservoirs, or canals to complete the transfer. Closed transfers use new or existing conveyance facilities (e.g., pipelines, tunnels) which terminate into another body of water or a terminal water storage reservoir adjacent to a water treatment facility. General mitigations for each of these transfer types and associated facilities for the West-Central/South-Central Study Areas are listed below:

Table V-8

Qualitative Rank of Potential Environmental Impacts
West-Central/South-Central Study Areas

Environmental Component	Rank Impact	Explanation	Uncertainty of Analysis Rank
Microbes			
Fecal Coliforms	Low	Low levels of fecal coliforms in most of the river basins	Moderate
Other Microbes	Low-Moderate	Potential presence of a human protozoan parasite (*Cryptosporidium parvum*); potential increases in Biological Oxygen Demand levels could cause taste and odor problems	High
Algae	Low-Moderate	Potential taste/odor, human health, and toxic effects to fish from algal blooms; potential long-term wear problems on pipelines and pumps from algae	High
Aquatic Plants	Low-Moderate	Potential transfer of noxious aquatic plants	Moderate
Zooplankton	Unknown	Lack of historic/recent zooplankton data	Not Applicable
Benthic Invertebrates			
Mollusks	Low-Moderate	Potential construction/operational activities impact on native mollusks; potential clogging of intakes by an exotic mollusk (Asiatic clam)	High
Other	Unknown	No site-specific data	Not Applicable
Amphibians/Reptiles	Low-Moderate	Local construction impacts on breeding and nursery habitat (littoral zone, river back-waters); alteration of small river/creek habitat due to potential increase in flow	High
Fish	Low-Moderate	Potential transfer of exotic fish species, introduction of non-indigenous/native forms, and impacts from construction/operational activities (impingement, entrainment, etc.) on threatened, endangered, and indigenous species	Moderate

(1) open transfers from reservoirs/rivers:

- the intake site should be located in the middle (transitional zone) or (lower lacustrine zone) section of the reservoir to reduce impacts on aquatic biological communities (e.g., aquatic plants, fishes, amphibians, reptiles);
- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).

(2) new channel reservoirs (open/closed transfers):

- design intake structure to minimize impingement of fish by utilizing surface to mid-water withdrawal, horizontal screens, and deflectors;
- use a series of progressively smaller screens to help eliminate transfer of other aquatic organisms (if engineering alternatives are feasible).
- if necessary, treat the intake area with algicides prior or during pumping to alleviate potential long-term pump damage;
- design the reservoir with steep sides or schedule periodic 30-day water level drawdowns (initial design must allow this to occur concurrently with operation) to limit the establishment of the Asiatic clam.

(3) conveyance structures in closed transfers:

- design or plan to use horizontal screens in intake structures to reduce the impact of fish impingement;
- utilize screens with mesh size of less than 0.08 centimeters (cm), remove shells manually, or use mechanical clam traps at appropriate points in the system, and/or conduct periodic chlorination at the intake site to control the Asiatic clam in the system;
- use materials in pipelines (i.e., mortar lining) that will resist damage from transferred aquatic organisms (e.g., algae, bacteria);
- use bar screens (one inch diameter) to prevent the entrainment of fish;

(3) conveyance structures in closed transfers (continued):

- use aeration devices along the conveyance route to reduce Biological Oxygen Demand (BOD) from decaying aquatic organisms.

(4) terminal water storage reservoirs;

- design the terminal water storage reservoir to hold maximum long-term water storage capacity and/or design an overflow system to ensure that noxious/exotic organisms which may survive the transfer do not escape into nearby water bodies;
- design the terminal water storage reservoir to prevent establishment of noxious aquatic plants;
- utilize aeration devices during operation if odor/taste problems result from algal blooms and/or high BOD levels.

(5) water treatment facilities:

- conduct pre-construction and/or pre-treatment surveys to determine the presence or absence of pathogenic organisms (i.e., *Cryptosporidium parvum*, *Giardia*, *Escheri coli*, enterovirsuses, total/fecal coliforms) in the recipient system, as specified by the USEPA's (1994) ICR, D/DBPR, ESWTR, and if necessary, add additional water devices (e.g., micron porosity pressure filters, ozone) in the treatment plant to ensure a safe water supply.

In summary, open systems have a higher potential for significant adverse environmental impacts because of the lack of available controls to prevent potential dispersal, introduction, and establishment of introduced and exotic aquatic organisms. Although significant environmental impacts could occur in closed transfers, detrimental environmental impacts are more likely to occur in open systems. Closed transfer systems which involve the transfer of water from the donor system directly to a water treatment facility are recommended for interbasin water transfers since the transfer of aquatic organisms can be controlled to a greater degree than transfers through open or open/closed systems. If environmental problems are identified which are unavoidable, mitigation plans should be developed to lessen or alleviate the impacts. If mitigation plans are unacceptable to regulators, the design should be changed or the site should be relocated to the best alternative location.

SECTION VI

ENVIRONMENTAL/MITIGATION COSTS

1.0 ENVIRONMENTAL/MITIGATION COSTS

1.1 Introduction

Harmful nonindigenous aquatic species (exotic organisms) annually cost the United States hundreds of millions to perhaps billions of dollars. Economically significant species occur in all groups of aquatic organisms and affect numerous economic sectors (i.e., fisheries and water use, utilities, natural areas, and human health). Available accountings tend to underestimate losses attributable to nonindigenous species and inadequately account for intangible, non-market impacts. Harmful nonindigenous aquatic species also threaten indigenous aquatic species and exact a significant toll on United States ecosystems. Numerous declines in populations of indigenous and threatened/endangered aquatic species (e.g., razorback sucker [*Xyrauchen texanus*], woundfin [*Plagopterus argentissimus*]) have been attributed to nonindigenous and native aquatic species (e.g., grass carp [*Ctenopharyngodon idella*] and red shiner [*Cyprinella lutrensis*]) (Deacon 1988). The worst nonindigenous aquatic species have caused species extinctions (e.g., California's Lake Mono: predatory sunfishes [*Lepomis* spp.]; Great lakes: sea lamprey [*Petromoyzon marinus*]) and wholesale transformations of ecosystems (e.g., Great Lakes: zebra mussel [*Dreissena polymorpha*], Flathead River-Lake: opposum shrimp [*Mysis relicta*]) (Spencer et al. 1991; Courtenay 1993; Mills et al. 1993).

Environmental/mitigation costs for adverse impacts on aquatic ecosystems depend entirely on the type and severity of the impact. The range of possible impacts associated with water transfer is wide: aquatic ecosystem changes, scouring/silting of channels, species transfer, health problems (including waterborne and waterbased diseases), and alterations in water quality/quantity. Such spillover or uncompensated costs for these impacts are normally included in benefit/cost ratios associated with economic analysis. Economic analysis of past introductions is feasible through careful research, although relatively little has been done and the studies that exist are of highly uneven quality. Even less has been done in the way of future projections that attempt to predict economic scenarios with and without a particular introduction. To date no "standard accounting practice" exists for nonindigenous benefits costs, whether past or projected. Projecting future economic effects necessarily follows detailed scientific analysis (e.g., detailed risk assessment or Environmental Impact Statement). Projections of future economic effects are available for some prominent exotic organisms (e.g., zebra mussel and purple loosestrife [*Lythrum salicaria*]). Potential economic losses (worst-case scenario) for water transfers over the next few years could surpass

Table VI-1

Documented Benefit/Cost Ratio for Eradication, Control, or Prevention of Selected Nonindigenous Aquatic Species

	Direct Effects		Indirect Effects		Costs						
Impacts	Market Goods	Nonmarket Goods	Multiplier Effects[1]	Related Goods	Direct Control Costs	Opportunity Costs	Distribution Costs Considered	Year of Study	1991 Total Benefits	1991 Total Costs	Benefit/ Cost Ratio
Past Impacts-Plants											
Hydrilla and water hyacinth	0.497	-	-	0.016	-	-	No	1974	1.260	0.041	31/1
Hydrilla and water hyacinth	-	0.023	-	-	0.100	-	No	1977	0.047	0.203	0.23/1
Hydrilla and water hyacinth	-	0.567	-	-	0.003	-	No	1978	1.075	0.006	179/1
Hydrilla and water hyacinth	-	0.869	-	-	0.019	-	No	1979	1.514	0.033	45.9/1
Hydrilla and water hyacinth	-	0.468	-	-	0.089	-	No	1982	0.641	0.122	5.25/1
Past Impacts-Fish											
Sea lamprey	-	550[2]	-	-	40	-	No	1980	878.588	63.897	13.75/1
Sea lamprey	-	219,748	-	42,896	8.681	-	No	1988	296.421	9.797	30.25/1
Potential Impacts-Plants											
Purple loosestrife	6.54	39.32	-	-	0.100	1.6	No	1987	53.477	1.982	27/1

1 Not applicable

2 These estimates are the value of all sport and commercial fishers in the Great Lakes. This study used "all or none" valuation technique and hence overstates benefits to sea lamprey control.

Notes: Dollar figures are in millions; total columns give Net Present Values in 1991 dollars. The ratios given compare the benefits to the costs of eradicating, controlling, or preventing the non-indigenous aquatic species invasion under the circumstances that were studied.

Source: Talhelm and Bishop 1980; Colle et al. 1987; Thompson et al. 1987; Spaulding and McPhee 1989; Cochran 1992

Table VI-2

Average Zebra Mussel Monitoring and Control Costs for Facilities Reporting these Costs by Water Source

	Years						
Water Source	1989	1990	1991	1992	1993	1994	1989-1994
Great Lakes							
Facilities[1]	22	46	66	73	76	77	84
Costs[2]	25.2	51.0	112.2	176.0	170.1	95.1	513.6
Tributaries							
Facilities	9	14	24	30	32	30	37
Costs	6.7	33.2	16.2	60.9	79.8	64.3	195.2
Inland Waters							
Facilities	0	1	3	4	4	4	4
Costs	0.0	10.0	6.6	28.6	168.8	18.8	223.6

[1]Facilities include power-generating utilities, municipal water suppliers, and industries
[2]In thousands of dollars

Source: Hushak et al. 1995

Table VI-3

Dollars Spent to Manage Hydrilla and Floating Plants in Florida from 1980-1991

Year(s)	Hydrilla	Floating Plants*
1980 - 88[1]	$43,572,000	$35,668,000
1989[2]	4,493,000	2,632,000
1990[2]	4,142,000	2,016,000
1991[2]	3,146,000	2,872,000
Total	55,352,000	43,188,000

*Water hyacinth and water lettuce
[1]Estimated cost of operations in all waters except those exempt from permitting and reporting requirements
[2]Dollars spent under state and federal funding programs in public waters

Source: Schmitz et al. 1993

outbreak in Milwaukee, Wisconsin in 1993. The estimated financial toll on the City of Milwaukee was in excess of $54 million dollars (Fox 1994) and can be broken down as follows:

- $37.0 million - lost wages and productivity
- $13.0 million - hospitalization
- $2.0 million - clinic treatment
- $1.3 million - water utility expenses
- $0.5 million - emergency room treatment
- $0.3 million - statewide water testing
- $0.2 million - city health department

Three new rules (Information Collection Rule [ICR], Disinfectants/Disinfection Byproducts Rule [D/DBR], and Enhanced Surface Water Treatment Rule [ESWTR]) have been developed in a regulatory negotiation, with participation from federal, state, and local health and regulatory agencies and elected officials, consumer groups, environmental organizations, and the drinking water industry. Estimated costs to implement these rules by the year 2000 are listed in Table VI-4. These cost projections would directly affect any closed interbasin water transfer utilizing a terminal water storage reservoir adjacent to a water treatment facility and indirectly, open transfers (U.S. Environmental Protection Agency [USEPA] 1994a).

In addition to human health waterborne-related diseases, viral or bacterial fish pathogens and fish parasites could affect organisms in the receiving basin and cause various environmental problems (i.e., decline or extirpation of indigenous fish species). Open interbasin water transfers are especially susceptible to parasites and fish diseases. Kopchynski (1994) calculated in 1992 dollars the preliminary cost analysis for the disinfection, filtration, and treatment of 500 million gallons per day (MGD) flow of Garrison Diversion Unit (GDU) water. Preliminary construction costs and operation and maintenance costs for ozonation, chlorination, UV (ultra violet) light disinfection, direct filtration and direct in-line filtration of GDU water are shown in Table VI-5. A more detailed discussion of the preliminary cost analysis in given in Moretti et al. (1993).

Construction of a large scale treatment facility for the prevention of biota transfer in trans-basin diversions might be technical feasible. Some conclusions drawn for the above proposed facility for the

Table VI-4

Estimated Costs for Information Collection Rule (ICR), Disinfectants/Disinfection Byproducts Rule (D/DBPR), and Enhanced Surface Water Treatment Rule (ESWTR)

Rule	Capital ($)	Operations and Maintenance	Total[1] ($/yr)	Monitoring	State Implementation
ICR[2]	$57 million	-	NA	$73 million	-
D/DBPR Stage 1	$4.4 billion	$489 million/ year	$1.035 billion	$58 million/ year	$23 million/ year
ESWTR	$3.7 billion[3]	TBD	$400 million[3]	TBD	$3 million/year

[1]Total annual costs are the sum of annualized capital costs plus annual operations and maintenance costs
[2]ICR capital costs are for bench- and pilot-scale studies. ICR monitoring costs are total, not annual, costs
[3]Insufficient data for accurate estimate. Costs indicated are only for one proposed option that is capital cost intensive. Total costs only include amortized capital costs

Legend: NA = Not Applicable
TBD = To Be Determined
yr = year

Source: USEPA 1994a

Table VI-5

Preliminary Costs for the Ozonation, Chlorination/Dechlorination, UV Light Disinfection, Direct Filtration, and Direct In-Line Filtration of GDU Water (500 MGD Treatment Flow)

Treatment Process	Preliminary Construction Costs (millions of dollars)	Operation and Maintenance Costs (millions of dollars per year)
Ozonation	17	0.46
Chlorination/Dechlorination	3	0.85
UV Light Disinfection	19	1.90
Direct Filtration	58	4.50
Direct In-Line Filtration	34	4.50

Legend: GDU = Garrison Diversion Unit
MGD = million gallons per day
UV = ultra violet

Source: Kopchynski 1994

GDU are (1) in-line filtration can provide turbidity removals comparable to direct filtration removals; (2) filtration provides an effective barrier to particulates (which can shelter microorganisms from disinfection) and large organisms resistant to infection (e.g., fish larvae and multi-cellular fish parasites); (3) disinfection process effectively inactivates microorganisms which escape the filtration process; and (4) inclusion of fish screens (i.e., horizontally traveling screens) over multiple barriers (e.g., coarse grids, high-flow rock-wall dams, etc.) would serve to reduces solid loadings to plant filters by removing fish, algae, and other large particulates from the treatment stream (Kopchynski 1994). The fish screen facility could be constructed with an initial capacity of 646 MGD with construction cost of about $40 million (1981 dollars) and annual operation and maintenance costs of about $1.3 million (U.S. Bureau of Reclamation 1982).

Interbasin water transfers can be evaluated in terms of efficiency and equity, two criteria often used to evaluate economic performance. Benefit cost analysis, despite several drawbacks, is at least an operational starting point for assessment. An interbasin transfer is economically efficient if its social benefits exceed its social costs and if it is the least expensive alternative to the water problem at issue. Economic assessment involves the study of the economic impacts of the interbasin water transfer in the region from which water is exported, in the region receiving water, in regions through which water is transported, and in any region which produces competitive output.

Major methodological and empirical problems arise in the estimation of benefits and costs. Among the more serious are the difficulties of estimating benefits in the water-receiving zone, the problem of estimating the opportunity costs of water in the zone of water origin, the controversial role of secondary or indirect benefits, the issue of estimating displaced economic activity in competitive regions, and the problem of estimating extra-market values associated with environmental impacts. In term of equity or income distribution, interbasin transfers nearly always redistribute income to regions receiving water while imposing disproportionate costs on the regions from which water is transferred (Veeman 1987).

In order to reduce costs associated with control and eradication, more emphasis is needed on the prevention of problems associated with interbasin water transfers. Ecologists, biologists, and engineers need to work together during the site selection and preliminary engineering design phases for the proposed interbasin water transfers to identify alternative site locations and engineering designs to prevent the transfer of nonindigenous/native aquatic organisms and the potential problems they may create.

Environmental assessments and long-term pre-project plans are needed to identify potential impacts and subsequently alternative engineering designs to lessen long-term environmental costs associated with control and eradication of nonindigenous/native aquatic organisms.

1.2 Proposed Transfers

1.2.1 Treatment Level

The critical level of treatment required for the safe transport of water will vary with site specific conditions at the intake for single pipeline transfers and in canals, rivers, and reservoirs for interbasin/multi-basin open/closed transfers. Extensive water quality tests are needed prior to the design phase for the treatment facility to ensure that the critical level of treatment is completed before public consumption. In general, the critical treatment level should meet the: (1) Texas Surface Water Quality Standards [TSWQS] including Drinking Water Standards (30 Texas Administrative Code [TAC] § 307, Chapter 341 Texas Health and Safety Code); and Criteria to Protect Aquatic Life (30 TAC § 307); and (2) the USEPA's ICR, D/DBR, and ESWTR (i.e., to prevent increased microbial risk).

1.2.2 Potential Costs

The proposed transfers involve a variety of closed (pipeline), open (canals, rivers), and closed/open scenarios. The Colorado River/Sandy Creek to Lake Texana/O.N. Stevens Terminal Water Storage Reservoir transfer (see Section III) was utilized to provide potential environmental/mitigation costs associated with all of the proposed interbasin transfers since transfer volumes are unknown for all of the other proposed transfers (e.g., Southeast, West-Central, and South-Central study areas).

- Water Treatment

Based on cost projections for a 500 MGD treatment flow for the Garrison Diversion Unit (GDU) by Kopchynski (1994) and similar water quality, preliminary construction and operation/costs for ozonation, chlorination, UV light disinfection, direct filtration, and direct in-line filtration were calculated (Table VI-6). An engineering evaluation/assessment needs to be completed on each proposed transfer to determine the treatment process or processes necessary to meet applicable drinking water standards each

Table VI-6

Ozonation, Chlorination/Dechlorination, UV Light Disinfection, Direct Filtration, and Direct In-Line Filtration Treatment Cost of the Colorado River and Lake Texana Water

	Preliminary Construction Costs (millions of dollars/MGD)			Operation and Maintenance Costs (dollars/MG)		
Treatment Process	Colorado River/ Sandy Creek	Lake Texana/ O.N. Stevens[1]	Total	Colorado River/ Sandy Creek	Lake Texana/ O.N. Stevens[1]	Total
Ozonation	0.544	0.455	0.999	40.33	33.74	74.07
Chlorination/Dechlorination	0.096	0.080	0.176	74.52	62.35	136.87
UV Light Disinfection	0.608	0.508	1.116	166.57	139.37	305.94
Direct Filtration	1.856	1.553	3.409	394.52	330.09	724.61
Direct In-line Filtration	1.088	0.910	1.998	394.52	330.09	724.61

* 31.23/37.35 MGD Treatment Flow
[1]Terminal Water Storage Reservoir

Legend: MGD = million gallons per day
MG = million gallons
UV = ultraviolet

proposed transfer to determine the treatment process or processes necessary to meet applicable drinking water standards efficiently and economically.

- Aquatic Organisms

Costs associated with monitoring and controlling aquatic exotic organisms are difficult to quantify due to the lack of presence/absence and density data from the intake sites. The Asiatic clam is relatively common in the study areas and could potentially cause fouling and increases in biological oxygen demand (BOD). Costs for controlling the similar exotic zebra mussel were reported to range from less than $20,000 per year for smaller water intakes of less than five mgd to $350,000 or more per year for intakes in excess of 300 mgd (Hushak et al. 1995). Based on management costs incurred to control hydrilla and floating plants in Florida lakes by Schmitz et al. (1993), the cost per acre to control these exotic aquatic plants was calculated (Table VI-7).

Potential mitigation costs associated with significant affects on threatened/endangered species are unknown due to the lack of site specific data from the intake sites. The life phases (eggs, larvae, and/or adults) of aquatic threatened/endangered species may be impinged (i.e., trapped on screens [death]), entrained (i.e., transferred to unsuitable habitat during the transfer), or affected by increases or decreases in flow. Aquatic surveys need to be conducted to determine potential impacts on threatened/endangered species and subsequent mitigation costs.

To adequately assess the mitigation methods and associated costs for eliminating or significantly reducing the risk of problems arising from the transfer of aquatic exotic organisms and impacts to threatened and endangered species, a preliminary engineering design of the proposed transfer(s) is required. Water quality data, presence/absence of endangered/threatened species (egg, larvae, and/or adults), and algal/macrophyte, zooplankton, macrobenthos, and fish densities would be needed before an accurate mitigation cost could be estimated for the proposed transfer(s). Information on the intake, screens, and pumps, site of new channel reservoir, flow rates through conduit, and other engineering plans would also be necessary.

Table VI-7

Cost to Manage Hydrilla and Floating Plants in Florida Lakes/Reservoirs from 1980-1991

	Hydrilla		Floating Plants*	
Year(s)	Acres Treated	Cost ($)/Acre	Acres Treated	Cost ($)/Acre
1980-88	268,029	162	77,762	450
1989	41,612	108	4,250	619
1990	57,055	73	2,669	755
1991	66,618	47	5,807	495
Total	433,314	128	90,488	477

* Water hyacinth and water lettuce

1.3 Summary

These cost estimates are highly speculative and can not be used to estimate potential mitigation costs since all of the engineering/environmental information needed to make accurate cost/estimate is not available for any of the proposed interbasin water transfers. Engineering plans and environmental surveys need to be completed during the pre-planning phase of each project to determine potential environmental problems and associated treatment/mitigation costs.

SECTION VII

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LITERATURE CITED

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APPENDIX A

AQUATIC FAUNA

Appendix A-1

List of Amphibians and Reptiles of the Colorado, Lavaca-Navidad, and Nueces River Basins in the Gulf Coastal Plains Province

Common/Scientific Name	River Basin Colorado	Lavaca-Navidad	Nueces
MOLE SALAMANDERS			
Smallmouth salamander/*Ambystoma texanum*		X[1,2]	
NEWTS			
Central newt/*Notophthalmus viridescens louisianensis*	X	X[1,2]	X
SIRENS			
Western lesser siren/*Siren intermedia nettingi*		X[1,2]	
CRICKET FROGS			
Blanchard's cricket frog/*Acris crepitans blanchardi*		X[1]	
TOADS			
Gulf Coast toad/*Bufo valliceps valliceps*		X[1]	
Woodhouse's toad/*Bufo woodhouseii woodhouseii*		X[1]	
NARROWMOUTH TOADS			
Eastern narrowmouth toad/*Gastrophryne carolinensis*		X[1,2]	
TREEFROGS			
Cope's gray treefrog/*Hyla chrysocelis*	X	X[1]	X
Green treefrog/*Hyla cinerea*	X	X[1,2]	X
Gray treefrog/*Hyla versicolor*	X	X[1]	X
CHORUS FROGS			
Spotted chorus frog/*Pseudacris clarkii*	X	X[1,2]	X
Upland chorus frog/*Pseudacris feriarum*		X[1,2]	
Strecker's chorus frog/*Pseudacris streckeri streckeri*		X[1]	
TRUE FROGS			
Rio Grande frog/*Rana berlandieri*			X
Bullfrog/*Rana catesbeiana*		X[1,2]	
Bronze frog/*Rana clamitans clamitans*		X[1]	
Pickerel frog/*Rana palustris*	X		
Southern leopard frog/*Rana utricularia*		X[1]	
SOFTSHELL TURTLES			
Midland smooth softshell/*Apalone mutica mutica*	X		
Guadalupe spiny softshell/*Apalone spinifera guadalupensis*	X	X[2]	X
SNAPPING TURTLES			
Common snapping turtle/*Chelydra serpentina serpentina*	X	X[2]	X

Appendix A-1 (Continued)

List of Amphibians and Reptiles of the Colorado, Lavaca-Navidad, and Nueces River Basins in the Gulf Coastal Plains Province

Common/Scientific Name	River Basin Colorado	Lavaca-Navidad	Nueces
MUD TURTLES			
Yellow mud turtle/*Kinosternon flavescens flavescens*		X[2]	
Mississippi mud turtle/*Kinosternon subrubrum hippocrepis*		X[2]	
COOTERS			
Texas river cooter/*Pseudemys texana*	X	X[2]	
SLIDERS			
Red-eared slider/*Trachemys scripta elegans*	X	X[2]	X
ALLIGATORS			
American alligator/*Alligator mississippiensis*		X[2]	
COPPERHEADS/COTTONMOUTHS			
Western cottonmouth/*Agkistrodon piscivorus leucostoma*	X	X[1,2]	X
RAT SNAKES			
Texas rat snake/*Elaphe obsoleta lindheimerii*		X[1]	
MUD SNAKES			
Western mud snake/*Farancia abacura reinwardtii*		X[2]	
WATER SNAKES			
Diamondback water snake/*Nerodia rhombifera rhombifera*	X	X[1,2]	X
Blotched water snake/*Nerodia erythrogaster transversa*	X	X[1,2]	X
Broad-banded water snake/*Nerodia fasciata confluens*		X[2]	
Mississippi green water snake/*Nerodia cyclopion*	X	X[2]	X
CRAYFISH SNAKES			
Graham's crayfish snake/*Regina grahamii*		X[2]	
Gulf crayfish snake/*Regina rigida sinicola*		X[2]	
GARTER/RIBBON SNAKES			
Eastern garter snake/*Thamnophis sirtalis sirtalis*		X[1,2]	

Potentially Occurring in [1]Sandy Creek or [2]Lake Texana

Source: Dixon 1987; Garrett and Barker 1987; Collins 1990; Tennant 1990

Appendix A-2

List of Fish Species of the Colorado, Lavaca-Navidad, and Nueces River Basins in the Gulf Coastal Plains Province

Common/Scientific Name	Habitats					River Basins		
	UP	LO	RI	ST	CR	Col	Lav-Nav*	Nuec
GARS								
Spotted gar/*Lepisosteus oculatus*	X	X	X	X		N	N[1,2]	N
Longnose gar/*Lepisosteus osseus*	X	X	X	X		N	N[1,2]	N
Alligator gar/*Lepisosteus spatula*		X	X			N	N[2]	N
Shortnose gar/*Lepisosteus platostomus*	X	X	X	X			N[2]	
BOWFINS								
Bowfin/*Amia calva*		X	X	X		N		
FRESHWATER EELS								
American eel/*Anguilla rostrata*	X	X	X	X		N	N	N
HERRINGS								
Skipjack herring/*Alosa chrysochloris*		X	X			N		
Gizzard shad/*Dorosoma cepedianum*	X	X	X	X		N	N[2]	N
Threadfin shad/*Dorosoma petenense*	X	X	X	X		N	N[1,2]	N
CARPS/MINNOWS								
Central stoneroller/*Campostoma anomalum*	X	X	X	X	X	N	N	N
Goldfish/*Carassius auratus*	X	X	X	X	X	I	I	I
Grass carp/*Ctenopharyngodon idella*	X	X	X				I[+2]	
Plateau shiner/*Cyprinella lepida*	X			X				E
Red shiner/*Cyprinella lutrensis*	X	X	X	X	X	N[0]	N[1,2]	N
Blacktail shiner/*Cyprinella venusta*	X	X	X	X	X	N[0]	N[1,2]	N
Common carp/*Cyprinus carpio*	X	X	X	X		I	I[1,2]	I
Roundnose minnow/*Dionda episcopa*	X			X		N	N	N
Nueces roundnose minnow/*Dionda serena*	X			X				E
Ribbon shiner/*Lythrurus lirus*			X	X		N		
Plains minnow/*Hybognathus placitus*	X		X	X		N		
Speckled chub/*Macrhybopsis aestivalis*	X	X	X	X		N[0]	N	N
Golden shiner/*Notemigonus crysoleucas*	X	X	X	X	X	N[0]	N[2]	N
Texas shiner/*Notropis amabilis*	X	X	X	X		N[0]	N[1]	N
Pallid shiner/*Notropis amnis*	X	X	X	X		N[0]	N	
Smalleye shiner/*Notropis buccula*	X	X	X	X		I		
Ghost shiner/*Notropis buchanani*	X	X	X	X		N	N	N
Sharpnose shiner/*Notropis oxyrhynchus*	X	X	X			I		
Chub shiner/*Notropis potteri*	X	X	X			NI		
Silverband shiner/*Notropis shumardi*	X	X	X	X		N[0]		
Sand shiner/*Notropis stramineus*	X	X	X	X		N[0]	N[2]	N
Weed shiner/*Notropis texanus*	X	X	X	X	X	N[0]	N	N
Mimic shiner/*Notropis volucellus*	X	X	X	X	X	N[0]	N	N
Pugnose minnow/*Opsopoeodus emiliae*	X	X	X	X	X	N	N[1]	N
Suckermouth minnow/*Phenacobius mirabilis*	X	X	X	X		N[0]		
Fathead minnow/*Pimephales promelas*	X	X	X	X	X	N	I	I
Bullhead minnow/*Pimephales vigilax*	X	X	X	X	X	N[0]	N[1,2]	N
Creek chub/*Semotilus atromaculatus*	X	X		X	X	I		

Appendix A-2 (Continued)

List of Fish Species of the Colorado, Lavaca-Navidad, and Nueces River Basins in the Gulf Coastal Plains Province

	Habitats					River Basins		
Common/Scientific Name	UP	LO	RI	ST	CR	Col	Lav-Nav*	Nuec
SUCKERS								
River carpsucker/*Carpiodes carpio*	X	X	X	X	X	N[0]	N[1,2]	N
Blue sucker/*Cycleptus elongatus*	X	X	X			N[0]	N	N
Lake chubsucker/*Erimyzon sucetta*	X	X			X	N	N	
Smallmouth buffalo/*Ictiobus bubalus*	X	X	X	X		N[0]	N[2]	N
Spotted sucker/*Minytrema melanops*	X	X	X	X	X	NI		
Gray redhorse/*Moxostoma congestum*	X	X	X	X		N[0]	N	N
CHARACINS								
Mexican tetra/*Astyanax mexicanus*	X	X	X	X	X	I	I	N
BULLHEADS/CATFISHES								
Black bullhead/*Ameiurus melas*	X	X	X	X	X	N	NI[2]	NI
Yellow bullhead/*Ameiurus natalis*	X	X	X	X	X	N	N[1,2]	N
Blue catfish/*Ictalurus furcatus*	X	X	X	X		N	N[2]	N
Channel catfish/*Ictalurus punctatus*	X	X	X	X		N[0]	N[1,2]	N
Tadpole madtom/*Noturus gyrinus*	X	X		X	X	N	N[1]	N
Freckled madtom/*Noturus nocturnus*	X	X	X	X	X		N[1]	
Flathead catfish/*Pylodictis olivaris*	X	X	X	X		N[0]	N[1,2]	N
PIRATE PERCHES								
Pirate perch/*Aphredoderus sayanus*	X			X	X	N	I[2]	
KILLIFISHES								
Golden topminnow/*Fundulus chrysotus*		X	X	X	X	N		
Blackstripe topminnow/*Fundulus notatus*	X	X	X	X	X	N	N	
Plains killifish/*Fundulus zebrinus*	X			X	X	N		
LIVEBEARERS								
Mosquitofish/*Gambusia affinis*	X	X	X	X	X	N	N[1,2]	N
Amazon molly/*Poecilia formosa*	X	X	X	X	X		I	I
Sailfin molly/*Poecilia latipinna*	X	X	X	X	X	N	N	N
Guppy/*Poecilia reticulata*	X			X	X	I	I	
SILVERSIDES								
Brook silverside/*Labidesthes sicculus*	X	X	X	X	X		N[2]	
Rough silverside/*Membras martinica*		X	X			N	N	N
Inland silverside/*Menidia berylina*	X	X	X	X		N[0]	N[2]	N
PIPEFISHES								
Gulf pipefish/*Syngnathus scovelli*		X	X	X		N	N[2]	N
TEMPERATE BASSES								
White bass/*Morone chrysops*	X	X	X	X		I	I[2]	I
Striped bass/*Morone saxatilis*	X	X	X	X		I	I[2]	

Appendix A-2 (Continued)

List of Fish Species of the Colorado, Lavaca-Navidad, and Nueces River Basins in the Gulf Coastal Plains Province

Common/Scientific Name	Habitats					River Basins		
	UP	LO	RI	ST	CR	Col	Lav-Nav*	Nuec
SUNFISHES								
Redbreast sunfish/*Lepomis auritus*	X	X	X	X		I	I[2]	I
Green sunfish/*Lepomis cyanellus*	X	X	X	X	X	N[0]	N[1,2]	N
Warmouth/*Lepomis gulosus*	X	X	X	X	X	N	N[1,2]	N
Orangespotted sunfish/*Lepomis humilis*	X	X	X	X	X	N		
Bluegill/*Lepomis macrochirus*	X	X	X	X	X	N	N[1,2]	N
Longear sunfish/*Lepomis megalotis*	X	X	X	X	X	N[0]	N[1,2]	N
Redear sunfish/*Lepomis microlophus*	X	X	X	X	X	N	N[2]	N
Spotted sunfish/*Lepomis punctatus*	X	X		X	X	N	N	N
Bantam sunfish/*Lepomis symmetricus*	X	X		X	X	N	N[1]	
Smallmouth bass/*Micropterus dolomieu*	X		X	X		I	I[2]	
Spotted bass/*Micropterus punctulatus*	X	X	X	X		N	NI	
Largemouth bass/*Micropterus salmoides*	X	X	X	X	X	N	N[2]	N
Guadalupe bass/*Micropterus treculi*	X	X	X	X		N[0]	N	I
White crappie/*Pomoxis annularis*	X	X	X	X		N	N[2]	N
Black crappie/*Pomoxis nigromaculatus*	X	X	X	X		I	I[2]	I
PERCHES								
Bluntnose darter/*Etheostoma chlorosomum*	X	X	X	X	X	N	N	
Slough darter/*Etheostoma gracile*	X	X	X	X	X	N	N	N
Greenthroat darter/*Etheostoma lepidum*	X	X	X	X	X	N	N	N
Cypress darter/*Etheostoma proeliare*		X	X	X		N		
Orangethroat darter/*Etheostoma spectabile*	X	X	X	X		N	N	
Logperch/*Percina caprodes*	X	X	X	X	X	N[0]		
Bigscale logperch/*Percina macrolepidum*	X	X	X	X		N	N	N
Dusky darter/*Percina sciera*	X	X	X	X	X	N[0]	N[1]	N
DRUMS								
Freshwater drum/*Aplodinotus grunniens*	X	X	X	X		N	N[2]	N
CICHLIDS								
Rio Grande cichlid/*Cichlasoma cyanoguttatum*	X	X	X			I	I	I
Blue tilapia/*Tilapia aurea*	X	X	X			I	I	
MULLETS								
Striped mullet/*Mugil cephalus*	X	X	X	X		N	N[1,2]	N

+Triploid
*Includes species in [1]Sandy Creek and [2]Lake Texana
[0] Fishes collected in the Egypt Study reach (intake area) of the Colorado River

Legend:
UP = Upland
LO = Lowland
RI = River
ST = Stream
CR = Creek
Col = Colorado
Lav-Nav = Lavaca-Navidad
Nuec = Nueces
N = Native
I = Introduced
E = Endemic
NI = Considered native but possibly introduced

Source: USDI 1974; Conner and Suttkus 1986; Hubbs et al. 1991; Robbins et al. 1991; Morales 1991; Bayer et al. 1992; Mosier and Ray 1992; Patek 1994; Chilton 1995; Jons 1995

Appendix A-3

List of Freshwater Mollusks in the Various River Basins and Man-Made Impoundments Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast					West-Central		South-Central
	Sabine	Neches	Trinity	San Jacinto	Brazos	Colorado	Guadalupe	Nueces
UNIONIDAE								
Threeridge/*Amblema plicata**	X	X	X	X	X	X	X	—
Giant floater/*Anodonta grandis**	X	X	X	X	X	X	X	X
Paper pondshell/*Anodonta imbecillis**	X	X	X	X	X	X	X	X
Flat floater/*Anodonta suborbiculata**	X	X	—	—	—	—	—	—
Rock-pocketbook/*Arcidens confragosus**	X	X	X	X	X	X	X	—
Ouachita rock-pocketbook/*Arkansia wheeleri*	—	—	—	—	—	—	—	—
Tampico pearlymussel/*Cyrtonaias tampicoensis*	—	—	I	—	X	X	X	X
Spike/*Elliptio dilatata*	—	—	—	—	—	—	X	—
Texas pigtoe/*Fusconaia askewi*	X	X	?	?	—	—	—	—
Wabash pigtoe/*Fusconaia flava*	X	X	?	?	—	—	—	—
Triangle pigtoe/*Fusconaia lananensis*	—	X	—	X	—	—	—	—
Round pearlshell/*Glebula rotundata*	X	X	X	X	?	?	X	—
Texas fatmucket/*Lampsilis bracteata*	—	—	—	—	X	X	X	X
Plain pocketbook/*Lampsilis cardium*	—	—	—	—	—	—	—	—
Louisiana fatmucket/*Lampsilis hydiana**	X	X	X	X	X	X	X	X
Sandbank pocketbook/*Lampsilis satura*	X	X	?	?	—	—	—	—
Yellow sandshell/*Lampsilis teres**	X	X	X	X	X	X	X	X
White heelsplitter/*Lasmigona complanata*	—	—	—	—	—	—	X	—
Fragile papershell/*Leptodea fragilis**	X	X	X	X	X	X	—	—
Pond mussel/*Ligumia subrostrata**	X	X	X	X	X	X	X	—
Washboard/*Megalonaias nervosa**	X	X	X	X	X	X	X	X

Appendix A-3 (Continued)

List of Freshwater Mollusks in the Various River Basins and Man-Made Impoundments Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast					West-Central		South-Central
	Sabine	Neches	Trinity	San Jacinto	Brazos	Colorado	Guadalupe	Nueces
UNIONIDAE (Continued)								
Threehorn wartyback/*Obliquaria reflexa**	X	X	X	—	—	—	—	—
Southern hickorynut/*Obovaroa jacksoniana*	X	X	—	—	—	—	—	—
Bankclimber/*Plectomerus dombeyanus*	X	X	X	X	—	—	—	—
Louisiana pigtoe/*Pleurobema riddelli*	X	X	X	X	—	—	—	—
Texas hornshell/*Popenaias popei*	—	—	—	—	—	—	—	—
Texas heelsplitter/*Potamilus amphichaenus*	X	X	X	—	—	—	—	—
Pink papershell/*Potamilus ohiensis*	—	—	X	—	X	?	—	—
Bleufer/*Potamilus purpuratus**	X	X	X	X	X	X	X	I
Salina mucket/*Potamilus salinasensis*	—	—	—	—	—	—	—	—
Southern mapleleaf/*Quadrula apiculata**	X	X	X	X	X	X	X	X
Golden orb/*Quadrula aurea*	—	—	—	—	—	X	X	X
Rio Grande monkeyface/*Quadrula couchiana*	—	—	—	—	—	—	—	—
Smooth pimpleback/*Quadrula houtonensis*	—	—	?	?	X	X	X	—
Western pimpleback/*Quadrula mortoni**	X	X	X	X	—	—	—	—
Wartyback/*Quadrula nodulata*	X	X	—	—	—	—	—	—
Texas pimpleback/*Quadrula petrina*	—	—	—	—	X	X	X	—
Pimpleback/*Quadrula pustulosa*	?	?	?	?	—	—	—	—
Mapleleaf/*Quadrula quadrula*	X	X	X	X	—	—	—	—
False spike/*Quincuncina mitchelli*	—	—	—	—	X	X	X	—
Squawfoot/*Strophitus undulatus*	X	X	X	X	X	X	X	—
Lilliput/*Toxolasma parvus*	X	X	X	X	X	X	X	?

Appendix A-3 (Continued)

List of Freshwater Mollusks in the Various River Basins and Man-Made Impoundments
Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast					West-Central		South-Central
	Sabine	Neches	Trinity	San Jacinto	Brazos	Colorado	Guadalupe	Nueces
UNIONIDAE (Continued)								
Texas lilliput/*Toxolasma texasensis**	X	X	X	X	X	X	X	X
Pistolgrip/*Tritogonia verrucosa*	X	X	X	X	X	X	X	X
Mexican fawnsfoot/*Truncilla cognata*	—	—	—	—	—	—	—	—
Fawnsfoot/*Truncilla donaciformis*	X	X	X	X	—	—	—	—
Texas fawnsfoot/*Truncilla macrodon*	—	—	—	X	X	X	—	—
Deertoe/*Truncilla truncata*	X	X	X	X	—	—	—	—
Tapered pondhorn/*Uniomerus declivis**	X	X	X	X	X	X	X	X
Pondhorn/*Uniomerus tetralasmus**	X	X	X	X	X	X	X	?
Little spectaclecase/*Villosa lienosa*	X	X	X	X	—	—	—	—
SPHAERIIDAE								
Fingernail clam/*Sphaerium* spp.*	X	X	X	X	X	X	X	X
CORBICULIDAE								
Asiatic clam/*Corbicula fluminea**	I	I	I	I	I	I	I	I
Total	36	37	36	34	26	28	27	17

* Common occurring species
? Distribution is questionable

Legend: I = Introduced   spp. = species

Source: Britton 1982; Neck 1982; Turgeon et al. 1988; Howells 1995a, 1995c

Appendix A-4

List of Fish Species in the Various River Basins and Man-Made Impoundments
Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast			West-Central			South-Central
	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
LAMPREYS							
Chestnut lamprey	N						
Southern Brook lamprey	N	N					
PADDLEFISHS							
Paddlefish	N[1]	N[1]					
GARS							
Spotted gar	N	N	N	N	N	N	N
Longnose gar	N	N	N	N	N	N	N
Alligator gar	N	N	N	N	N	N	N
Shortnose gar					N		
BOWFINS							
Bowfin	N	N	N	N			
FRESHWATER EELS							
American eel	N	N	N	N	N	N	N
HERRINGS							
Skipjack herring	N	N	N	N			
Gizzard shad	N	N	N	N	N	N	N
Threadfin shad	N	N	N	N	N	N	N
CARPS/MINNOWS							
Central stoneroller		N	N	N		N	N
Goldfish	I	I	I	I		I	I
Grass carp	I	I[2]			I	I[3]	
Plateau shiner						E	E
Red shiner	N	N	N	N	N	N	N
Blacktail shiner	N	N	N	N	N	N	N
Common carp	I	I	I	I	I	I	I
Roundnose minnow				N		N	N
Nueces roundnose minnow							E

Appendix A-4 (Continued)

List of Fish Species in the Various River Basins and Man-Made Impoundments
Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast			West-Central			South-Central
	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
CARPS/MINNOWS (Continued)							
Cypress minnow	N						
Mississippi silvery minnow	N	N	N				
Plains minnow			N	N			
Ribbon shiner	N	N	N	N	N	N	
Redfin shiner	N	N			N	N	N
Speckled chub	N		N	N		N	N
Silver chub			NI				
Golden shiner	N	N	N	N	N	N	N
Texas shiner				N	N	N	N
Pallid shiner	N	Ep	Ep	Ep		N	
Emerald shiner	N	N					
Blackspot shiner	N	N	N				
Smalleye shiner			E	I			
Ghost shiner	N	N	N	N		N	N
Ironcolor shiner	N					N	
Taillight shiner	N						
Sharpnose shiner			E	I			
Chub shiner		NI	N	NI			
Sabine shiner	N	N					
Silverband shiner	I	N	N	N			
Sand shiner		N	N	N	N	N	
Weed shiner	N	N	N	N	N	N	N
Mimic shiner	N	N	N	N		N	N
Pugnose minnow	N	N	N	N	N	N	N
Suckermouth minnow	N	N		N			
Fathead minnow	I	N	N	N		I	I
Bullhead minnow	N	N	N	N	N	N	N
Rudd			I			I	
Creek chub	N	N		I			
SUCKERS							
River carpsucker	N	N	N	N	N	N	N
Blue sucker	N	N	N	N		N	N

Appendix A-4 (Continued)

List of Fish Species in the Various River Basins and Man-Made Impoundments
Associated with the Trans-Texas Water Program Study Areas

	Southeast			West-Central			South-Central
Taxa	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
SUCKERS (Continued)							
Creek chubsucker	N	N	N				
Lake chubsucker	N	N	N	N		N	
Smallmouth buffalo	N	N	N	N	N	N	N
Bigmouth buffalo	N						
Black buffalo	N		NI				
Spotted sucker	N	N	N	NI			
Gray redhorse			N	N		N	N
Blacktail redhorse	N	N					
CHARACINS							
Mexican tetra	I	I	I	I		I	N
BULLHEADS/CATFISHES							
Black bullhead	N	N	N	N	N	NI	NI
Yellow bullhead	N	N	N	N	N	N	N
Brown bullhead	I						
Blue catfish	N	N	N	N	N	N	N
Channel catfish	N	N	N	N	N	N	N
Tadpole madtom	N	N	N	N	N	N	N
Freckled madtom	N	N			N		
Flathead catfish	N	N	N	N	N	N	N
Widemouth blindcat						E[4]	
Toothless blindcat						E[4]	
SUCKERMOUTH CATFISHES							
Suckermouth catfish		I				I	
PIKES							
Grass pickerel	N	N	N				
Chain pickerel	N						
TROUTS							
Rainbow trout			I		I		

Appendix A-4 (Continued)

List of Fish Species in the Various River Basins and Man-Made Impoundments Associated with the Trans-Texas Water Program Study Areas

	Southeast			West-Central			South-Central
Taxa	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
PIRATE PERCHES							
Pirate perch	N	N	N	N			
KILLIFISHES							
Golden topminnow	N	N	N	N		N	
Blackstripe topminnow	N	N	N	N		N	
Blackspotted topminnow	N	N	N				
Plains killifish		N	N	N			
LIVEBEARERS							
Mosquitofish	N	N	N	N	N	N	N
Largespring gambusia				I		E	
San Marcos gambusia						E	
Amazon molly						I	I
Sailfin molly	N	N	N	N	N	N	N
Guppy				I		I	
SILVERSIDES							
Brook silverside	N	N			N		
Rough silverside	N	N	N	N		N	N
Inland silverside	N	N	N	N		N	N
PIPEFISHES							
Gulf pipefish	N	N	N	N	N	N	N
TEMPERATE BASSES							
White bass	I	I	I	I	I	I	I
Yellow bass	N	N					
Striped bass	I	I	I	I	I	I	I
SUNFISHES							
Rock bass				I		I	
Flier	N	N	N				
Banded pygmy sunfish	N	N	N				

Appendix A-4 (Continued)

List of Fish Species in the Various River Basins and Man-Made Impoundments
Associated with the Trans-Texas Water Program Study Areas

	Southeast			West-Central			South-Central
Taxa	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
SUNFISHES (Continued)							
Redbreast sunfish	I	I	I	I	I	I	I
Green sunfish	N	N	N	N	N	N	N
Warmouth	N	N	N	N	N	N	N
Orangespotted sunfish	N	N	N	N			
Bluegill	N	N	N	N	N	N	N
Dollar sunfish	N	N	N				
Longear sunfish	N	N	N	N	N	N	N
Redear sunfish	N	N	N	N	N	N	N
Spotted sunfish	N	N	N	N		N	N
Bantam sunfish	N	N	N	N	N		
Smallmouth bass			I	I	I	I	
Spotted bass	N	N	N	N		NI	
Largemouth bass	N	N	N	N	N	N	N
Guadalupe bass			N	N	N	N	I
White crappie	N	N	N	N	N	N	N
Black crappie	N	N	N	I	I	I	I
PERCHES							
Western sand darter	N						
Scaly sand darter	N	N					
Mud darter	N						
Bluntnose darter	N	N	N	N	N	N	
Fountain darter						E	
Slough darter	N	N	N	N	N	N	N
Harlequin darter	N	N					
Greenthroat darter				N		N	N
Goldstripe darter	N	N	N				
Cypress darter	N	N		N			
Orangethroat darter		N	N	N			
Logperch				N			
Bigscale logperch	N	N	N	N		N	
Blackside darter	N						
Dusky darter	N	N	N	N	N	N	

Appendix A-4 (Continued)

List of Fish Species in the Various River Basins and Man-Made Impoundments Associated with the Trans-Texas Water Program Study Areas

Taxa	Southeast			West-Central			South-Central
	Sabine/Neches/Angelina	San Jacinto/Trinity	Brazos	Colorado	Lavaca	Guadalupe/San Antonio	Nueces
PERCHES (Continued)							
River darter	N			N		N	
Walleye	I		I	I			
DRUMS							
Freshwater drum	N	N	N	N		N	N
CICHLIDS							
African lake cichlid						I	
Convict cichlid						I	
Rio Grande cichlid			I	I		I	I
Blue tilapia		I		I		I	
Mozambique tilapia						I	
Redbelly tilapia						I	
MULLETS							
Striped mullet	N	N	N	N	N	N	N

[1] Found only in riverine systems below most downstream dams
[2] Reproducing population in the Trinity River and Galveston Bay
[3] Introduced radio-tracked specimens in Guadalupe River below the City of Sequin
[4] Subterranean fishes

Legend: N = Native I = Introduced NI = Considered native but possibly introduced E = Endemic Ep = Historically present but apparently extirpated

Source: Conner and Suttkus 1986; Trimm et al. 1989; Howells et al. 1991; Hubbs et al. 1991; Pitman 1991; Robbins et al. 1991; Mosier and Ray 1992; Steidensticker and Parks 1992, 1993; Whiteside and Berkhouse 1992; Bechler and Harrell 1994; Patek 1994; San Antonio River Authority 1994b

SECTION VIII

LIST OF PREPARERS AND AGENCIES/PERSONS CONTACTED

LIST OF PREPARERS

Joseph Kaskey	Senior Biologist Years of Experience:	 22	M.S. Botany B.S. Biological Sciences	Report Preparation
Ross Rasmussen	Senior Biologist Years of Experience:	 19	B.S. Fisheries Mgmt. B.S. Resource Mgmt. Graduate Studies Aquatic Entomology	Report Preparation
David Pitts	Staff Biologist Years of Experience:	 4	B.S. Wildlife/Fisheries	Report Preparation
Chris Ingram	Senior Ecologist Years of Experience:	 26	M.S.(Candidate), Fisheries M.S. Wildlife Biology B.S. Zoology	Technical Review
Dan Wilkinson	Senior Ecologist Years of Experience:	 26	Ph.D. Botany M.S. Wildlife Ecology B.S. Biology	Technical Review
Patricia Knowles	Editor	26	B.S. Education	Editor
Robert Wood	Graphics Technician	4	B.S. Forestry	Graphics
Michael Warren	Graphics Technician	2	B.S. Industrial Graphics	Graphics

AGENCIES AND PERSONS CONTACTED-INTERBASIN WATER TRANSFER

Alabama Power Company	Mr. Ed Tyberghein
Alan Plumer Associates, Inc.	Mr. Steven Coonan
American Water Works Association	Mr. Dan Petersen
Angelina and Neches River Authority	Mr. John Porterfield
Brazos River Authority	Mr. Tom Conry
Central Power and Light	Ms. Nancy Hutton
Colorado State University	
Larval Fish Laboratory	Mr. Darrell Snyder
Guadalupe-Blanco River Authority	Mr. James Arnst
HDR Engineering, Inc.	Mr. Ken Choffel
HNTB Corporation	Mr. John Curtis
Lower Colorado River Authority	Mr. Quinton Martin
	Mr. Doyle Mosier
Lower Neches Valley Authority	Mr. Dennis Becker
Nationwide Water Resources	Mr. Duane Stubblefield
Navidad-Lavaca River Authority	Mr. Jack C. Nelson
North Texas Municipal Water District	Mr. Dolan McKnight
Northwestern University Library	
Transportation Library	Ms. Renee McHenry
O.N. Stevens Water Treatment Plant	Mr. James Dodsen
	Mr. Ed Garana
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Sabine River Authority	Mr. Miles Hall
San Antonio River Authority	Mr. Mike Gonzales
San Jacinto River Authority	Mr. Bill Moler

San Marcos Aquatic Station	Mr. Gordon Liam
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	Mr. Allen Groeger
	Mr. Dave Hoffman
	Mr. David Lemke
	Mr. Bobby Whiteside
Tennessee Valley Authority	Mr. Bob Wallus
Texas A & M University	Mr. Ken Johnson
	Dr. Hugh Wilson
Center for Coastal Studies	Dr. Quintin Dokken
	Dr. Wes Tunnel
Texas Department of Health	Mr. John McDaniels
	Mr. Larry Mitchell
Texas Municipal Power Authority	Mr. Don Plitt
Texas Natural Resource Conservation Committee	Mr. Charles Dvorski
	Mr. Larry Mitchell
	Mr. Bruce Moulton
	Mr. Robert Organ
Texas Parks and Wildlife Department	Mr. Bill Bowling
	Ms. Lorraine Fryes
	Mr. Gary Garrett
	Mr. Dick Herrington
	Mr. Bob Howells
	Mr. Randy Moss
	Mr. Ken Rice

Texas Parks and Wildlife Department (Continued)	
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	Mr. Jimmy Dean
	Mr. Larry Hartmann
	Mr. Rhandy Helton
	Mr. Mike Reed
	Mr. Lance Robinson
	Mr. Paul Seidensticker
	Mr. Dave Terre
	Mr. Mark Webb
Texas Water Development Board	Mr. Dennis Crowley
	Mr. Ray Matthews
	Mr. Gary Powell
University of Tennessee-Chattanooga	Mr. Mark Schorr
University of Texas-Austin	Dr. Clark Hubbs
	Dr. Riley Nelson
Center for Water Resources	Dr. Neil Armstrong
	Dr. George Ward
U.S. Geological Survey-Austin, Texas	Mr. Nick Baldys
	Mr. Peter Bush
	Mr. Mark Dorsey
	Mr. Mark Matthews
	Mr. Bruce Moring
U.S. Geological Survey-Raleigh, North Carolina	Mr. Mike Meador