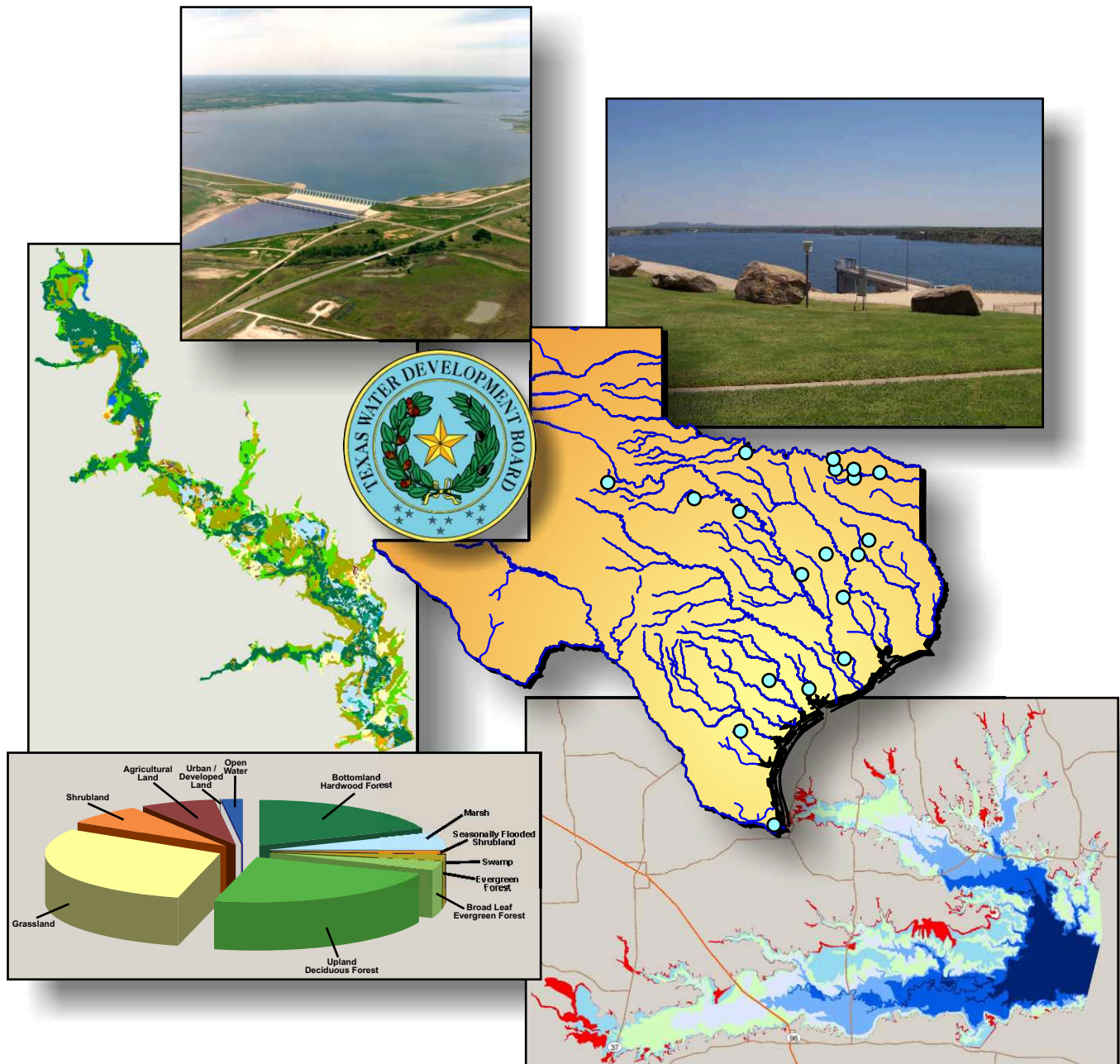# Reservoir Site Protection Study

February 2007

Reservoir Site Protection Study

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February 2007

Reservoir Site Protection Study

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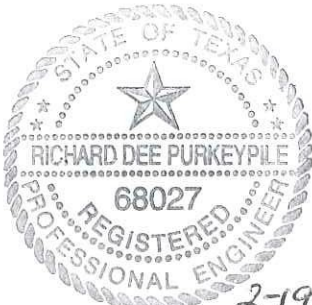
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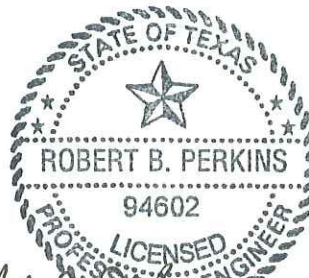
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Executive Summary

ES.1 Introduction

For more than four decades, the Texas Water Development Board (TWDB) has been responsible for developing and updating the Texas State Water Plan in cooperation with other state agencies and numerous regional, local, and private interests across the State (Figure ES-1).   Approximately 100 potential reservoirs have been identified or recommended in the various State Water Plans completed during this period and many more reservoir sites have been considered by state or federal agencies, river authorities, and others. While some of these reservoirs have been constructed,

Figure ES-1. State Water Plans

many remain under consideration today as demands for reliable surface water supplies for municipal, industrial, steam-electric power generation, and other purposes continue to grow.

The 2007 State Water Plan recommends the Legislature consider 17 major reservoir sites identified by Regional Water Planning Groups and the TWDB for protection by designation as unique reservoir sites. The Texas Water Code provides that *the legislature may designate a site of unique value for the construction of a reservoir* [Section 16.051(f)(2)] and that *a state agency or political subdivision of the state may not obtain a fee title or an easement that would significantly prevent the construction of a reservoir on a site designated by the legislature under Subsection (f) of this section* [Section 16.051(g)(2)]. Lack of such designation has allowed state, federal, or local governments or private entities to take actions that have significantly impacted the feasibility of constructing reservoirs at some sites. A recent example of such an action is the unilateral establishment of the Neches River National Wildlife Refuge by the U.S. Fish & Wildlife Service on the site of the only new reservoir planned by the City of Dallas in the next 50 years and included in the 2007 State Water Plan.

Perhaps the most certain means of ensuring protection for unique reservoir sites is acquisition of the properties necessary for the reservoir projects, holding such properties in the

public trust, and preventing conversion or uses of the properties for purposes ultimately precluding future reservoir development. Reservoir site acquisition must be considered in the context of compensatory ecological resource protection and preservation for mitigation of valuable ecological resources lost to permanent inundation. Hence, this research project includes land cover classification for reservoir sites potentially included in an acquisition program. Most importantly, this research project includes development and application of technical resources and matrix screening processes necessary to provide recommendations as to the most appropriate reservoir sites for State protection and/or acquisition.

Major tasks accomplished in this research project are listed as follows and summarized in Figure ES-2:

(1) Research and data compilation for about 150 potential reservoir projects;

(2) Adoption of screening criteria and application of a matrix screening process resulting in the selection of 16 reservoir sites for technical evaluation;

(3) Application of geographic information system (GIS) techniques for definition and mapping of reservoir sites including elevation-area-capacity relationships, potential conflicts, and land cover classification;

(4) Assessment of reservoir firm yield available under drought of record conditions subject to senior water rights and provisions for environmental flow needs;

(5) Estimation of costs associated with dams and appurtenant structures, major relocations, and acquisition of reservoir and mitigation lands; and

(6) Recommendation of reservoir sites for protection and/or acquisition.

Although the primary objective of this study is selection of reservoir sites most appropriate for protection, it is understood that such protection as may be afforded by the Legislature is not intended to circumvent the planning and permitting processes through which any major reservoir project must meet the requirements of applicable law prior to implementation. It is further understood that designation of reservoir sites recommended herein as unique, and even acquisition of these sites, does not preclude the planning, permitting, and construction of major reservoirs at alternative sites.
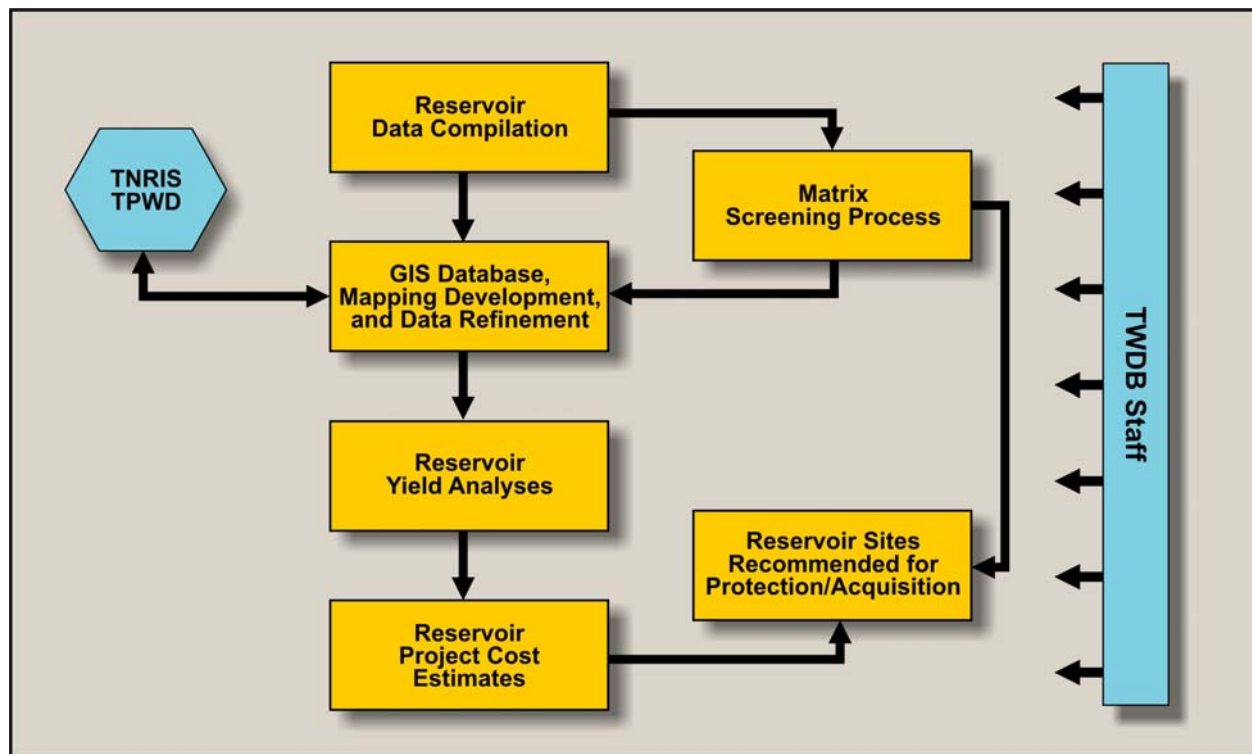
Figure ES-2. Reservoir Site Protection Study Tasks

ES.2   Reservoir Site Screening Process

Research in the course of this study has identified over 220 major reservoir sites in Texas that have been included in State or Regional Water Plans or in significant planning studies by state or federal agencies, river authorities, or water districts interested in water supply development. For the purposes of this study, a major reservoir is defined to be one having a conservation storage capacity of at least 5,000 acft. To date, reservoirs have been constructed at approximately 70 of these sites. For the remaining number of about 150 reservoir sites, consultants have conducted intensive library and archive research to compile key descriptive information including reservoir name, river basin and state water planning region location, firm yield, unit cost of raw water at the reservoir, and surface area at the proposed conservation storage pool level. Figure ES-3 shows the locations of the reservoir sites considered in the matrix screening process.
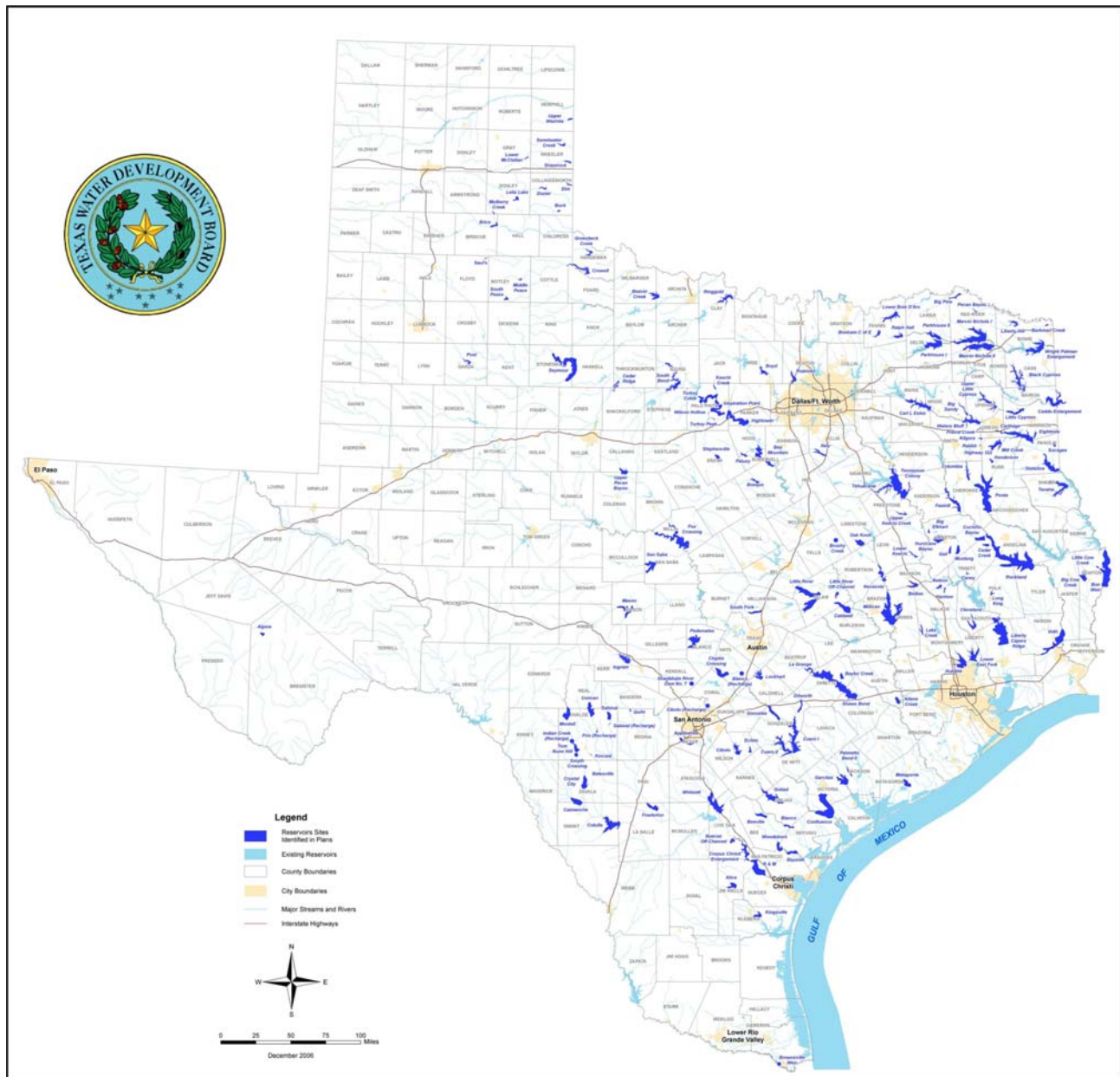
Figure ES-3. Reservoir Sites Identified in Plans

Eleven screening criteria and the relative weightings of these criteria were adopted by TWDB staff and the consultants for the reservoir site screening process. These criteria are listed as follows in the order of relative importance based on an assigned integer weighting from five (most important) to one (least important).

- Recommended Water Management Strategy or Unique Reservoir Site in the 2007 State Water Plan (5)
- Firm Yield (5)
- Unit Cost of Water (4)

- Special Considerations (3)
- Ecologically Significant Stream Segment (3)
- Terrestrial Impacts (2)
- Water Supply Needs within 50 Miles (2)
- Least Distance to a Major Demand Center (2)
- System Operations Opportunity (2)
- Water Quality Concerns (1)
- Yield per Unit Surface Area (1)

The 19 top-ranked sites for protection or acquisition are shown in Figure ES-4 and listed in alphabetical order as follows:

- Allens Creek
- Bedias
- Brownsville Weir
- Brushy Creek
- Cedar Ridge (Breckenridge)
- Columbia (Eastex)
- Cuero II (Sandies Creek, Lindenau)
- Fastrill (Weches)
- Lower Bois d'Arc Creek
- Marvin Nichols IA
- Nueces Off-Channel
- Palmetto Bend – Stage II
- Parkhouse I
- Parkhouse II
- Post
- Ralph Hall
- Ringgold
- Tehuacana
- Wilson Hollow

As indicated in Figure ES-4, three reservoir sites (Allens Creek, Columbia, and Post) have already been designated as unique by the Texas Legislature, 12 are recommended unique reservoir sites in the 2007 State Water Plan, and four are recommended for designation as unique reservoir sites as a result of this study. There are certainly other viable reservoir sites and some of them may be suitable for designation as unique. Study funds, however, were sufficient to update technical information for only the 16 top ranked sites not previously designated as unique.
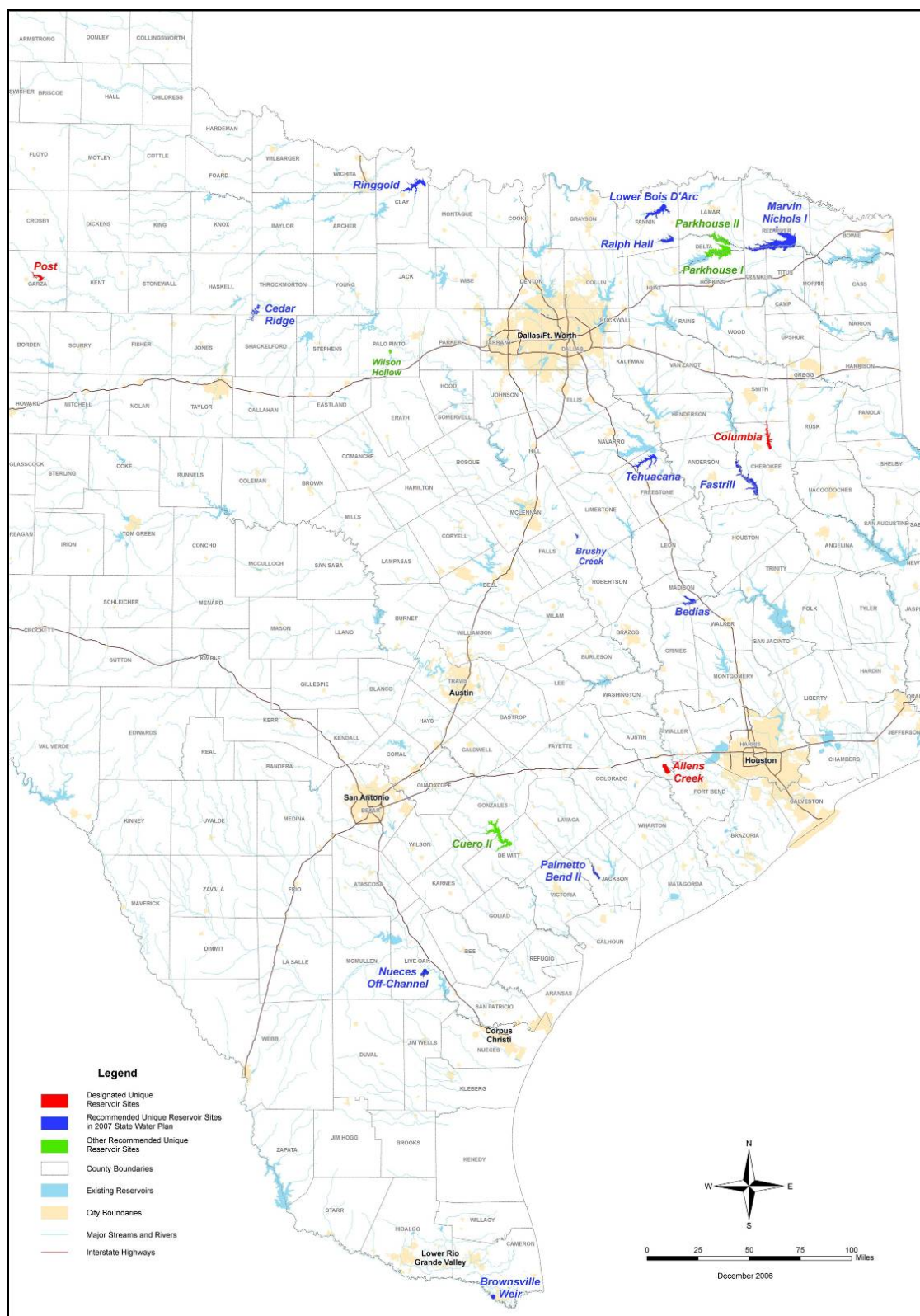
Figure ES-4. Designated and Recommended Unique Reservoir Sites

ES.3   Reservoir Sites Recommended for Protection

Technical evaluations including project description, firm yield computation, cost estimation, and assessment of environmental consideration have been performed for each of the 16 reservoir sites recommended for protection and/or acquisition. Key information from these technical evaluations is summarized in Table ES-1. Observations and comparisons of these 16 reservoir sites are presented in the following paragraphs in the order of relative importance for the screening process that was applied to about 150 sites.

ES.3.1   Recommended Water Management Strategy or Unique Reservoir Site in the 2007 State Water Plan

All of the reservoir sites recommended for protection, with the exceptions of Cuero II (Sandies Creek, Lindenau), George Parkhouse I, and George Parkhouse II, are recommended water management strategies and/or are recommended for designation as unique reservoir sites in the 2007 State Water Plan. The Parkhouse I and II Reservoirs are identified as alternative water management strategies for several major water suppliers in the 2006 Region C Water Plan. The Cuero II reservoir site is not explicitly mentioned in the 2006 Region L Water Plan, though it might be considered Additional Storage which is referenced therein as a water management strategy in need of further study and funding prior to implementation.

ES.3.2   Firm Yield

The largest firm yield or dependable supply during a drought of record (602,000 acft/yr) can be provided by the Marvin Nichols IA reservoir site. Depending upon the ultimate development of other sites recommended for protection in the Sulphur River Basin (e.g., Parkhouse I, Parkhouse II, and/or Ralph Hall) and their priorities relative to Marvin Nichols IA, the firm yield of Marvin Nichols IA could be as low as 460,800 acft/yr (Appendix A). The Brushy Creek reservoir site provides the least firm yield (1,380 acft/yr) among the sites recommended for protection, however, it is the recommended water supply strategy for the City of Marlin.

Table ES-1.
Comparison of Reservoir Sites Recommended for Protection

Reservoir Site	River Basin	Region	Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	Firm Yield (acft/yr)	Unit Cost of Water - Raw @ Reservoir ($/acft/yr)	Special Considerations (Permitted)	Ecologically Significant Stream Segment (# Criteria)	Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2060 Water Supply Needs within 50 miles (acft/yr)	Least Distance to Major Demand Center (miles)	System Operations Opportunity	Water Quality Concerns (Treatment)	Yield / Surface Area
Bedias	Trinity	G & H	Yes	75,430	$232	No	No Impact	Just Upstream (6)	284,552	85	Yes	No	7.5
Brownsville Weir	Rio Grande	M	Yes	20,643	$181	Yes	Inundating (4)	No Impact	223,489	29	Yes	No	34.4
Brushy Creek	Brazos	G	Yes	1,380	$484	Yes	No Impact	No Impact	246,820	83	No	No	2.0
Cedar Ridge	Brazos	G	Yes	36,891	$230	No	No Impact	No Impact	17,240	146	Yes	No	6.0
Cuero II	Guadalupe	L	No	71,437	$501	No	No Impact	No Impact	346,140	71	Yes	No	2.7
Fastrill	Neches	I	Yes	134,038	$152	No	Inundating (3)	Inundating (1)	136,476	127	Yes	No	5.4
Lower Bois D'Arc	Red	C	Yes	126,280	$140	No	Inundating (3)	Inundating (4)	728,028	80	Yes	No	7.6
Marvin Nichols IA	Sulphur	D	Yes	602,000	$61	No	Indirect (2)	Inundating (1)	103,879	124	Yes	No	8.9
Nueces Off-Channel	Nueces	N	Yes	39,935	$432	No	No Impact	No Impact	159,640	56	Yes	No	7.5
Palmetto Bend II	Lavaca	P	Yes	22,964	$515	Yes	Indirect (2)	No Impact	79,857	93	Yes	No	5.0
Parkhouse I	Sulphur	D	No	122,000	$174	No	No Impact	Upstream (1)	561,591	93	Yes	No	4.2
Parkhouse II	Sulphur	D	No	144,300	$107	No	No Impact	Upstream (1)	473,850	94	Yes	No	10.0
Ralph Hall	Sulphur	C	Yes	32,940	$430	No	No Impact	No Impact	419,136	72	Yes	No	4.3
Ringgold	Red	B	Yes	32,800	$273	No	No Impact	No Impact	313,933	96	Yes	No	2.2
Tehuacana	Trinity	C	Yes	41,900	$320	No	Indirect (3)	Just Upstream (5)	890,895	79	Yes	No	2.8
Wilson Hollow	Brazos	G	Yes	5,873	$920	No	No Impact	No Impact	511,124	79	Yes	No	17.6

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ES.3.3   Unit Cost of Water

The Marvin Nichols IA site provides firm raw water supply at the reservoir for the least unit cost among the reservoir sites recommended for protection. Even with potential reductions in firm yield due to prior development of upstream reservoirs, Marvin Nichols IA would still have the least unit cost for additional firm water supply. The greatest unit cost is associated with the Wilson Hollow site which is an off-channel reservoir including pumping and transmission facilities to move water from Lake Palo Pinto. It is important to remember that costs reported in this study include neither transmission from the source reservoir to the ultimate user nor treatment to drinking water standards.

ES.3.4   Special Considerations

Permits have been issued by the Texas Commission on Environmental Quality (TCEQ) or a predecessor regulatory agency for reservoirs at the Brownsville Weir, Brushy Creek, and Palmetto Bend II sites. A water rights application is pending at TCEQ for the Ralph Hall site and water rights applications are in various stages of preparation for the Cedar Ridge, Fastrill, Lower Bois d'Arc Creek, and Wilson Hollow sites.

ES.3.5   Ecologically Significant Stream Segments

Six of the 16 reservoir sites recommended for protection are expected to have some effect upon stream segments identified as ecologically significant by the Texas Parks & Wildlife Department (TPWD). The Brownsville Weir, Fastrill, and Lower Bois d'Arc Creek sites would affect recommended segments by inundation, while the Marvin Nichols IA, Palmetto Bend II, and Tehuacana sites could have indirect effects upon recommended segments as a result of changes in flow regime below the reservoirs.

ES.3.6   Terrestrial Impacts

Seven of the 16 reservoir sites recommended for protection are expected to have some effect upon prioritized bottomland hardwood preservation sites identified by the USFWS. The Fastrill, Lower Bois d'Arc Creek, and Marvin Nichols IA sites would affect such bottomland hardwood preservation sites by inundation, while the Bedias and Tehuacana sites would be located immediately upstream of potential preservation sites. Although the Parkhouse I and Parkhouse II sites would be located some distance upstream of a prioritized bottomland

hardwood preservation site, detailed hydrological and biological studies would likely be required to assess potential reservoir impacts. Development of reservoir projects at all 16 of the sites recommended for protection in this study would significantly affect only two of 14 Priority 1 bottomland hardwood preservation sites in Texas. Since publication of the prioritized bottomland hardwood preservation sites by USFWS in 1985, no major reservoirs have been constructed that consequentially affect any of the 14 Priority 1 sites.

ES.3.7   Water Supply Needs within 50 Miles

The Lower Bois d'Arc Creek, Parkhouse I, Parkhouse II, Ralph Hall, Tehuacana, and Wilson Hollow reservoir sites have the greatest projected needs for additional water supply at year 2060 for counties within (or partially within) a 50-mile radius of the sites. The Cedar Ridge and Palmetto Bend II sites have the least projected needs for potential users geographically proximate to the reservoir sites. It is noted, however, that projected needs near the Cedar Ridge site could be underestimated because existing reservoirs serving users in the area are in the midst of a drought more severe than that experienced in the 1950s.

ES.3.8   Least Distance to a Major Demand Center

Among the 16 reservoir sites recommended for protection, the Brownsville Weir and Nueces Off-Channel reservoir sites are the closest to some of the largest current population centers in Texas, while the Cedar Ridge, Fastrill, and Marvin Nichols IA sites are the most distant.

ES.3.9   System Operations Opportunity

Each of the 16 reservoir sites recommended for protection, with the exception of Brushy Creek, presents some opportunity for enhancement of firm yield through system operations with one or more existing reservoirs or alternative water supply sources.

ES.3.10 Water Quality Concerns

None of the 16 reservoir sites recommended for protection exhibit water quality characteristics expected to significantly affect costs of treatment to drinking water standards.

ES.3.11 Yield per Unit Surface Area

The Brownsville Weir and Wilson Hollow reservoir sites, though relatively small, are the most efficient in terms of firm yield per unit of inundated surface area.

ES.4   Reservoir Site Acquisition Program

Sixteen (16) reservoir sites are recommended for protection through legislative designation as being of unique value for the construction of a reservoir. Beyond such designation, the Texas Legislature could choose to create a reservoir site acquisition program in order to exercise greater control over federal, state, or local government actions that would significantly impact the feasibility of future reservoir construction for water supply purposes. Table ES-2 summarizes the conservation, or normal, pool areas for the 16 reservoir sites evaluated in detail in this study, as well as the estimated costs for acquisition in 2005 dollars. Land for Brushy Creek Reservoir has been purchased by the City of Marlin and purchase of land for Brownsville Reservoir is not expected to be necessary because the land to be inundated is managed and controlled by the International Boundary and Water Commission. As shown in Table ES-2, acquisition of the remaining 14 sites up to the conservation storage level would entail purchase of about 244,000 acres at an estimated capital cost of about $428,000,000 for land only. This capital cost equates to an annual cost of about $28,400,000 assuming a 40-year debt service period and an annual interest rate of 6 percent.

A reservoir site acquisition program should include sites that the Legislature has already designated as being of unique value for the construction of a reservoir. These designated sites are: Allens Creek on Allens Creek near the confluence with the Brazos River in Austin County; Columbia on Mud Creek, a tributary of the Angelina River, in Cherokee and Smith Counties; and Post on the north fork of the Double Mountain Fork of the Brazos River in Garza County. As land for Allens Creek has already been purchased, only Columbia and Post need be included in a reservoir site acquisition program. Addition of the Columbia and Post sites (up to conservation storage level) would bring the reservoir site acquisition program to a total of about 256,500 acres at an estimated capital cost of about $447,000,000 (Table ES-2) and an annual cost of about $29,700,000.

Consideration may also be given to protection and/or acquisition of five additional sites recommended for designation as unique reservoir sites in the 2007 State Water Plan, but not technically evaluated in this study. These sites are: Lake 07 and Lake 08 on the North Fork of

the Double Mountain Fork of the Brazos River in Lubbock County; and Little River Reservoir and Little River Off-Channel on, or adjacent to, the Little River, a tributary of the Brazos River in Milam County.

Table ES-2.
Reservoir Site Acquisition Program

Reservoir	Conservation Pool Elevation (ft-msl)	Conservation Pool Area (acres)	Land Unit Cost[1] ($/ac)	Conservation Pool Land Cost[1] ($)
Bedias	210	10,000	$3,288	$32,880,000
Brownsville Weir	26	600 / 0[2]	$0[2]	$0[2]
Brushy Creek	380.5	697 / 0[3]	$0[3]	$0[3]
Cedar Ridge	1430	6,190	$850	$5,261,500
Cuero II	232	28,154	$3,100	$87,277,400
Fastrill	274	24,948	$1,825	$45,530,100
Lower Bois d'Arc	534	16,526	$2,675	$44,207,050
Marvin Nichols IA	328	67,392	$1,201	$80,937,792
Nueces Off-Channel	275.3	5,294	$1,450	$7,676,300
Palmetto Bend II	44	4,564	$1,627	$7,425,628
Parkhouse I	401	28,855	$1,201	$34,654,855
Parkhouse II	410	14,387	$1,201	$17,278,787
Ralph Hall	551	7,605	$2,675	$20,343,375
Ringgold	844	14,980	$850	$12,733,000
Tehuacana	315	14,938	$2,009	$30,010,442
Wilson Hollow	1077	333	$4,250	$1,415,250
Total		**244,166**		**$427,631,479**
Columbia[4]	315	10,000	$1,825	$18,250,000
Post[4]	2,420	2,283	$566	$1,292,278
Grand Total		**256,449**		**$447,173,657**

[1]Land costs in 2005 dollars.

[2]All of the inundated area associated with the Brownsville Reservoir lies within the channel portion of the Rio Grande and is managed and controlled by the United States and Mexican Sections of the International Boundary and Water Commission for flood protection purposes; therefore, it is anticipated that purchase of this land will not be necessary.

[3]All of the land to be inundated by Brushy Creek Reservoir has been purchased by the City of Marlin.

[4]Texas Legislature has designated this site as being of unique value for the construction of a reservoir.

Additional acreage for project facilities and above the conservation storage level up to the 100-year or standard project flood level is usually purchased around the perimeter of a reservoir. Comprehensive hydrologic and hydraulic studies that define these flood levels, however, are typically a part of final design and have not been undertaken for most of the 18 reservoir sites recommended for protection and/or acquisition. Implementation of a reservoir site acquisition program will also necessarily entail substantial additional costs for title research, negotiations, land surveying, and legal proceedings.

As an important part of this reservoir site acquisition study, TPWD performed land cover classifications for each of the 16 reservoir sites selected for technical evaluation. Figure ES-5 summarizes landcover classification by percentage for the potential acquisition program lands including all 16 reservoir sites technically evaluated herein up to their conservation storage levels. As shown in Figure ES-5, the predominant landcovers are Grassland (30 percent) and Upland Deciduous Forest (23 percent). Approximately 19 percent of the acquisition program lands are classified as Bottomland Hardwood Forest with more than 75 percent of such forests located in the Marvin Nichols IA and Parkhouse I reservoir sites. Only about 7 percent of the acquisition program lands are classified as Agricultural Land.
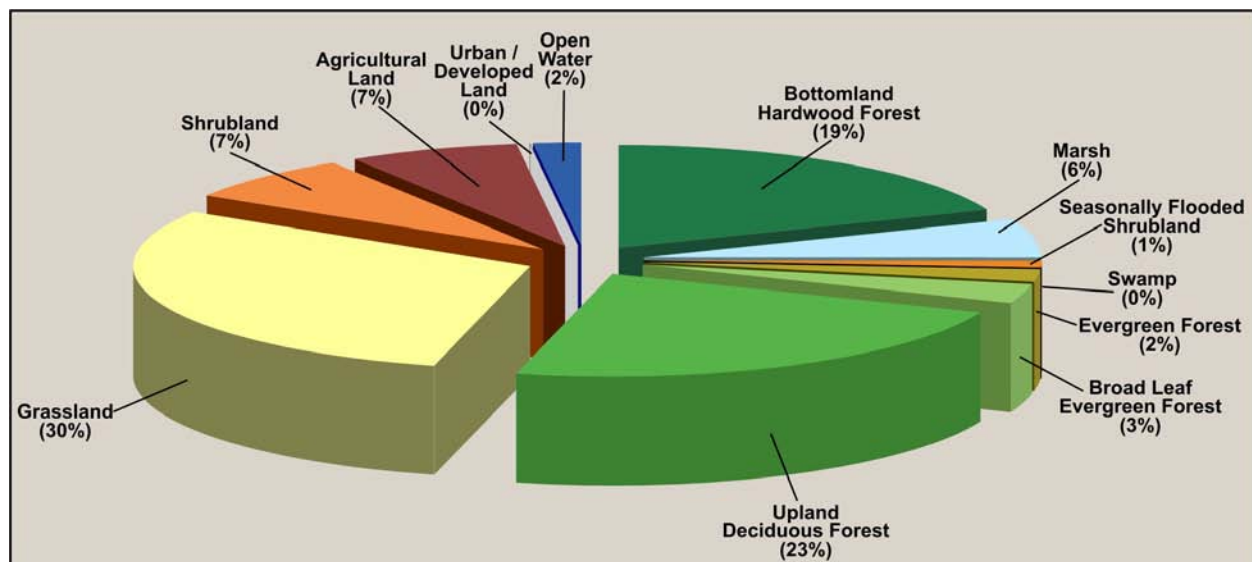
Figure ES-5. Landcover Classification for 16 Reservoir Sites

ES.5 Recommendations

- Legislatively designate the 16 reservoir sites technically evaluated and recommended in this study as unique.

- Conduct more detailed studies to define total lands for protection including reservoir flood pools and land required for project facilities.

- Consider further investigation (including updated landcover assessments) and potential protection of bottomland hardwood preservation sites for mitigation of habitat losses associated with future reservoir development.

Section 1
Introduction

1.1   Background

For more than four decades, the Texas Water Development Board (TWDB) has been responsible for developing and updating the Texas State Water Plan in cooperation with other state agencies and numerous regional, local, and private interests across the State (Figure 1.1-1). Approximately 100 potential reservoirs have been identified or recommended in the various State Water Plans completed during this period and many more reservoir sites have been considered by state or federal agencies, river authorities, and others. While some of these reservoirs have been constructed, many remain under consideration today as demands for reliable surface water supplies for municipal, industrial, steam-electric power generation, and other purposes continue to grow.
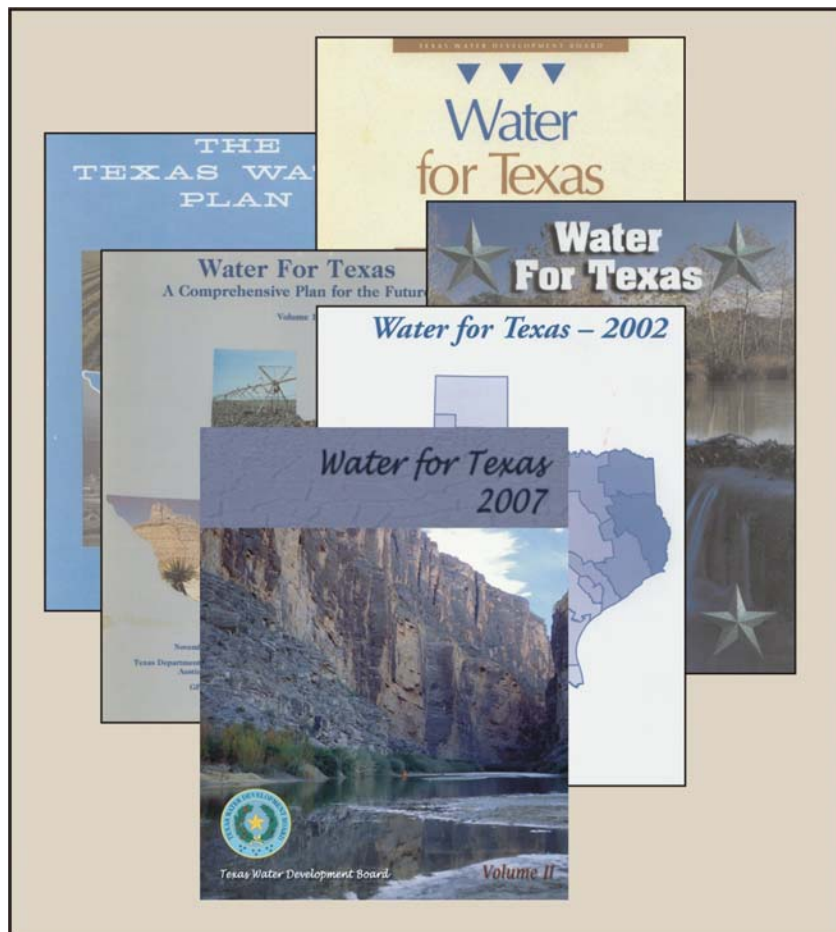
Figure 1.1-1. State Water Plans

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The 2007 State Water Plan recommends the Legislature consider 17 major reservoir sites identified by Regional Water Planning Groups and the TWDB for protection by designation as unique reservoir sites. The Texas Water Code provides that *the legislature may designate a site of unique value for the construction of a reservoir* [Section 16.051(f)(2)] and that *a state agency or political subdivision of the state may not obtain a fee title or an easement that would significantly prevent the construction of a reservoir on a site designated by the legislature under Subsection (f) of this section* [Section 16.051(g)(2)]. Lack of such designation has allowed state, federal, or local governments or private entities to take actions that have significantly impacted the feasibility of constructing reservoirs at some sites. A recent example of such an action is the unilateral establishment of the Neches River National Wildlife Refuge by the U.S. Fish & Wildlife Service on the site of the only new reservoir planned by the City of Dallas in the next 50 years and included in the 2007 State Water Plan.

Perhaps the most certain means of ensuring protection for unique reservoir sites is acquisition of the properties necessary for the reservoir projects, holding such properties in the public trust, and preventing conversion or uses of the properties for purposes ultimately precluding future reservoir development. Reservoir site acquisition must be considered in the context of compensatory ecological resource protection and preservation for mitigation of valuable ecological resources lost to permanent inundation. Hence, this research project includes land cover classification for reservoir sites potentially included in an acquisition program. Most importantly, this research project includes development and application of technical resources and matrix screening processes necessary to provide recommendations as to the most appropriate reservoir sites for State protection and/or acquisition.

1.2   Authorization and Objectives

The reservoir site acquisition study summarized in this report was authorized by the TWDB through Contract No. 0604830615 effective April 17, 2006. The primary objective of the study is selection of reservoir sites most appropriate for protection and/or acquisition by the State of Texas in order to provide for future development of essential surface water supplies. Major tasks leading to accomplishment of this objective, along with the section of this report in which pertinent information can be found, are listed as follows and summarized in Figure 1.2-1:

(1) Research and data compilation for about 150 potential reservoir projects (Section 2);

(2) Adoption of screening criteria and application of a matrix screening process resulting in the selection of 16 reservoir sites for technical evaluation (Section 2);

(3) Application of geographic information system (GIS) techniques for definition and mapping of reservoir sites including elevation-area-capacity relationships, potential conflicts, and land cover classification (Section 3);

(4) Assessment of reservoir firm yield available under drought of record conditions subject to senior water rights and provisions for environmental flow needs (Section 3);

(5) Estimation of costs associated with dams and appurtenant structures, major relocations, and acquisition of reservoir and mitigation lands (Section 3); and

(6) Recommendation of reservoir sites for protection and/or acquisition (Section 4).

Although the primary objective of this study is selection of reservoir sites most appropriate for protection, it is understood that such protection as may be afforded by the Legislature is not intended to circumvent the planning and permitting processes through which any major reservoir project must meet the requirements of applicable law prior to implementation. It is further understood that designation of reservoir sites recommended herein as unique, and even acquisition of these sites, does not preclude the planning, permitting, and construction of major reservoirs at alternative sites.
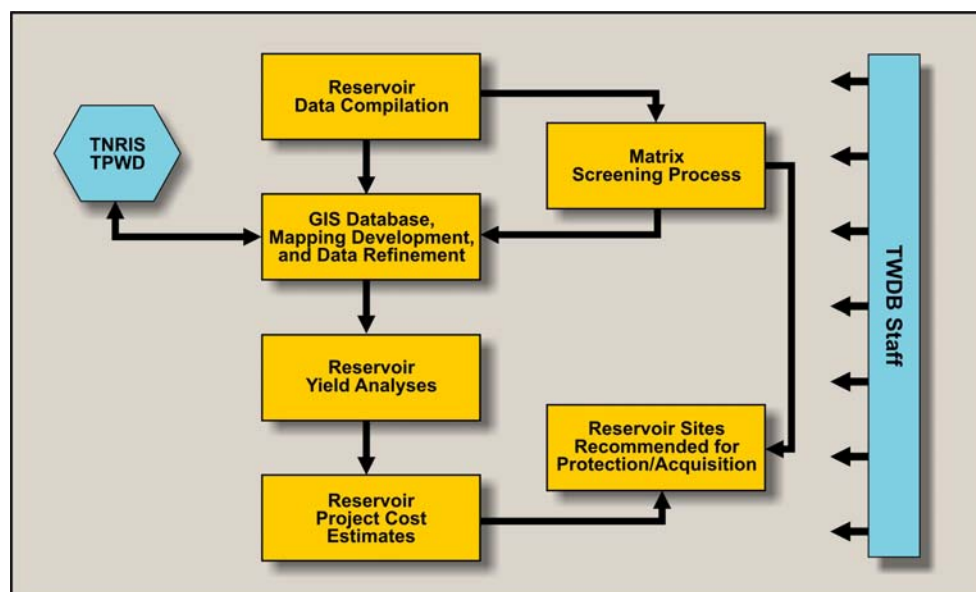
Figure 1.2-1. Reservoir Site Protection Study Tasks

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Section 2
Reservoir Site Screening Process

2.1   Data Compilation and Sources

Research in the course of this study has identified over 220 major reservoir sites in Texas that have been included in State or Regional Water Plans or in significant planning studies by state or federal agencies, river authorities, water districts, or other water purveyors interested in water supply development. A tabular summary of these reservoir sites and plans in which they appear is included in the matrix screening tool described in Section 2.4 along with a reference bibliography. For the purposes of this study, a major reservoir is defined to be one having a conservation storage capacity of at least 5,000 acft. To date, reservoirs have been constructed at approximately 70 of these sites. For the remaining number of about 150 reservoir sites, consultants have conducted intensive library and archive research to compile key descriptive information including reservoir name, river basin and state water planning region location, firm yield, unit cost of raw water at the reservoir, and surface area at the proposed conservation storage pool level. In addition, shape files for use in GIS applications have been compiled or created for all of these remaining sites at which reservoirs have not been constructed. Exhibit 1 shows the locations of the reservoir sites that have been identified in plans and are considered in the matrix screening process summarized in Section 2.2.

2.2   Matrix Screening Process

In cooperation with TWDB staff, consultants developed and applied a matrix screening process with the objective of identifying potential reservoir sites most suitable for protection or acquisition by the State of Texas for the purpose of water supply development. Steps in this matrix screening process included:

(1) Identification of potential screening criteria;

(2) Selection and refinement of screening criteria in cooperation with TWDB staff;

(3) Assignment of appropriate relative importance, or weighting, to each selected screening criterion in cooperation with TWDB staff;

(4) Development and testing of a matrix screening tool;

(5) Compilation of supplemental data necessary to populate a matrix of reservoir sites and screening criteria;

(6) Application of the matrix screening tool to identify a select group of approximately 15 to 20 reservoir sites for more detailed technical evaluations as a part of this study; and

(7) TWDB staff selection of 16 reservoir sites for technical evaluation.

Information and activities relevant to each of these steps comprising the matrix screening process are described in Sections 2.3 through 2.5.

2.3   Screening Criteria

2.3.1   Criteria Identification Process

Potential screening criteria to be used in this study were first contemplated as part of an initial meeting on May 1, 2006 during which TWDB staff articulated goals for the study and critical issues to be considered in meeting these goals. With this guidance from TWDB staff, the consultants developed a preliminary list of potential screening criteria and met with TWDB staff to discuss on May 17, 2006. These discussions provided supplemental guidance leading to significant refinement of the preliminary list prior to development of the matrix screening tool. On August 14, 2006, the consultants met with TWDB staff to finalize the screening criteria and associated relative weightings as well as to demonstrate a draft version of the matrix screening tool using a sample set of nine reservoir sites. Integration of limited refinements suggested by TWDB staff resulted in the 11 criteria adopted for use in the matrix screening tool. This tool was used to assess approximately 150 reservoir sites across the state.

2.3.2   Criteria Discussion and Relative Weighting of Criteria

Eleven screening criteria and the relative weightings of these criteria were adopted by TWDB staff and the consultants prior to population and application of the matrix screening tool. These criteria are briefly discussed in the following paragraphs in the order of relative importance based on an assigned integer weighting from five (most important) to one (least important). The integer weighting factor is shown in parentheses following the criterion.

2.3.2.1   Recommended Water Management Strategy or Unique Reservoir Site in the 2007 State Water Plan (5)

One of the most important indications of a reservoir site that merits protection is its status in the current 2007 State Water Plan. As part of this planning process, each potential reservoir project recommended as a water management strategy and/or considered a unique reservoir site

has been subject to public comment and due consideration by one or more Regional Water Planning Groups representing diverse interests.

2.3.2.2   *Firm Yield (5)*

Since projected needs for additional water supply in Texas are great, the magnitude of firm yield or dependable supply during drought becomes a very important consideration. Larger reservoirs that are capable of meeting many needs may provide an economy of scale and concentration of impacts deemed beneficial from a state-wide perspective. Estimates of firm yield used in the matrix screening process are based on prior appropriation and include adjustments to reflect inflow passage for environmental flow needs.

2.3.2.3   *Unit Cost of Water (4)*

The unit cost of water is a composite measure of project efficiency and is computed as the annual costs of debt service on the dam and appurtenant works, land acquisition, and relocations plus operations and maintenance divided by the firm yield. Lower unit cost indicates that more dependable water supply is developed per dollar expended and is scored more favorably. Estimates of project cost obtained from older plans were updated to current dollars prior to calculation of unit cost and use in the matrix screening process.

2.3.2.4   *Special Considerations (3)*

The Allens Creek, Columbia, and Post Reservoir sites have been designated as unique by the Texas Legislature pursuant to SB1593 (76th Legislature), SB1362 (78th Legislature), and HB3096 (77th Legislature), respectively. In addition, the Brownsville Weir, Brushy Creek, and Palmetto Bend II Reservoir projects have been issued permits by the Texas Commission on Environmental Quality (TCEQ) or one of its predecessor regulatory agencies. This Special Considerations criterion provides recognition of the more advanced regulatory status of these six reservoir sites as compared to others.

2.3.2.5   *Ecologically Significant Stream Segment (3)*

The Texas Parks & Wildlife Department (TPWD) has identified a number of stream segments throughout the state as ecologically significant on the bases of biological function, hydrologic function, riparian conservation, exceptional aquatic life uses, and/or threatened or

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endangered species (Figure 2.3-1) (TPWD, 1999). To date, 15 stream segments (seven in Region E and eight in Region H) have been recommended by Regional Water Planning Groups for designation as unique. Subject to this criterion, reservoir sites that do not conflict with identified ecologically significant stream segments are scored more favorably. Applications of this criterion account for differences between inundation of and indirect impacts to stream segments.

2.3.2.6   *Terrestrial Impacts (2)*

The U.S. Fish & Wildlife Service (USFWS) issued a report (USFWS, 1985) on the Texas Bottomland Hardwood Preservation Program in which numerous potential preservation sites, located primarily in east Texas, were identified and prioritized for protection (Figure 2.3-2). The terrestrial impacts criterion scores reservoir sites that do not conflict with these prioritized bottomland hardwood preservation sites more favorably. Applications of this criterion account for differences between reservoir sites inundating, or being located immediately upstream or some distance upstream of bottomland hardwood preservation sites. Consideration was also given to preservation site habitat quality as reflected in the priority assigned by USFWS.

2.3.2.7   *Water Supply Needs within 50 Miles (2)*

Reservoir sites that are geographically proximate to areas having long-term water supply needs may have advantages of lower cost for transmission facilities and lesser concerns with inter-basin transfer as well as greater opportunities for economic development and increased likelihood of local support. Projected municipal, industrial, and steam-electric power generation water supply needs at year 2060 for counties within (or partially within) a 50-mile radius of a reservoir site are summed, and sites with greater needs are scored more favorably.

2.3.2.8   *Least Distance to a Major Demand Center (2)*

Similar to the previous criterion, the least distance to a major demand center criterion scores reservoir sites more favorably the closer they are located to one or more of the largest current population centers in Texas (Figure 2.3-3).

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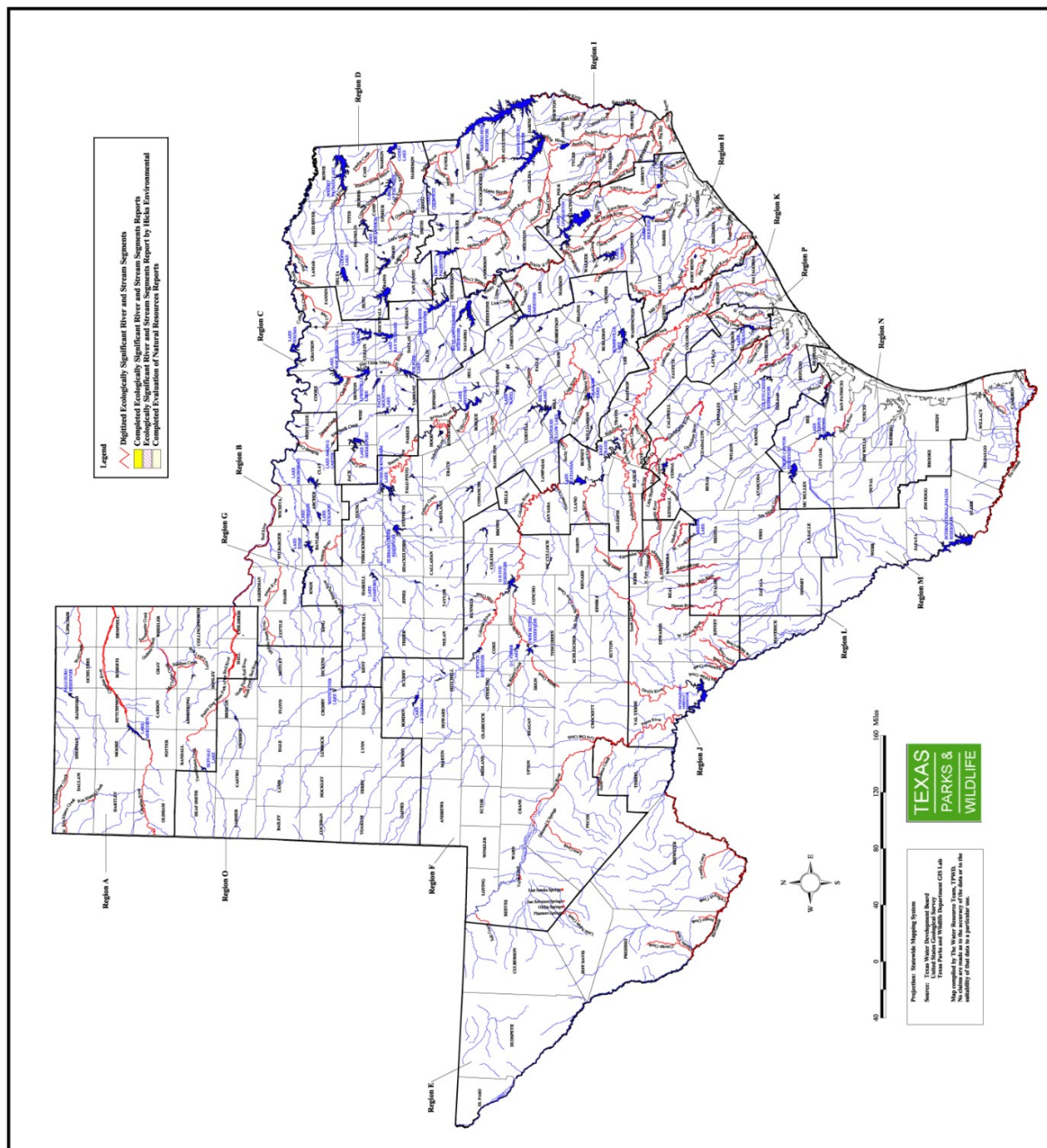
Figure 2.3-1. Ecologically Significant River and Stream Segments as Identified by TPWD

Figure 2.3-2. Bottomland Hardwood Preservation Sites as Recommended by USFWS
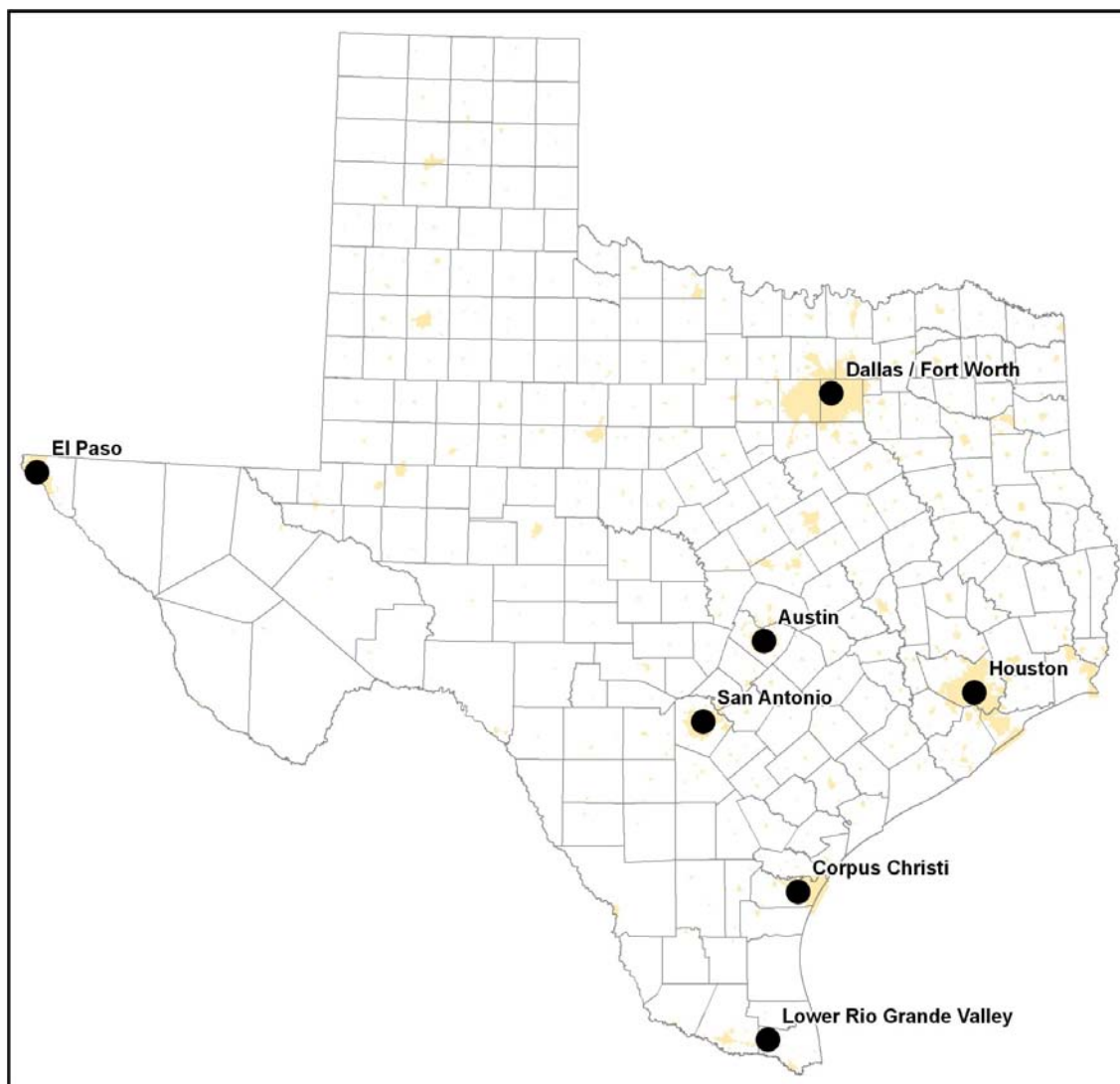
Figure 2.3-3. Major Water Demand Centers

2.3.2.9 *System Operations Opportunity (2)*

Numerous studies have shown that system operation of reservoirs can significantly increase firm yield from that obtained through independent operations. Hence, the system operations opportunity criterion assigns preference to reservoir sites proximate to one or more existing reservoirs or alternative water supply sources.

2.3.2.10 *Water Quality Concerns (1)*

Subject to the water quality concerns criterion, preference is afforded to reservoir sites for which there are no known inflow constituents likely to significantly increase difficulty and cost of treatment to drinking water standards.

2.3.2.11   Yield per Unit Surface Area (1)

The yield per unit surface area criterion provides a relative measure of reservoir site efficiency with respect to inflow, topography, and evaporation losses. Preference is given to reservoir sites for which available inflow is efficiently stored and evaporation losses are minimized, thereby maximizing firm yield.

2.4   Matrix Screening Tool Description

A matrix screening tool has been constructed in Microsoft Excel to provide for organized storage of compiled information regarding numerous reservoir sites and to expediently create a table preferentially ranking these reservoir sites based on criteria and assigned weights discussed above. The scoring system used within the matrix screening tool is briefly summarized in the following paragraphs.

Four of the criteria (Recommended to Meet Needs or as a Unique Reservoir Site in the 2007 State Water Plan, Special Considerations, System Operations Opportunity, and Water Quality Concerns) are based on a simple yes or no entry and receive a base score of 5 or 1, respectively. This base score is then multiplied by the assigned weight and added to the composite score for each reservoir site.

Five of the criteria (Firm Yield, Unit Cost of Water, Water Supply Needs within 50 Miles, Least Distance to Major Demand Center, and Yield per Unit Surface Area) are derived from numerical data specific to each reservoir site. Comprehensive data are not available for all reservoir sites, so techniques were integrated in the matrix screening tool to minimize potential biases resulting from missing data. Application of each of these five criteria is based on segregating the reservoir sites into five groups of similar numerical values (each group including 20 percent of the reservoir sites), and assigning an integer base score ranging from 5 (most favorable) to 1 (least favorable) to each group. This base score is then multiplied by the assigned weight and added to the composite score for each reservoir site.

The Ecologically Significant Stream Segment criterion is evaluated for each reservoir site by first assigning 1 to each yes entry as to the potential effect of a reservoir on biological functions, hydrologic functions, riparian conservation areas, exceptional aquatic life uses, and/or threatened or endangered species specifically identified by TPWD. Then, a secondary weighting factor is assigned according to whether the reservoir would actually inundate the stream segment (1.0), be located immediately upstream and indirectly impact the stream segment (0.5), or have

no significant impact upon the stream segment (0.0). The base score for each reservoir site is calculated by multiplying the number of yes entries by the secondary weighting factor and subtracting the product from 5. Therefore, base scores for this criterion may range from 5 (most favorable, no impacts) to 0 (least favorable, inundation impacts in all five categories). The base score is then multiplied by the assigned weight and added to the composite score for each reservoir site.

The Terrestrial Impacts criterion is evaluated by determining whether a reservoir site conflicts with an identified bottomland hardwood preservation site and assigning an initial score based on the priority attributed to the preservation site by USFWS. The initial score ranges from 1 for conflict with a Priority 1 bottomland hardwood preservation site up to 5 for no conflict or conflict with a Priority 5 or 6 bottomland hardwood preservation site. Then, a secondary weighting factor is assigned according to whether the reservoir would actually inundate the preservation site (1.0), be located immediately upstream (1.5), or be located some distance upstream (2.0). The base score for each reservoir site is calculated by multiplying the initial score by the secondary weighting factor and dividing by 2. Therefore, base scores for this criterion may range from 5 (most favorable, no impacts) to 0.5 (least favorable, inundation of Priority 1 preservation site). The base score is then multiplied by the assigned weight and added to the composite score for each reservoir site.

The 11 weighted criterion scores are summed to obtain a composite score for each reservoir site. This composite score is then used to rank all reservoir sites from highest to lowest in terms of favorability for protection or acquisition. Appendix E includes summary excerpts from the populated matrix screening tool showing ranking for all sites evaluated, criteria and relative weighting used to obtain this ranking, and compiled data for reservoir sites grouped by river basin. Recognizing likely interest in scoring and ranking of reservoir sites subject to a spectrum of criteria weightings, the populated matrix screening tool is set up for convenient modification of criteria weights, and routines have been installed for instant update and summary of reservoir site rankings.

2.5   *Results of Matrix Screening Process*

During a September 21, 2006 meeting, consultants demonstrated application of the populated matrix screening tool to TWDB staff and presented a ranking of reservoir sites based
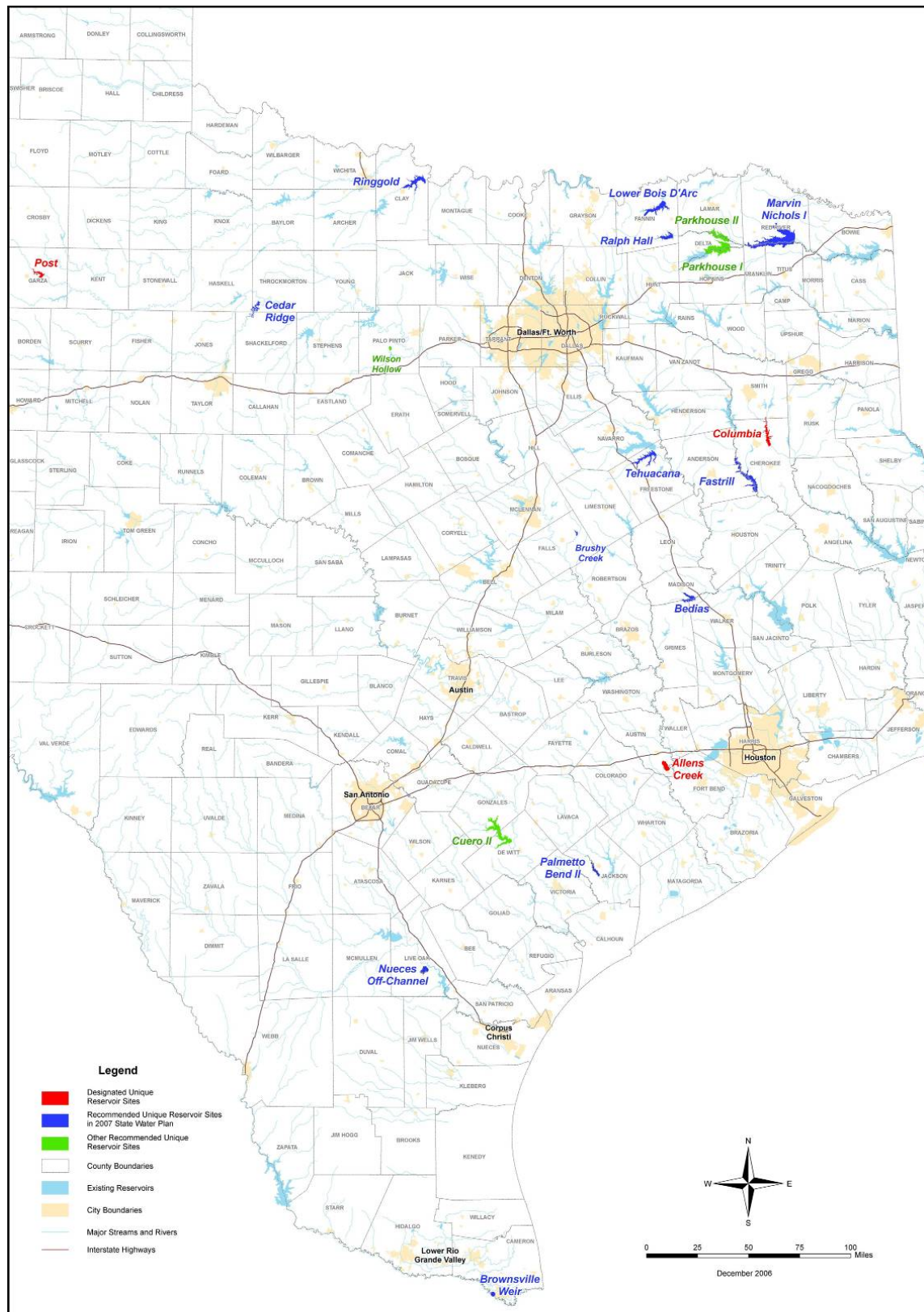
Figure 2.5-1. Designated and Recommended Unique Reservoir Sites

on criteria and weightings previously adopted. The 19 top-ranked sites for protection or acquisition are shown in Figure 2.5-1 and Exhibit 2 and are listed in alphabetical order as follows: Allens Creek, Bedias, Brownsville Weir, Brushy Creek, Cedar Ridge (Breckenridge), Columbia (Eastex), Cuero II (Sandies Creek), Fastrill (Weches), Lower Bois D'Arc, Marvin Nichols IA, Nueces Off-Channel, Palmetto Bend II, Parkhouse I, Parkhouse II, Post, Ralph Hall, Ringgold, Tehuacana, and Wilson Hollow. As indicated in Figure 2.5-1, three reservoir sites have already been designated as unique by the Texas Legislature, 12 are recommended unique reservoir sites in the 2007 State Water Plan, and four are identified as potential unique reservoir sites as a result of this study. Detailed information regarding these reservoir sites, individually and collectively, is presented in Sections 3 and 4, respectively.

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Section 3
Reservoir Sites Recommended for Protection

3.1 Designated Unique Reservoir Sites

Application of the matrix screening process considering approximately 150 potential reservoir sites resulted in the identification of 19 sites that appear most suitable for protection or acquisition by the State of Texas to ensure availability for future water supply development. Pursuant to actions of the Texas Legislature, three of these sites have been designated as being of unique value for the construction of a dam and reservoir. The three sites designated as unique are: Allens Creek on Allens Creek near the confluence with the Brazos River in Austin County; Columbia on Mud Creek, a tributary of the Angelina River, in Cherokee and Smith Counties; and Post on the North Fork of the Double Mountain Fork of the Brazos River in Garza County. As these three sites have already received some degree of protection from the State, detailed study has been focused upon development and compilation of technical information about the other 16 reservoir sites that emerged from the matrix screening process. Such information is summarized by reservoir site in Section 3.4 and general assumptions regarding water supply modeling and cost estimates are presented in Sections 3.2 and 3.3, respectively.

3.2 Assumptions for Water Supply Modeling

The general hydrologic assumptions and procedures used in the technical evaluations of the 16 reservoir sites selected for detailed study are described below. Exceptions to these assumptions and procedures are explained in the documentation provided for each potential reservoir site in Section 3.4.

1. The latest applicable Water Availability Model (WAM) from the Texas Commission on Environmental Quality (TCEQ) is used to simulate operation of each reservoir with no return flows not specifically referenced in a surface water right. This is corresponds to TCEQ WAM Run 3 assumptions. Any necessary modifications of TCEQ WAM basic data (e.g., naturalized flows, net evaporation) or uses of alternative modeling tools (e.g., Corpus Christi Water Supply Model) are described in Section 3.4.

2. Unless already permitted, each potential reservoir is modeled at the most junior priority date in the applicable TCEQ WAM, and other unpermitted reservoirs are excluded. An abbreviated series of sensitivity analyses to assess the effects of the relative priority of various Sulphur River Basin reservoirs upon the firm yields of one another is included as Appendix A.

3. Firm yields are calculated for a minimum of four reservoir conservation storage capacities, including that from the most recent previous analysis, to generally assess optimum development of the site. If a reservoir is already permitted or an application has been filed, only the conservation capacity in the permit or application is considered.

4. Environmental flow requirements are modeled using Consensus Criteria for Environmental Flow Needs (CCEFN), except for those reservoirs already permitted or that have applications pending at the TCEQ. For those reservoirs with a permit or pending application, the environmental flow criteria stated in the permit or application have been used in the yield analyses. For the recommended conservation storage capacity only, firm yield also has been evaluated without environmental flow passage requirements in order to assess the potential yield commitment to environmental flow needs.

5. For off-channel reservoirs dependent upon pumped storage from a nearby stream or existing reservoir, the maximum pumping rate recommended in the most recent previous study is used for all simulations.

3.3   Assumptions for Cost Estimates

The general assumptions and procedures used to develop cost estimates for the 16 reservoir sites selected for detailed study are described below. Exceptions to these assumptions and procedures are explained in the documentation provided for each potential reservoir site in Section 3.4.

1. General Cost Considerations – Costs are estimated for each reservoir at its recommended conservation capacity and reported in 2005 dollars.

2. Capital Costs — Dam and spillway costs are based on configuration and dimensions in the most recent study available. Costs for dams and spillways, relocations, and

resolution of facility conflicts are calculated using comparable unit costs to the extent reasonable. The Texas Natural Resources Information System (TNRIS) provided technical support with identification of potential relocations and facility conflicts including roadways, railroads, active oil and gas wells, product transmission pipelines, power transmission lines, and state lands.

3. Other Project Costs — Contingencies, engineering, and legal fees associated with reservoir development are estimated at 35 percent of capital costs. Land acquisition costs are calculated using the median land value for 2005 as published on the Texas A&M University Real Estate Center website for the Land Market Area in which the reservoir site is located. Environmental and archaeological studies, as well as mitigation and recovery costs, are estimated as 100 percent of the land acquisition cost. Interest during construction is computed using a 6 percent annual interest rate on total borrowed funds, less a 4 percent rate of return on investment of unspent funds.

4. Annual Costs — Debt service is calculated using a six percent annual interest rate over a 40 year amortization period. Annual operations and maintenance of dams and spillways is estimated to be 1.5 percent of the total construction cost for the dam and spillway. Pumping energy costs, where appropriate for off-channel reservoirs, is calculated using horsepower and a purchase cost of $0.06/kW-hr, which is consistent with Senate Bill 1 cost estimate requirements. Recent data indicates that current energy costs can be higher.

5. Unit Cost of Water — Unit cost of raw water at the reservoir is computed by dividing total annual cost (including debt service, operations and maintenance, and applicable pumping energy) by the firm yield of the potential reservoir. Thus, it represents unit cost at full reservoir development.

3.4   *Proposed Reservoir Sites Recommended for Protection*

Technical evaluations, comprised of project description, firm yield, cost estimate, and environmental considerations are included for each of the 16 reservoir sites selected for detailed study in this section. These technical evaluations are supplemented by special contributions

from the Texas Natural Resource Information System (TNRIS), Texas Parks and Wildlife Department (TPWD), and Texas Water Development Board (TWDB).

TNRIS staff members researched and assembled extensive geodatabases in order to map and tabulate conflicts with existing facilities location within or near each reservoir site. Such conflicts are mapped in the following sub-sections and include: primary Interstate or U.S. highways, secondary state or Farm to Market roads, railroads, power transmission lines, product transmission pipelines, active oil and gas wells, recorded water wells, and state parks or forests.

The TPWD GIS Lab prepared a landcover / land use database and summary map for each of the 16 reservoirs selected for technical evaluation in this study. Using imagery representative of conditions during the 1999 to 2003 period, TPWD prepared landcover classifications and mapping considered sufficient for planning level evaluation of reservoir sites. Landcover classifications used include: open water, swamp, marsh, seasonally flooded shrubland, bottomland hardwood forest, upland deciduous forest, evergreen forest, broad-leaf evergreen forest, shrubland, grassland, agricultural land, and urban / developed land. Procedures and technical assumptions are summarized in Appendix C and a map of existing landcover is provided for each reservoir in the following sub-sections. Summary landcover information for all 16 reservoir sites recommended for protection and/or acquisition is included in Section 4.2.

TWDB staff members prepared a memorandum summarizing a Cultural Resource Assessment for this Reservoir Site Protection Study that is included as Appendix B. Though resolution of conflicts regarding cultural resources within reservoir sites can be quite significant with respect to time and costs associated with excavations and recovery, detailed information regarding specific locations of such resources is often unknown and, even when known, is necessarily protected. In order to provide some insight with respect to the potential occurrence of sensitive cultural resources within 19 reservoir sites having or recommended for unique status, TWDB staff has tabulated county-level frequency of occurrence for the 27 counties potentially affected and grouped results into four regions. Reservoir sites within the northeast region have the greatest likelihood of occurrence of sensitive cultural resources and include the following: Columbia, Fastrill, Lower Bois d'Arc Creek, Marvin Nichols IA, George Parkhouse I, George Parkhouse II, and Ralph Hall.

3.4.1 Bedias Reservoir

3.4.1.1   *Description*

Bedias Reservoir is a proposed reservoir on Bedias Creek, a tributary of the Trinity River in the Trinity River Basin, that is being considered jointly by the Trinity River Authority and the San Jacinto River Authority as a potential water supply project. As illustrated in Figure 3.4.1-1, the proposed reservoir is located in Madison, Grimes, and Walker counties about 3.5 miles west of the U.S. Hwy. 75 crossing of Bedias Creek. The addition of conveyance facilities will allow diversion of a portion of the created supply into the West Fork of the San Jacinto River for use by the San Jacinto River Authority. Bedias Reservoir would help to meet the demands of Montgomery County, which will exceed available groundwater and Lake Conroe supplies beginning in the year 2020. The projected needs within 50 miles of the proposed reservoir site by 2060 are 284,552 acft/yr. The nearest major demand center is the greater Houston area, which is located approximately 85 miles southeast of the project site.
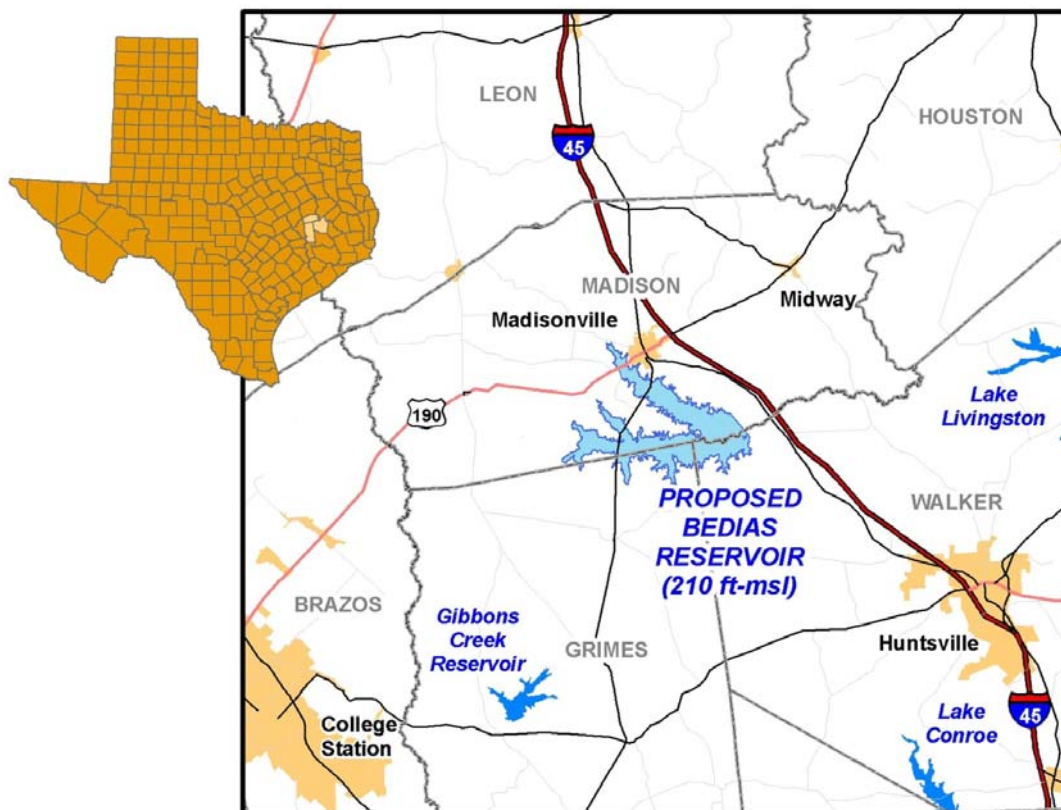
Figure 3.4.1-1. Location Map of Bedias Reservoir

Bedias Reservoir was previously studied by the Bureau of Reclamation (USBR) as part of a federal water supply plan investigating viable alternatives to meet municipal water needs for the year 2000 (Burns and McDonnell, 1989).   Subsequently, the proposed reservoir and an associated water transfer project were recommended as a water management strategy in the 2001 Region H Water Plan as well as the 2002 Texas State Water Plan (TWDB, 2002). In the 2006 Region H Water Plan, the Bedias Reservoir and transfer project were replaced with a shared interbasin transfer project from the Trinity River Basin to Lake Houston. The Bedias project is currently included in the Trinity River Basin Master Plan (Trinity River Authority of Texas, 2003).

For the reservoir location evaluated in this study, the upstream drainage area of the project is approximately 395 square miles. At a normal pool elevation of 210 ft-msl, the reservoir would have a conservation capacity of 192,700 acft and would inundate 10,000 acres.

3.4.1.2   *Reservoir Yield Analysis*

Detailed information regarding the proposed location and conservation storage capacity of Bedias Reservoir was not available from the recent Region H planning study. It is not clear that this reservoir was actually modeled as part of the planning process, even though a recommended conservation pool level of 230 feet msl is stated in the Region H Plan. Therefore, for purposes of this reservoir siting investigation, information pertaining to the reservoir obtained from the previous Burns and McDonnell report (1989) has been used. Of the four potential reservoir sites that were investigated by the Burns and McDonnell study, the Bedias 10-mile site, with a conservation pool level of 210 feet msl and a maximum storage capacity of 192,700 acft, was recommended as the most feasible reservoir location. This site is approximately 10 miles upstream of FM 247 (3.5 miles west of U.S. Highway 75) and has been used as the basis for the current yield analysis.

The firm yield of Bedias Reservoir has been calculated using the Trinity River Basin water availability model (WAM) (dated July 16, 2004) using Run 3 assumptions, as obtained from the Texas Commission on Environmental Quality (TCEQ). The WAM simulations were performed using the Water Rights Analysis Package program (WRAP, executable dated 5/24/2004). A new control point was added on Bedias Creek at the reservoir site. The location is the same as the existing primary control point 8BEMA in the WAM. The naturalized flows

and adjusted net evaporation for this primary control point were used in this study of the yield analysis of Bedias Reservoir.

The Bedias Reservoir elevation-area-capacity relationship is presented in Table 3.4.1-1 and shown in Figure 3.4.1-2. The elevation-area-capacity data in Table 3.4.1-1 were developed in the previous USBR's water supply plan investigating using U.S. Geological Survey topographic maps. Figure 3.4.1-3 shows the reservoir inundation at 10-foot contours.

Table 3.4.1-1.
Elevation-Area-Capacity Relationship for
Bedias Reservoir

Elevation (ft-msl)	Area (acres)	Capacity (acft)
160.0	0	0
180.0	3,750	52,500
200.0	7,600	105,500
210.0	10,000	192,700
220.0	18,200	337,000
230.0	23,000	541,400
235.0	26,800	665,700
240.0	30,500	808,100

For purposes of this yield study, it is assumed that Bedias Reservoir will be subject to environmental flow passage requirements based Consensus Criteria for Environmental Flow Needs (CCEFN). These minimum environmental flow requirements are summarized in Table 3.4.1-2. The reservoir has to pass the lesser of the inflow and the values of Table 3.4.1-2 depending on storage in the reservoir, i.e., the median flow when the storage is greater than 80 percent of the conservation storage capacity, the 25-percentile flow when the storage is greater than 50 percent of the conservation storage capacity, and the 7Q2 flow when the when the storage is less than 50 percent of the conservation storage capacity.

Table 3.4.1-2.
Consensus Criteria for Environmental Flow Needs for Bedias Reservoir

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Median	acft/mo	1,853	2,394	1,719	1,142	1,640	421	43	5	23	23	253	861
	cfs	30.1	42.7	27.9	19.2	26.7	7.1	0.7	0.1	0.4	0.4	4.3	14.0
25th	acft/mo	412	735	730	379	388	68	5	0	0	0	16	79
	cfs	6.7	13.1	11.9	6.4	6.3	1.1	0.1	0.0	0.0	0.0	0.3	1.3
7Q2	acft/mo	6	6	6	6	6	6	6	6	6	6	6	6
	cfs	0.1											

Note: The 7Q2 value is used when the 7Q2 value exceeds the value of the median and/or quartile.
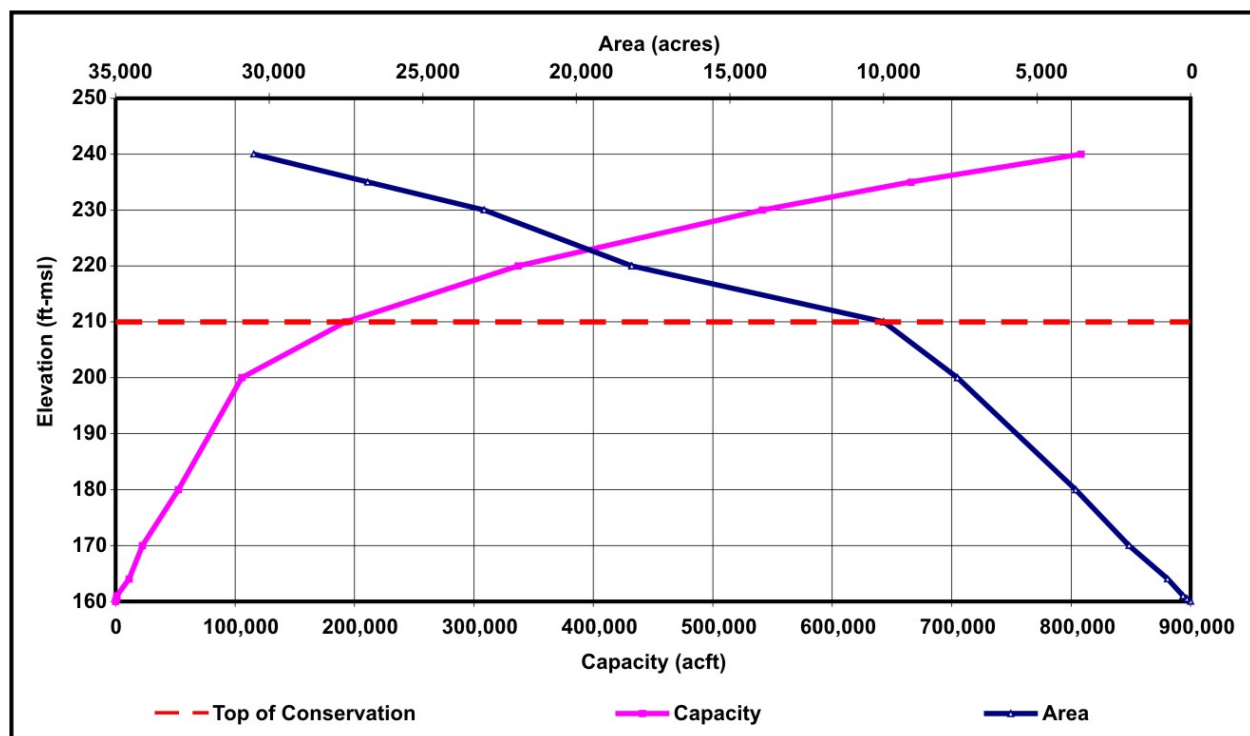
Figure 3.4.1-2. Elevation-Area-Capacity Relationship for Bedias Reservoir
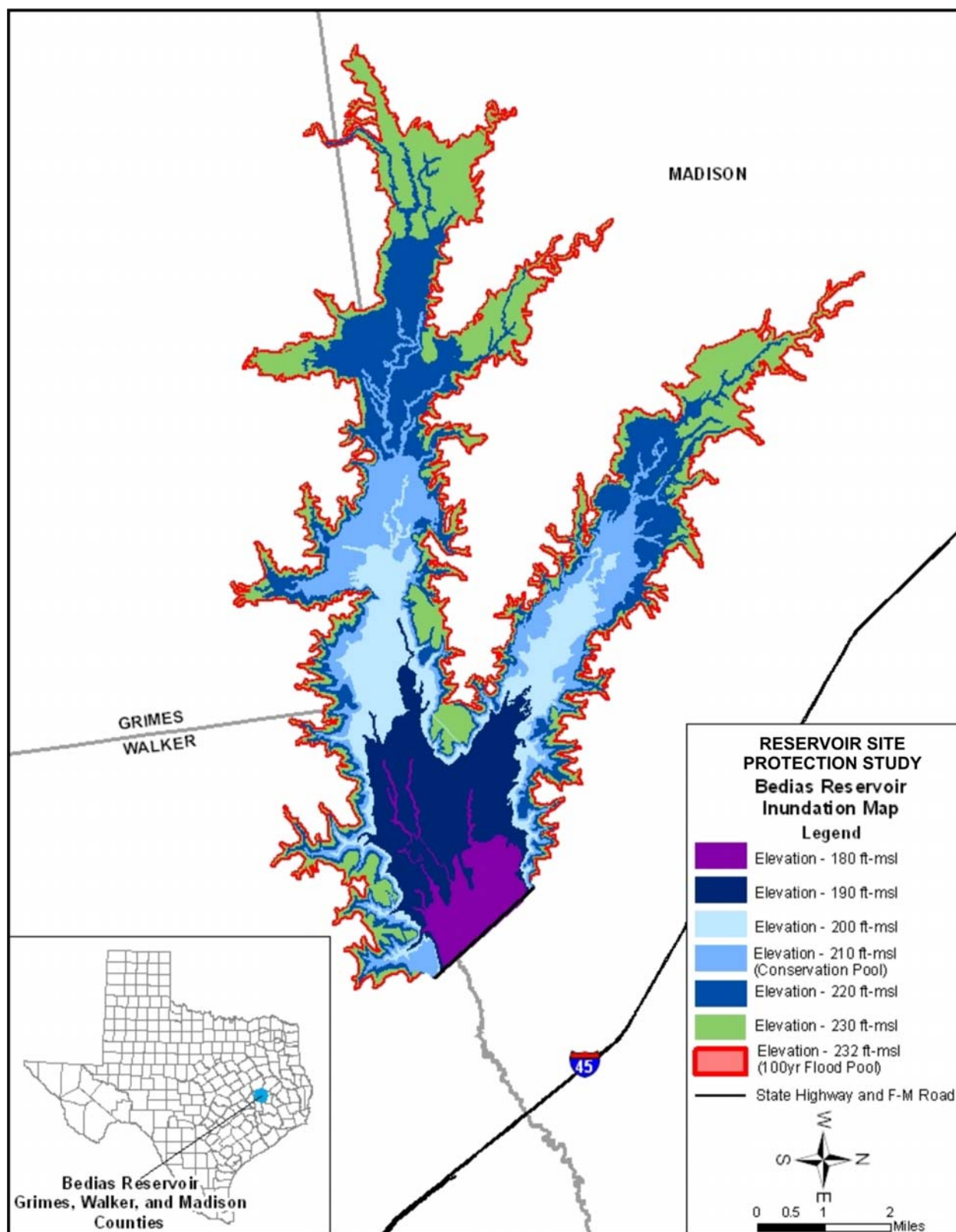
Figure 3.4.1-3. Inundation Map for Bedias Reservoir

As stated in Certificate of Adjudication No. 4248, Lake Livingston, even though senior in priority, will be subordinated to Bedias Reservoir when and if Bedias Reservoir is issued a water right by the TCEQ. The Lake Livingston subordination to Bedias Reservoir is recognized and modeled in this yield study.

WAM simulations were made to determine firm yield using conservation pool elevations of 200, 210, 220, 230, and 240 ft-msl, assuming stand alone reservoir operations and no minimum reserve content. Results of these simulations are summarized in Table 3.4.1-3 and Figure 3.4.1-4. At the conservation pool level of 210 ft-msl, or 192,700 acft of conservation storage capacity, the firm yield is 75,430 acft/yr. Application of CCEFN reduces the firm yield of the reservoir by 150 acft/yr. The firm annual yield determined in the Bedias Project Investigation (Burns and McDonnell, 1989) was 78,500 acft/yr for the same conservation pool level.

At the conservation pool elevation of 210 ft-msl, the reservoir would be full about 19 percent of the time and would be below 50 percent of the conservation storage capacity about 18 percent of the months simulated from January 1940 to December 1996. Figure 3.4.1-5 presents the storage trace for Bedias Reservoir as simulated with the WAM assuming a conservation storage capacity of 192,700 acft (elevation 210 ft-msl) and an annual firm yield diversion of 75,430 acft. The corresponding storage frequency curve for the reservoir is also shown in Figure 3.4.1-5.

Table 3.4.1-3.
Firm Yield vs. Conservation Storage for Bedias Reservoir

Pool Elevation (ft-msl)	Storage (acft)	Environmental Bypass Criteria	Firm Yield (acft/yr)	Critical Period
200.0	105,500	CCEFN	57,220	6/50-1/58
210.0*	192,700	CCEFN	75,430	6/50-1/58
		None	75,580	6/50-1/58
220.0	337,000	CCEFN	91,100	6/50-1/58
230.0	541,400	CCEFN	108,400	6/50-1/58
240.0	808,100	CCEFN	115,900	6/50-1/58
*Proposed conservation storage.				

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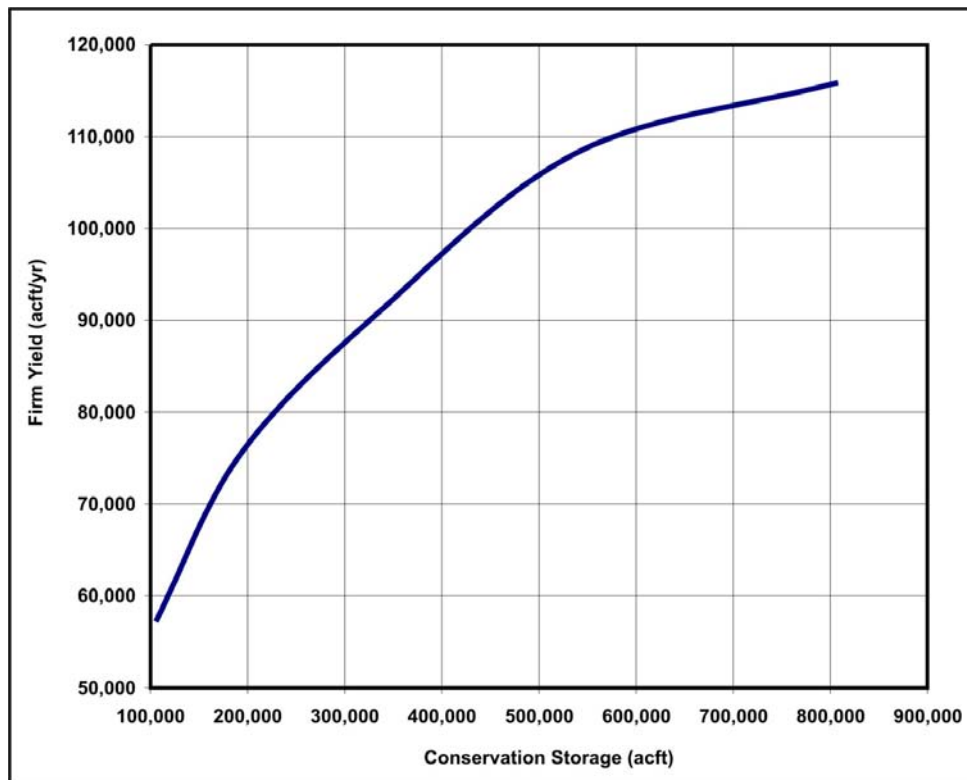
Figure 3.4.1-4. Firm Yield vs. Conservation Storage for Bedias Reservoir
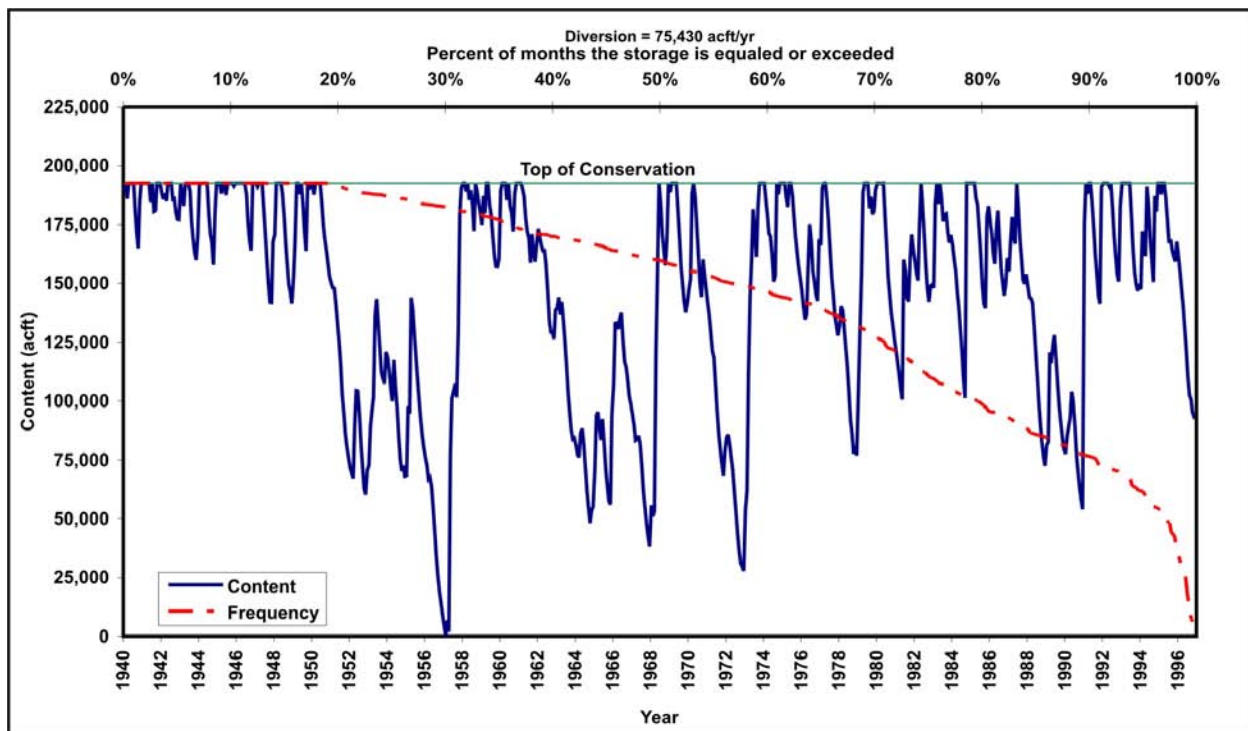
**Figure 3.4.1-5. Simulated Storage in Bedias Reservoir
(Conservation Elevation = 210 ft-msl, Diversion = 75,430 acft/yr)**

3.4.1.3   Reservoir Costs

The costs for Bedias Reservoir Dam assume a zoned earthen embankment with a maximum height of 70 feet. The spillway will consist of 8 tainter gates, each being 40 feet wide by 30 feet high. The length of the dam is estimated at 13,100 feet (Burns and McDonnell, 1989).

The conflicts identified at the site include pipelines, electrical distribution, phone lines, cemeteries, and a dike. A list of the potential conflicts is provided in Table 3.4.1-4. The conflict costs represent less than 4 percent of the total construction cost of the reservoir project. Figure 3.4.1-6 shows the conflicts as mapped by TNRIS.

Table 3.4.1-4.
List of Potential Conflicts for Bedias Reservoir

Description	Unit	Quantity
Pipelines	Mile	3.7
Electrical Distribution & Phone Lines	Mile	0.9
Cemeteries	Each	1.0
Dikes:		
Embankment	C.Y.	4,255
Soil Cement Facing	C.Y.	700

Table 3.4.1-5 summarizes the estimated capital costs for the Bedias Reservoir Project, including construction costs, engineering, permitting, and mitigation. Unit costs for the dam and reservoir are based on the cost assumptions used in this study. The total estimated cost of the project is $239.8 million (2005 prices). Assuming an annual yield of 75,430 acft/yr, raw water from the project will cost approximately $232 per acre-foot ($0.71 per 1,000 gallons) during the debt service period.

Figure 3.4.1-6. Potential Major Conflicts for Bedias Reservoir

Table 3.4.1-5.
Cost Estimate — Bedias Reservoir @ Elevation 210 ft-msl
(page 1 of 2)

	UNIT	QUANTITY	UNIT COST	COST
MOBILIZATION (5%)	LS	1		**$3,801,877**
EMBANKMENT:				
DIVERSION & CARE OF WATER	LS	1	$1,267,476.17	$1,267,476
CLEARING AND GRUBBING	AC	75	$2,000.00	$150,000
EXCAVATION, STRIPPING	CY	100,550	$2.00	$201,100
COMPACTED FILL	CY	2,513,761	$2.50	$6,284,403
DRAINAGE BLANKET	CY	226,238	$35.00	$7,918,330
RIP RAP	CY	93,009	$172.50	$16,044,053
BEDDING	CY	35,192	$35.00	$1,231,720
ROADWAY	LF	14,737	$150.00	$2,210,550
GRASSING	AC	25	$4,500.00	$112,500
FOUNDATION TREATMENT	CY	698,667	$2.50	$1,746,668
SUBTOTAL - EMBANKMENT CONSTRUCTION				**$37,166,799**
SPILLWAY:				
CLEARING & GRUBBING	AC	14	$4,000.00	$56,000
CARE OF WATER-CONSTRUCTION	LS	1	$844,984.11	$844,984
LINE DRILLING	SF	10,362	$12.84	$133,087
PERF. PIPE DRAINS	LF	1,398	$38.87	$54,339
REINFORCED CONCRETE	CY	51,810	$400.00	$20,724,000
MISCELLANEOUS STEEL	LB	167,712	$3.21	$538,356
TAINTER GATES & ANCHORAGE	LB	872,352	$2.20	$1,919,174
HOISTS & MACHINERY	LB	204,864	$7.94	$1,626,620
SLUICE GATES & OPERATORS	LS	1	$60,839.00	$60,839
BRIDGE	LF	377	$1,300.00	$490,100
CRANE	LS	1	$667,537.45	$667,537
ELECTRICAL FACILITIES	LS	1	$79,428.51	$79,429
STANDBY POWER UNIT	LS	1	$55,768.95	$55,769
POWER LINE TO SITE	LS	1	$40,559.24	$40,559
RIP RAP	CY	6,912	$172.50	$1,192,320
BEDDING	CY	2,368	$35.00	$82,880
SUBTOTAL - SPILLWAY CONSTRUCTION				**$28,565,994**
OUTLET WORKS:				
EXCAVATION & BACKFILL	CY	153,670	$2.50	$384,175
LINE DRILLING	SF	2,480	$12.84	$31,843
REINFORCED CONCRETE	CY	13,344	$400.00	$5,337,600
RIP RAP	CY	2,767	$172.50	$477,308
BEDDING	CY	922	$35.00	$32,270
ACCESS BRIDGE	LF	300	$1,300.00	$390,000
MISCELLANEOUS STEEL	LB	114,237	$3.21	$366,701
FLOOD GATES	LS	1	$1,233,676.80	$1,233,677
WATER OUTLET PIPE	LF	270	$456.29	$123,199
WATER SUPPLY GATES	LS	1	$163,926.92	$163,927
LOW FLOW RELEASE GATES	LS	1	$506,990.47	$506,990

Table 3.4.1-5.
Cost Estimate — Bedias Reservoir @ Elevation 210 ft-msl
(page 2 of 2)

	UNIT	*QUANTITY*	*UNIT COST*	*COST*
CONTROL HOUSE	LS	1	$483,330.91	$483,331
MISCELLANEOUS ITEMS	LS	1	$773,721.53	$773,722
SUBTOTAL - OUTLET WORKS CONSTRUCTION				**$10,304,742**
SUBTOTAL - DAM CONSTRUCTION				**$76,037,534**
UNLISTED ITEMS AT 10% OF CONSTRUCTION COSTS				$7,603,753
CLEARING RESERVOIR	AC	2,843	$1,000.00	$2,843,000
PERMANENT OPERATING FACILITIES	LS	1	$1,267,476.17	$1,267,476
SUBTOTAL - DAM & RESERVOIR CONSTRUCTION				**$91,553,640**
ENGINEERING & CONTINGENCIES (35% DAM & RESERVOIR)				**$32,043,774**
TOTAL - DAM & RESERVOIR CONSTRUCTION				**$123,597,414**
CONFLICTS (RELOCATIONS):				
PIPELINES	LF	19,536	$256.06	$5,002,306
ELEC. DISTR. & PHONE LINES	LF	4,752	$16.00	$76,032
CEMETERIES	EA	1	$506.99	$507
DIKES: EMBANKMENT	CY	4,255	$2.50	$10,638
SOIL CEMENT FACING	CY	700	$65.00	$45,500
				$5,134,982
ENGINEERING & CONTINGENCIES (35% CONFLICTS)				**$1,797,244**
LAND PURCHASE COSTS	AC	11,495	3,288.0	**$37,795,560**
ENVIRONMENTAL STUDIES & MITIGATION COSTS (100% LAND COSTS)				**$37,795,560**
CONSTRUCTION TOTAL				**$206,120,761**
INTEREST DURING CONSTRUCTION				**$33,686,832**
TOTAL COST				**$239,807,593**
ANNUAL COSTS				
DEBT SERVICE (6% FOR 40 YEARS)				**$15,937,981**
OPERATION & MAINTENANCE (1.5% OF DAM & SPILLWAY COSTS)				**$1,373,305**
TOTAL ANNUAL COSTS				**$17,311,286**
FIRM YIELD (ACRE-FEET PER ANNUM)				75,430
UNIT COST OF WATER (DURING AMORTIZATION)				
PER ACRE-FOOT				$232
PER 1,000 GALLONS				$0.71

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

3.4.1.4   *Environmental Considerations*

Bedias Reservoir is not located on an ecologically significant stream segment as identified by the Texas Parks and Wildlife Department (TPWD). It also has not been identified as an ecologically unique stream segment by the Region H Planning Group.

Real estate and recreational development will increase some property values and generate additional recreational income to the area; however, development of the lakeshore area also will bring congestion to a previously rural area, noise, and some unavoidable air pollution. On the other hand, residents in the area will likely welcome the additional camping, boating, and fishing activities that the reservoir would provide (Brown and Root and Turner Collie and Braden, Inc., 2001).

Bedias Reservoir will inundate 10,000 acres of land at conservation storage capacity. Table 3.4.1-6 and Figure 3.4.1-7 summarize existing landcover for the Bedias Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by upland deciduous forest (39 percent) and grassland (38 percent) with some bottomland hardwood forest (5 percent). Marsh, swamp, and open water total less than 2.3 percent of the reservoir area.

Table 3.4.1-6.
Acreage and Percent Landcover for Bedias Reservoir

Landcover Classification	Acreage[1]	Percent
Bottomland Hardwood Forest	443	5.2%
Marsh	190	2.2%
Seasonally Flooded Shrubland	14	0.2%
Evergreen Forest	96	1.1%
Broad Leaf Evergreen Forest	700	8.1%
Upland Deciduous Forest	3,387	39.4%
Grassland	3,287	38.2%
Shrubland	440	5.1%
Agricultural Land	45	0.5%
Open Water	4	0.0%
Total	8,606	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
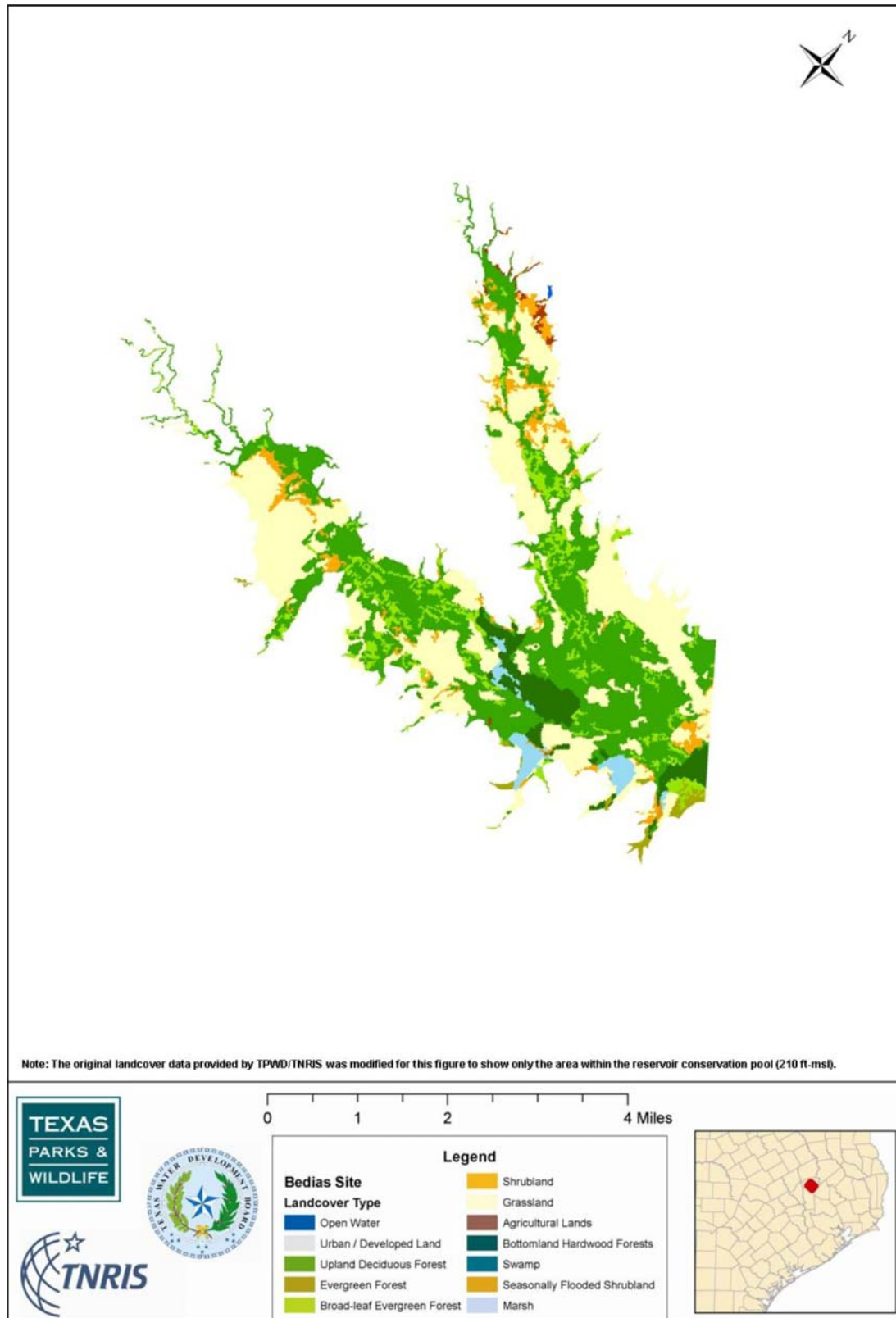
Figure 3.4.1-7. Existing Landcover for Bedias Reservoir

3.4.2   Brownsville Weir and Reservoir Project

3.4.2.1   Description

The Brownsville Public Utilities Board (PUB) is proposing to construct and operate the Brownsville Weir and Reservoir Project (BWR) on the Lower Rio Grande just below the City of Brownsville. The BWR (Water Rights Permit No. 5259) is designed to provide a maximum of 6,000 acft of storage capacity that will be used to capture and store excess flows of United States water in the Rio Grande that would otherwise flow to the Gulf of Mexico. The BWR, in conjunction with the PUB's existing excess flows diversion Permit No. 1838 (authorizes diversions of excess flows from the Rio Grande of 40,000 acft/yr), is to be operated as a system with PUB's existing Amistad-Falcon Reservoir storage rights to develop an additional municipal and industrial water supply for the PUB's customers located in south and southeastern Cameron County. The project is expected to provide an additional dependable supply of Rio Grande water on the order of 20,000 acft/yr. Approximately 71 percent of the time, it should be capable of supplying the full 40,000 acft/yr of municipal and industrial water authorized under Permit No. 1838.

This project has been recommended as a water management strategy in the 2001 and 2006 Region M Water Plans as well as the 2002 and 2007 Texas State Water Plans (Texas Water Development Board, 2002 and 2006).   The projected water needs within 50 miles of the proposed reservoir site by 2060 are 223,489 acft/yr. The nearest major demand center is the Lower Rio Grande Valley, which extends north of the reservoir for approximately 60 miles.

The proposed BWR Project consists of a weir structure, which is to be constructed across the channel of the Rio Grande approximately 8 miles downstream of the International Gateway Bridge at Brownsville, and an associated riverine impoundment that will extend along the length of the river channel upstream for a maximum distance of approximately 42 miles when the reservoir is full. The weir structure, which will be gated to allow flood flows and non-project water to pass without being impounded, will be located at River Mile 47.8 (river miles above the mouth of the Rio Grande).

At full stage, the water surface of the proposed Brownsville Reservoir will be at 26 feet above mean sea level (msl). The elevation of the flowline of the river channel at the location of the weir structure is about one foot below mean sea level; hence, the maximum depth of the impoundment at its most-downstream end will be about 27 feet. From this point, the depth of the

reservoir will gradually decrease in the upstream direction until it matches the normal depth of flow in the river.

At its normal maximum operating level, the Brownsville Reservoir will have a surface area of about 600 acres and store approximately 6,000 acft of water. Its top width will range from about 260 feet on the downstream end at the weir to less than a hundred feet where the upstream end of the pool meets the normal flow of the river. The average top width of the impoundment over its entire length will be about 110 feet. Under the normal maximum water level condition, the entire reservoir will be contained within the banks of the natural channel of the river. The general location of the BWR is shown on the map in Figure 3.4.2-1.
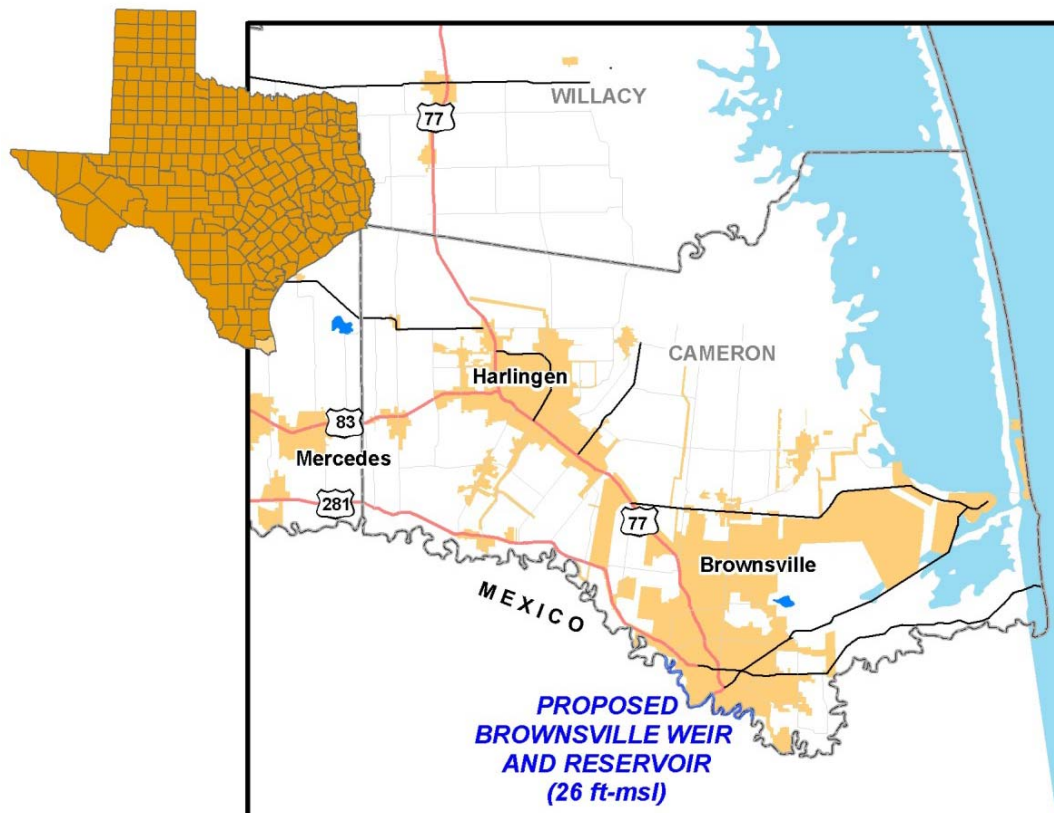
Figure 3.4.2-1. Location Map of Brownsville Weir and Reservoir

3.4.2.2   *Reservoir Yield Analysis*

The ability of the BWR to develop and provide an additional dependable supply of water from the Lower Rio Grande was investigated by the PUB as part of the water rights permitting process in the 1990s, and these earlier studies provide the basis for the project yield information

reported herein. This earlier work involved a computer modeling analysis whereby the operation and performance of the BWR was simulated under actual historical hydrologic and climatic conditions. For this analysis, the historical quantities of United States water that flowed past the Brownsville streamflow gage, excluding water released from Falcon Reservoir for authorized downstream users and water required for existing instream uses and maintenance of bay and estuarine resources, were assumed to be available for capture and diversion by the BWR.

Simulations of storage variations for the Brownsville Reservoir were made on a daily basis in response to the historical river inflows and system releases from Falcon Reservoir and specified project and system water rights diversions, releases for historical downstream United States users and Mexican water pass-throughs, specified releases for instream uses and bay and estuarine purposes (minimum of 25 cfs in accordance with Permit No. 1838), evaporative losses, and certain system operating rules. The underlying objective of these simulations was to determine the maximum amount of water that could be dependably diverted from the reservoir annually to provide an additional supply of water for PUB's customers.

Historical conditions corresponding to the period 1960 through 1997 were used for the water supply evaluation of the BWR. This period encompasses a broad spectrum of river flow conditions that are reflected in the historical streamflows measured at the Brownsville gage, including major floods in 1973, 1976 and 1991-1992 and critical low-flow conditions between 1984 and 1987 and during the middle to late 1990s. This period of record was selected primarily because Anzalduas Reservoir, which is located approximately 100 river miles upstream of the BWR site and provides regulation of normal flows in the Lower Rio Grande, was completed in 1960 and, since that time, has had a direct influence on normal (non-flood) river flows at the Brownsville gage.

For purposes of simulating the operation and performance of the Brownsville Reservoir, in conjunction with PUB's existing Amistad-Falcon water rights, the computer program referred to as SIMYLD-IID was employed. This program, which is an extension of the SIMYLD-II program originally developed by the Texas Water Development Board, provides for the simulation of the movement and storage of water through a system of river reaches, canals, reservoirs and non-storage river junctions on a daily basis. The program was modified extensively to account for travel time effects along the Lower Rio Grande from Falcon Dam to Brownsville and to properly represent the specific operational elements of the BWR. Table 3.4.2-1 lists the elevation-area-capacity data for the BWR, and Figure 3.4.2-2 presents these data

graphically. These data were originally developed by the PUB as part of the permitting studies. Since the proposed Brownsville Reservoir is entirely contained within the banks of the Rio Grande, an inundation map of the reservoir showing surface area as a function of elevation would not be meaningful and has not been prepared.

Table 3.4.2-1.
Elevation-Area-Capacity Relationship for
Brownsville Weir and Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
-1.0	0	0
10.0	84	460
15.0	185	1,390
20.0	308	2,830
25.0	470	5,220
26.0	600	6,000
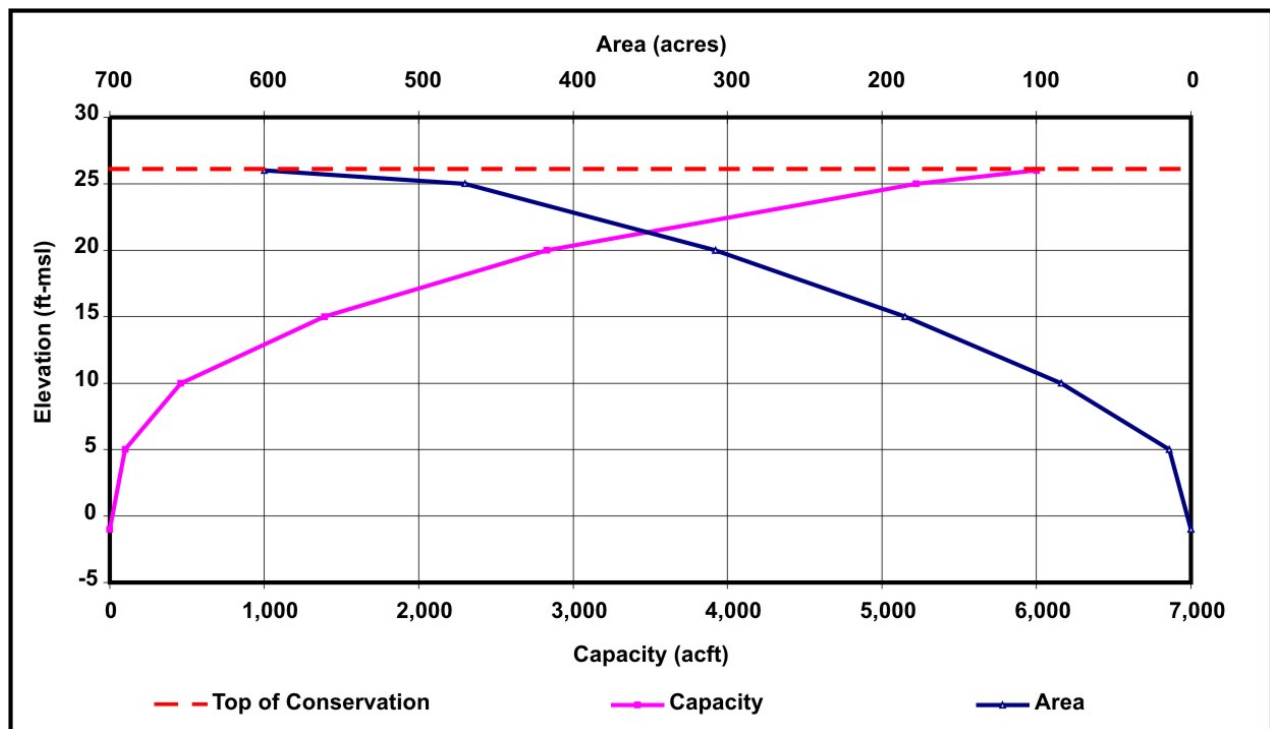
Figure 3.4.2-2. Elevation-Area-Capacity Relationship for Brownsville Weir and Reservoir

Results from the modeling of the BWR indicated that in most of the years of the 1960-1997 simulation period (71 percent), the total diversion of 40,000 acft/yr (as authorized under Permit No. 1838) could be fully achieved. In the most critical year of the simulation (1996), the total amount that could be diverted was 20,643 acft. This amount represents the additional dependable supply of Rio Grande water available to the PUB under Permit No. 1838 with the BWR Project in operation, and this is the amount considered to be the firm annual yield of the BWR. Figure 3.4.2-3 presents a simulated storage trace for the Brownsville Reservoir based on the minimum monthly storage amounts simulated with the SIMYLD-IID daily model. A frequency curve for storage content is also shown in Figure 3.4.2-3. Since the BWR is already permitted with a maximum storage capacity of 6,000 acft, no analyses of yield versus storage capacity have been performed.
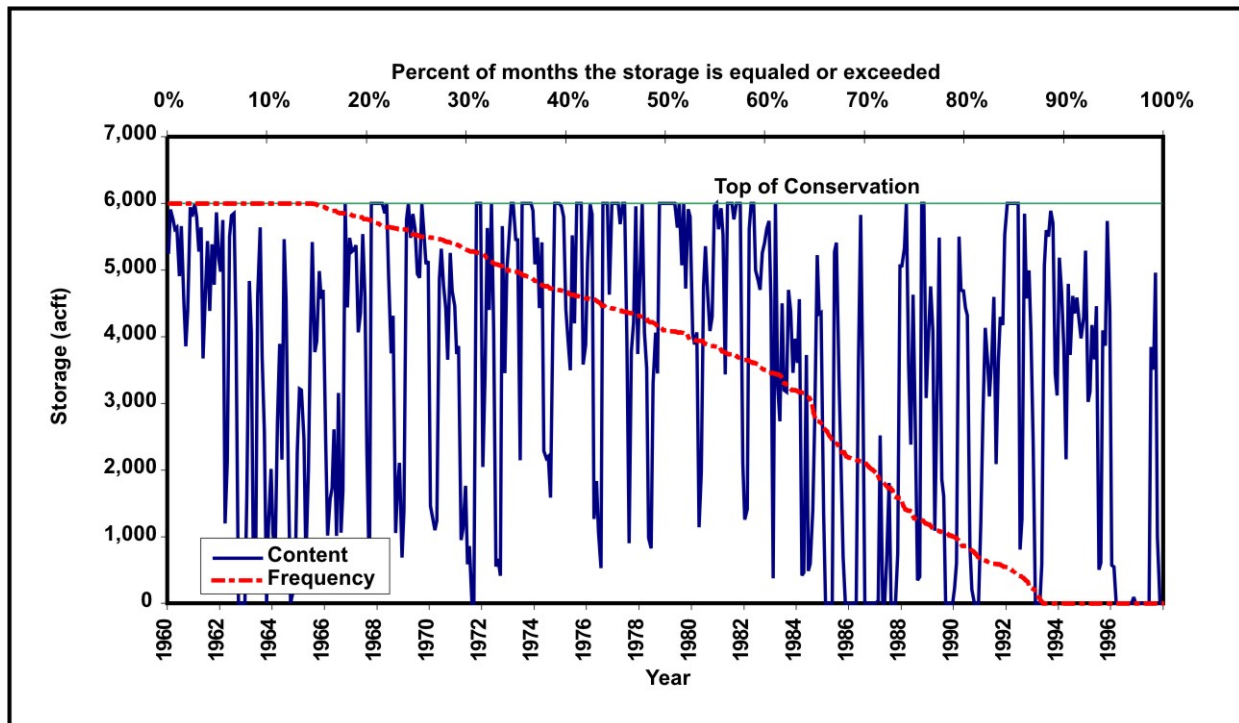
Figure 3.4.2-3. Simulated Storage in Brownsville Weir and Reservoir
(Conservation Elevation = 26 ft-msl, Diversion = 20,643 acft/yr)

3.4.2.3   *Reservoir Costs*

The proposed Brownsville Weir structure will consist of a concrete sill constructed on steel sheet piling across the bottom of the channel of the river. The crest elevation of the sill is to be one foot above mean sea level. Concrete abutments will be constructed on each end of the

sill, one on the United States side of the river and one on the Mexico side. Six radial gates 30 feet wide and 25 feet high, separated by concrete piers 6 feet wide, will be installed to close on the concrete sill. With the radial gates set on the bottom sill, water in the reservoir upstream will be impounded to a maximum elevation of 26.0 ft-msl. With the radial gates fully open, the design flood for the Rio Grande at Brownsville will be passed unobstructed at the current design flood level of the river. The length of the structure is approximately 400 feet, including the approach section. As proposed, the actual width of the gates and sill is approximately 210 feet.

A concrete stilling basin will be constructed downstream of the crest of the bottom sill, with its minimum bottom elevation set at -14.0 ft-msl. The overall facility also will include rock riprap downstream of the stilling basin, motorized gate hoists, a 12-foot wide service bridge across the weir, a control building, embankment erosion protection measures upstream and downstream of the weir, security fencing and other operational appurtenances. The top of the weir structure, at the deck of the service bridge, will be about 53 feet above the bottom of the existing river channel.

The foot-print of the weir and associated appurtenances will require approximately 11 acres of land. Access roads to the weir will require another 22 acres of land. During construction, a by-pass channel, requiring approximately 17 acres of land, will be constructed to divert river flows around the construction site. In addition, about 34 acres of land will be temporarily used for storage areas and other construction related activities.

The dam will be constructed within the active channel section of the Rio Grande and all stored water will be contained within the channel. Therefore, no conflicts are expected to be associated with this structure (Figure 3.4.2-4).

Table 3.4.2-2 shows the estimated capital costs for the Brownsville Weir, including costs for construction, engineering, permitting and mitigation. Unit costs for the dam and reservoir are based on the cost assumptions used in this study. The total estimated cost of the project is $45 million (2005 prices). Assuming an annual yield of 20,643 acft/yr, raw water from the project will cost approximately $181 per acre-foot ($0.55 per 1,000 gallons) during debt service period.
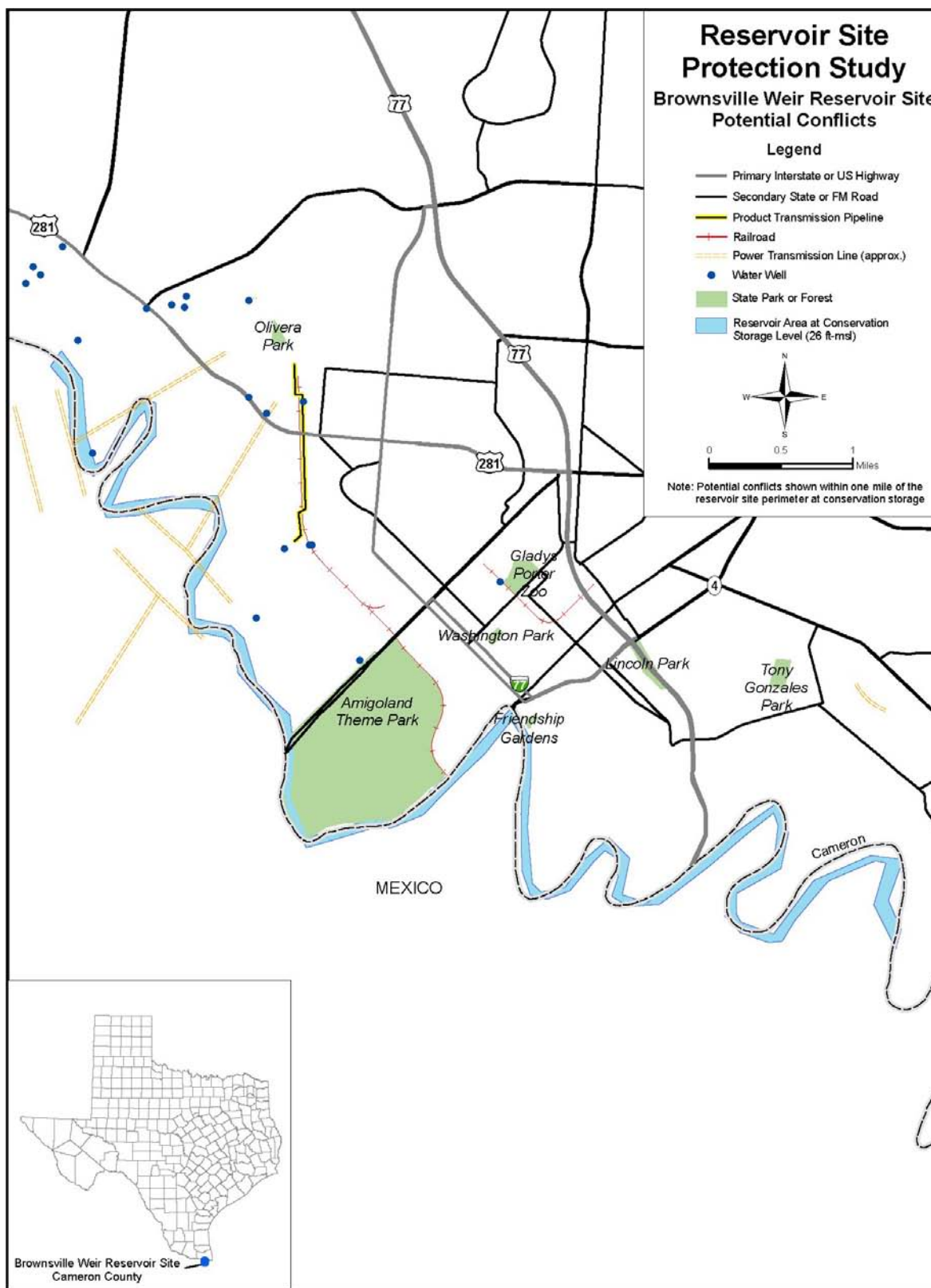
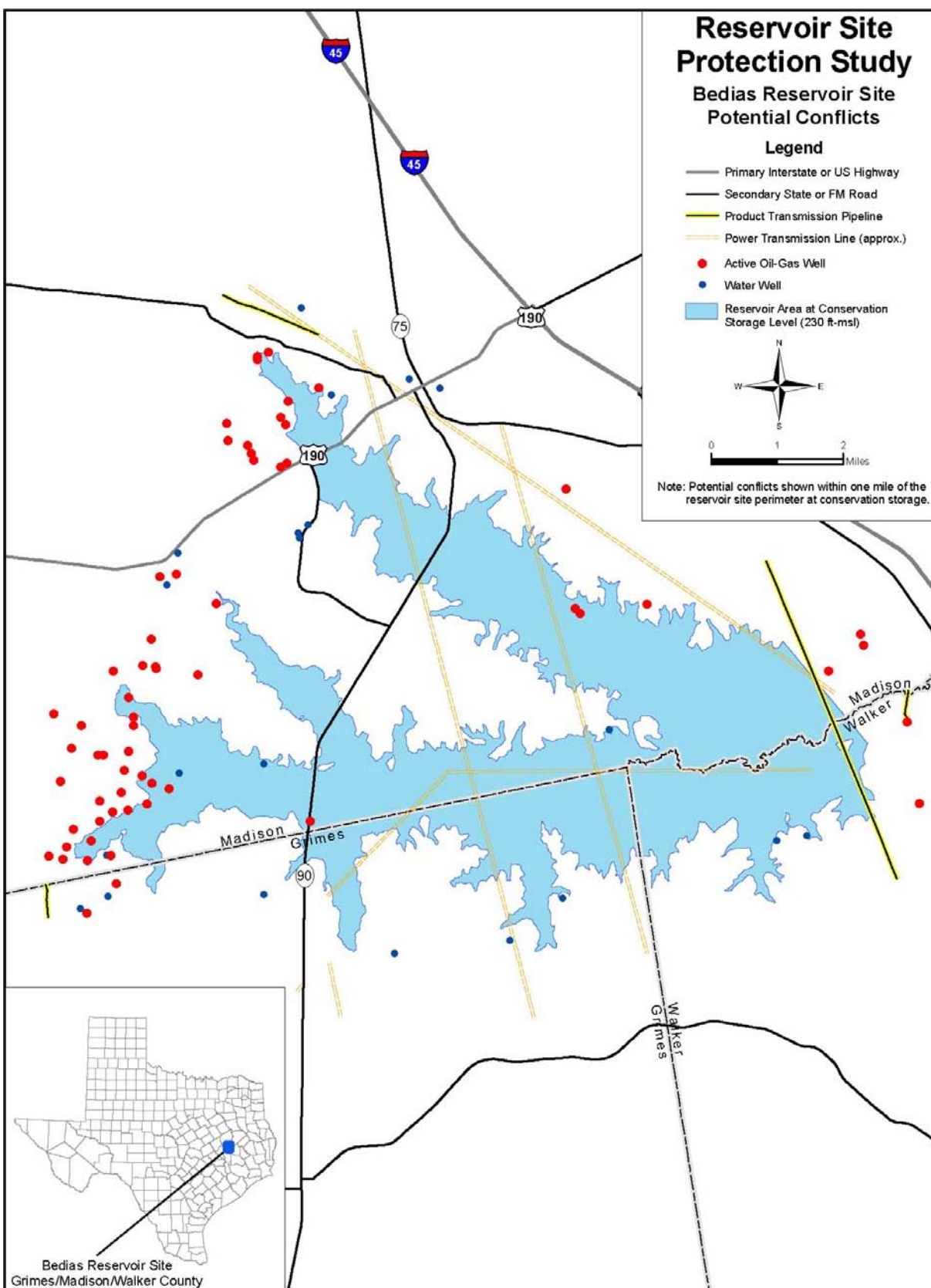**Figure 3.4.2-4. Potential Major Conflicts for Brownsville Weir and Reservoir**

Table 3.4.2-2.
Cost Estimate — Brownsville Weir @ Elevation 26 ft-msl
(page 1 of 4)

	UNIT	QUANTITY	UNIT COST	COST
MOBILIZATION (5%)	LS	1	$1,469,358	**$1,469,358**
ACCESS ROAD				
CLEARING AND GRUBBING	AC	3.4	$2,000.00	$6,800
COMPACTED FILL	CY	20,000	$2.50	$50,000
FLEX BASE- 6 IN.	CY	1,514	$120.00	$181,680
PIPE 24"- RCP	LF	140	$42.53	$5,954
METAL GUARD RAIL	LF	4,800	$36.45	$174,971
CARE OF ROADS	SY	8,020	$3.04	$24,362
DIVERSION CHANNEL				
CLEARING & GRUBBING	AC	10	$2,000.00	$20,000
DEWATERING SYSTEM	LS	1	$60,753.92	$60,754
EXCAVATION	CY	324,385	$2.50	$810,963
RIP RAP BEDDING	CY	3,364	$35.00	$117,740
RIP RAP	CY	6,726	$172.50	$1,160,235
CONST. CROSSING	LS	1	$170,110.97	$170,111
MAINTENANCE	SY	50,622	$1.22	$61,510
RESTORATION	CY	356,823	$1.58	$563,638
SEEDING	AC	11	$729.05	$8,020
COFFER DAMS				
RANDOM FILL	CY	40,774	$2.50	$101,935
RIP RAP BEDDING	CY	700	$35.00	$24,500
RIP RAP	CY	1,867	$172.50	$322,058
SHEETPILING	SF	21,280	$30.38	$646,422
FLEX BASE	CY	526	$120.00	$63,120
MAINTENANCE	LS	1	$12,150.78	$12,151
REMOVAL	LS	40,774	$3.65	$148,631
CARE OF WATER	LS	1	$243,015.67	$243,016
SHEET PILE CUTOFF				
CELLS SHEETPILES	SF	52,053	$44.96	$2,340,193
PILES OTHER	SF	13,000	$42.53	$552,861
FOUNDATION PILES				
TEST PILES	EA	4	$3,645.23	$14,581
DESIGNED PILES	LF	22,380	$36.45	$815,804
GENERAL EXCAV.				
CLEARING AND GRUBBING	AC	6	$2,000.00	$12,000
UPSTREAM	CY	78,400	$2.50	$196,000
DOWNSTREAM	CY	74,100	$2.50	$185,250
OGEE & ABUTMENTS	CY	70,460	$2.50	$176,150
FOUNDATION PREP.	SY	65,500	$1.50	$98,250
IMPERVIOUS FILL	CY	32,000	$3.00	$96,000
RANDOM FILL	CY	108,200	$2.50	$270,500
STILLING BASIN				
DEWATERING SYSTEM	LS	1	$48,603.13	$48,603
SUB-DRAIN SYSTEM	LS	1	$36,452.35	$36,452
SHEET PILE CUTOFF	SF	6,000	$42.53	$255,166

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Table 3.4.2-2.
Cost Estimate — Brownsville Weir @ Elevation 26 ft-msl
(page 2 of 4)

	UNIT	QUANTITY	UNIT COST	COST
REINFORCED CONCRETE				
COUNTERFORT WALLS	CY	7,360	$400.00	$2,944,000
OGEE CREST	CY	5,685	$400.00	$2,274,000
ABUTMENTS	CY	3,200	$400.00	$1,280,000
CUTOFF WALLS	CY	245	$400.00	$98,000
PIERS	CY	5,363	$400.00	$2,145,200
CONC. BASIN	CY	3,500	$400.00	$1,400,000
SPILLWAY BRIDGE	SF	3,840	$81.25	$312,000
(240'X16' PRESTRESSED)				
SPILLWAY RADIAL GATES				
RADIAL GATES 25'X35'	EA	6	$263,672.00	$1,582,032
GATA EMBEDS	EA	6	$70,474.54	$422,847
GATE HOISTS	EA	6	$208,993.47	$1,253,961
SUPPORTS				
WIRE ROPES				
ELEC. GENERATOR	EA	1	$21,871.41	$21,871
GEN. FUEL TANK	EA	1	$1,458.09	$1,458
ANCHORAGES	EA	12	$36,452.35	$437,428
OUTLET WORKS GATES				
3'X5' SLUICE GATES	EA	4	$97,206.27	$388,825
12X12 INCH SLUICE GATE	EA	2	$60,753.92	$121,508
18'X30' SLUICE GATE	EA	2	$85,055.48	$170,111
STOP GATES				
STOP GATES PLUS	LS	1	$243,015.67	$243,016
LIFTING BEAM				
LIFTING BEAM STORAGE PAD				
STOP GATE MONORAIL				
RAILS AND SUPPORTS	LS	1	$425,277.42	$425,277
ELECTRICAL SYSTEM				
TRAVELING HOIST				
BARRIER AND WARNING				
SYSTEM	LS	1	$64,399.15	$64,399
SITE WATER SERVICE				
BURIED WATER SERVICE	LF	10,500	$4.86	$51,033
SITE ELECTRICAL SYSTEM				
ELECT. EQUIPMENT SITE	LS	1	$291,618.80	$291,619
TRANSFORMER	LS	1	$24,301.57	$24,302
UNDERGROUND PRIM.LINE	LF	10,500	$9.72	$102,067
SITE COMPUTOR/TELEPHONE SERVICE				
UNDERGROUND LINE		10,500	$9.72	$102,067

Table 3.4.2-2.
Cost Estimate — Brownsville Weir @ Elevation 26 ft-msl
(page 3 of 4)

	UNIT	QUANTITY	UNIT COST	COST
CONTROL HOUSE				
CONCRETE BLDG.	SF	400	$48.60	$19,441
RESERVOIR GAGE	LS	1	$12,150.78	$12,151
MISC. INSTRUM.	LS	1	$12,150.78	$12,151
SEPTIC SYSTEM	LS	1	$5,467.85	$5,468
STEPS AND SIDEWALK	LS	1	$3,645.23	$3,645
FLAG POLE	LS	1	$1,215.08	$1,215
OPEN RISE PIEZOMETERS	EA	12	$2,673.17	$32,078
RIP RAP SLOPE PROTECTION				
UPSTREAM CHANNEL	CY	2,411	$172.50	$415,898
DOWNSTREAM CHAN.	CY	10,750	$172.50	$1,854,375
ABUTMENTS	CY	1,690	$172.50	$291,525
SURFACE MONUMENTS	EA	9	$6,075.39	$54,679
CHAIN LINK FENCE-6'	LF	2,500	$24.30	$60,754
BARBED WIRE FENCE	LF	5,000	$4.62	$23,086
CONCRETE PARKING AREA				
6 INCH CONC. PAVING	CY	550	$400.00	$220,000
LIGHTING	LS	1	$72,904.70	$72,905
GUARD RAIL	LF	1,520	$36.45	$55,408
4' CHAINLINK FENCE	LF	630	$18.23	$11,482
SEEDING AND LANDSCAPING	AC	11	$729.05	$8,020
SUBTOTAL WEIR CONSTRUCTION COSTS				**$29,387,680**
WEIR CONSTRUCTION COSTS				**$30,857,064**
ENGINEERING &CONTINGENCIES (35% WEIR CONSTRUCTION)				$10,799,972
TOTAL WEIR CONSTRUCTION				**$41,657,036**
CONFLICTS				
RESOLUTION OF CONFLICTS IN U.S. AND MEXICO	LS	1	$1,215,078.33	$1,215,078
IBWC STREAM GAGE AND ROAD RELOCATION	LS	1	$30,376.96	$30,377
SUBTOTAL CONFLICTS				**$1,245,455**
ENGINEERING &CONTINGENCIES (35% CONFLICTS)				$435,909
TOTAL CONFLICTS				**$1,681,365**
LAND PURCHASE COSTS	AC	86	$3,482	$299,452
ENVIRONMENTAL STUDIES & MITIGATIONS COSTS				$1,394,343
SUBTOTAL - OTHER PROJECT COSTS				**$3,375,159**
TOTAL CAPITAL COSTS				**$45,032,195**

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Table 3.4.2-2.
Cost Estimate — Brownsville Weir @ Elevation 26 ft-msl
(page 4 of 4)

	UNIT	*QUANTITY*	*UNIT COST*	*COST*
INTEREST DURING CONSTRUCTION				**$4,127,045**
TOTAL CAPITAL COSTS				**$49,159,241**
ANNUAL COSTS				
DEBT SERVICE (6% FOR 40 YEARS)				**$3,267,199**
OPERATION & MAINTENANCE (1.5% WEIR CONSTRUCTION)				**$462,856**
TOTAL ANNUAL COSTS				**$3,730,055**
FIRM YIELD (ACRE-FEET PER ANNUM)				**20,643**
UNIT COST OF WATER (DURING AMORTIZATION)				
PER ACRE FOOT				**$181**
PER 1000 GALLONS				**$0.55**
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.				

3.4.2.4 _Environmental Considerations_

The BWR Project impacts two Texas Commission for Environmental Quality (TCEQ) Designated Water Quality Segments: Rio Grande Tidal — Segment 2301 and Falcon Reservoir — Segment 2302. The tidally influenced portion of the Rio Grande forms the boundary between the United States and Mexico from just downstream of the Brownsville Irrigation and Drainage District (BIDD) rock weir to the Gulf of Mexico, approximately 49 miles. Segment 2302 extends from its headwater at Falcon Dam in Starr County to the BIDD weir, approximately 226 miles. Both sections are identified as ecologically significant by the Texas Parks and Wildlife Department (TPWD) because they contain priority bottomland habitat and extensive freshwater and estuarine wetland habitats (Bauer et al. 1991).

Additionally, the Region M Regional Water Plan details possible water quality impacts such as increased salinity within and downstream of the reservoir as a result of changes in downstream flow and salinity patterns. A water right for BWR issued on September 29, 2000, contains special conditions in order to mitigate these possible impacts. Some of these conditions include a required minimum streamflow of 25-cfs whenever water is being impounded in the reservoir; monitoring of salinity in the Rio Grande downstream of the weir near the

riverine/estuarine interface and only impounding water in the reservoir when measured salinity is less than the established near-fresh condition; and consulting with the appropriate agencies such as the TCEQ and TPWD to develop a mitigation plan for the entire BWR Project.

The BWR Project will inundate 600 acres of land at conservation storage capacity. Table 3.4.2-3 and Figure 3.4.2-5 summarize existing landcover for the BWR Project site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (32 percent), agricultural land (22 percent), urban/developed land (18 percent), and open water (17 percent).

Table 3.4.2-3.
Acreage and Percent Landcover for Brownsville Weir and Reservoir

Landcover Classification	Acreage[1]	Percent
Upland Deciduous Forest	47	7.6%
Grassland	199	32.0%
Shrubland	17	2.8%
Agricultural Land	136	21.9%
Urban / Developed Land	115	18.4%
Open Water	108	17.3%
Total	622	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
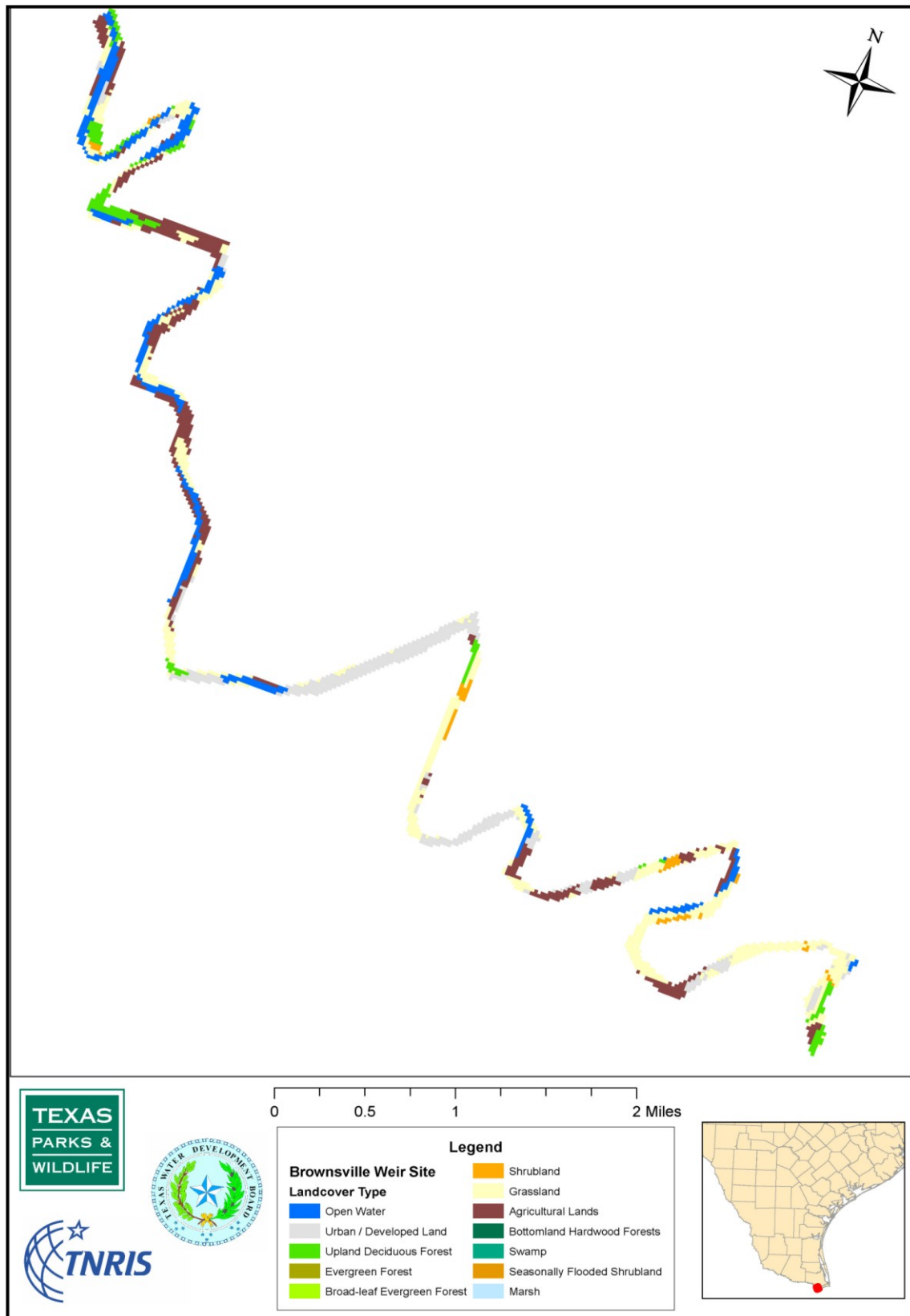
Figure 3.4.2-5. Existing Landcover for Brownsville Weir and Reservoir

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3.4.3   Brushy Creek Reservoir

3.4.3.1   <u>Description</u>

Brushy Creek Reservoir is a proposed reservoir which is part of the long-term plan developed by the City of Marlin and the Natural Resources Conservation Service (NRCS) for water supply and flood control purposes in the Big Creek watershed. Brushy Creek is a tributary of Big Creek, which is a tributary of the Brazos River. The Big Creek watershed, located in Central Texas in Falls, Limestone, and McLennan Counties, encompasses 369.6 square miles. The 1984 Big Creek Watershed Plan, described in a project report entitled "Watershed Plan and Environmental Impact Statement," includes three flood retarding structures located in the upper reaches of Brushy Creek and a larger multi-purpose dam located just above the confluence of Brushy Creek with Big Creek. This multi-purpose dam, when constructed, will form the Brushy Creek Reservoir (Figure 3.4.3-1) and impound runoff from a 44.3 square mile watershed. The projected needs within 50 miles of the proposed reservoir site by 2060 are 246,820 acft/yr. The nearest major demand center is the Austin area, which is located approximately 85 miles southwest of the reservoir site.
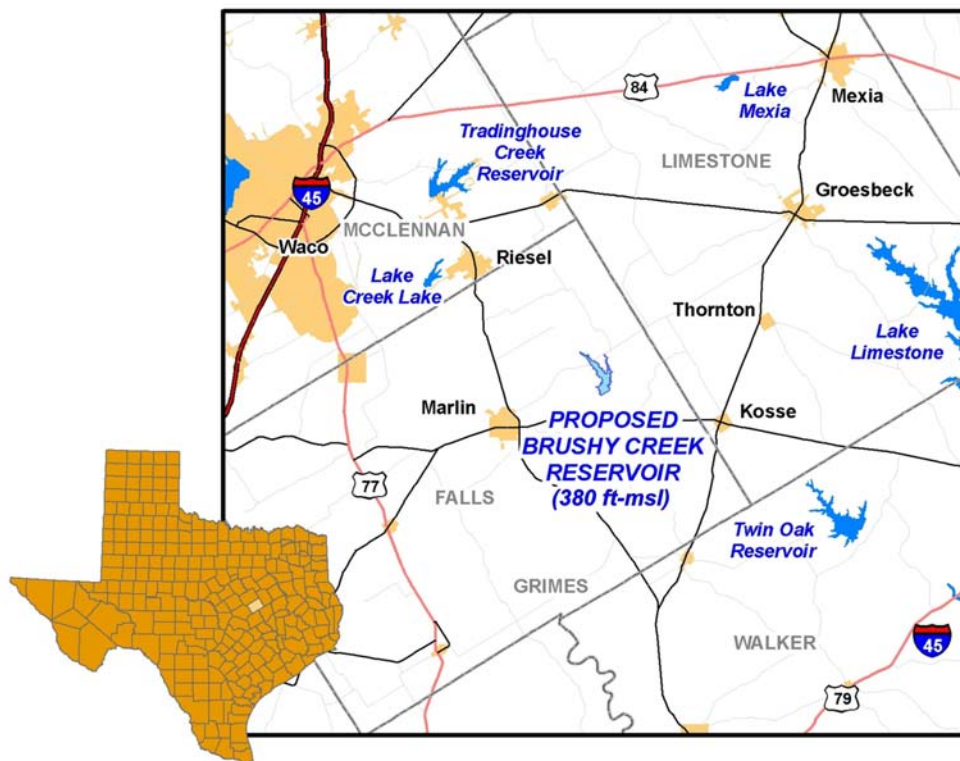
Figure 3.4.3-1. Location Map of Brushy Creek Reservoir

The purposes of the Brushy Creek Reservoir and the other structures included in the Big Creek Watershed Plan are to provide a dependable water supply for the City of Marlin, reduce channel erosion, reduce sedimentation, reduce downstream flooding, increase the availability of prime farmland soils, and increase the acreage of open water within the watershed. The Brushy Creek Reservoir itself is authorized as part of an existing water right (Certificate of Adjudication No. 12-4355) for water supply purposes for the City of Marlin as well as for flood control and recreation. Since the reservoir is authorized, it has been considered as an existing source of supply for the City of Marlin in the regional planning process. All of the land required for Brushy Creek Reservoir has been purchased by the City of Marlin.

3.4.3.2   *Reservoir Yield Analysis*

The firm yield of Brushy Creek Reservoir was calculated using the Brazos River Basin Water Availability Model (BWAM) with Run 3 assumptions as obtained from the Texas Commission on Environmental Quality (TCEQ). The monthly WAM simulations were performed using the Water Rights Analysis Package (WRAP). This existing BWAM model includes Brushy Creek Reservoir, and this representation of the reservoir has been reviewed and determined to be appropriate for this yield study.

The Brushy Creek Reservoir elevation-area-capacity relationship is presented in Table 3.4.3-1 and shown in Figure 3.4.3-2. The elevation-area-capacity data were developed by the Soil Conservation Service of the U.S. Department of Agriculture as part of the original watershed planning study. Figure 3.4.3-3 shows the area inundated by the reservoir at different water surface elevations.

For purposes of this yield study, Brushy Creek Reservoir is subject to an environmental flow restriction consistent with a special condition stipulated in the Certificate of Adjudication for the reservoir. This special condition requires a continuous release from the reservoir of at least 0.1 cfs.

WAM simulations were made to determine the firm yield of the reservoir for the authorized conservation pool elevation of 380.5 ft-msl, which corresponds to a maximum conservation storage capacity of 6,560 acft. The resulting firm yield is 1,380 acft/yr. Environmental flow requirements reduce the firm yield of the reservoir by approximately 55 acft.

Table 3.4.3-1.
Elevation-Area-Capacity Relationship for
Brushy Creek Reservoir

Elevation (ft-msl)	Area (acres)	Capacity (acft)
352.0	0	0
356.0	1	1
360.0	33	68
364.0	115	363
368.0	234	1,059
372.0	341	2,208
376.0	497	3,884
380.0	668	6,214
380.5	697	6,560
384.0	896	9,296
388.0	1,065	13,119
392.0	1,310	17,868
394.0	1,431	20,608
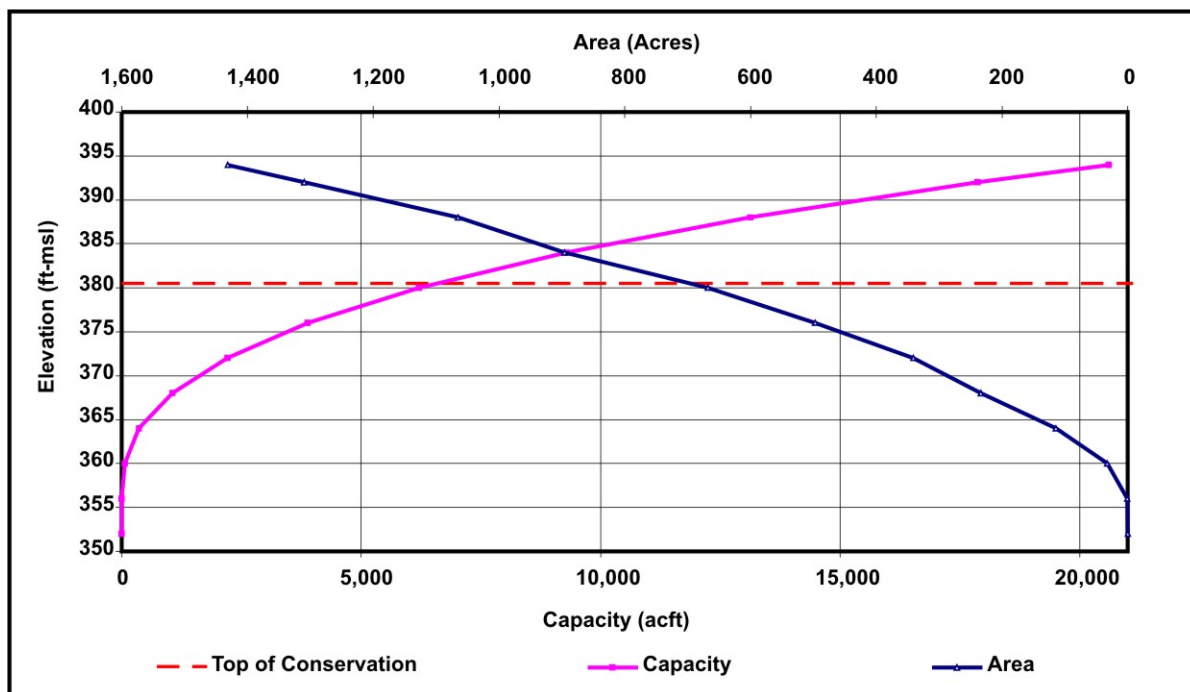
Figure 3.4.3-2. Elevation-Area-Capacity Relationship for Brushy Creek Reservoir
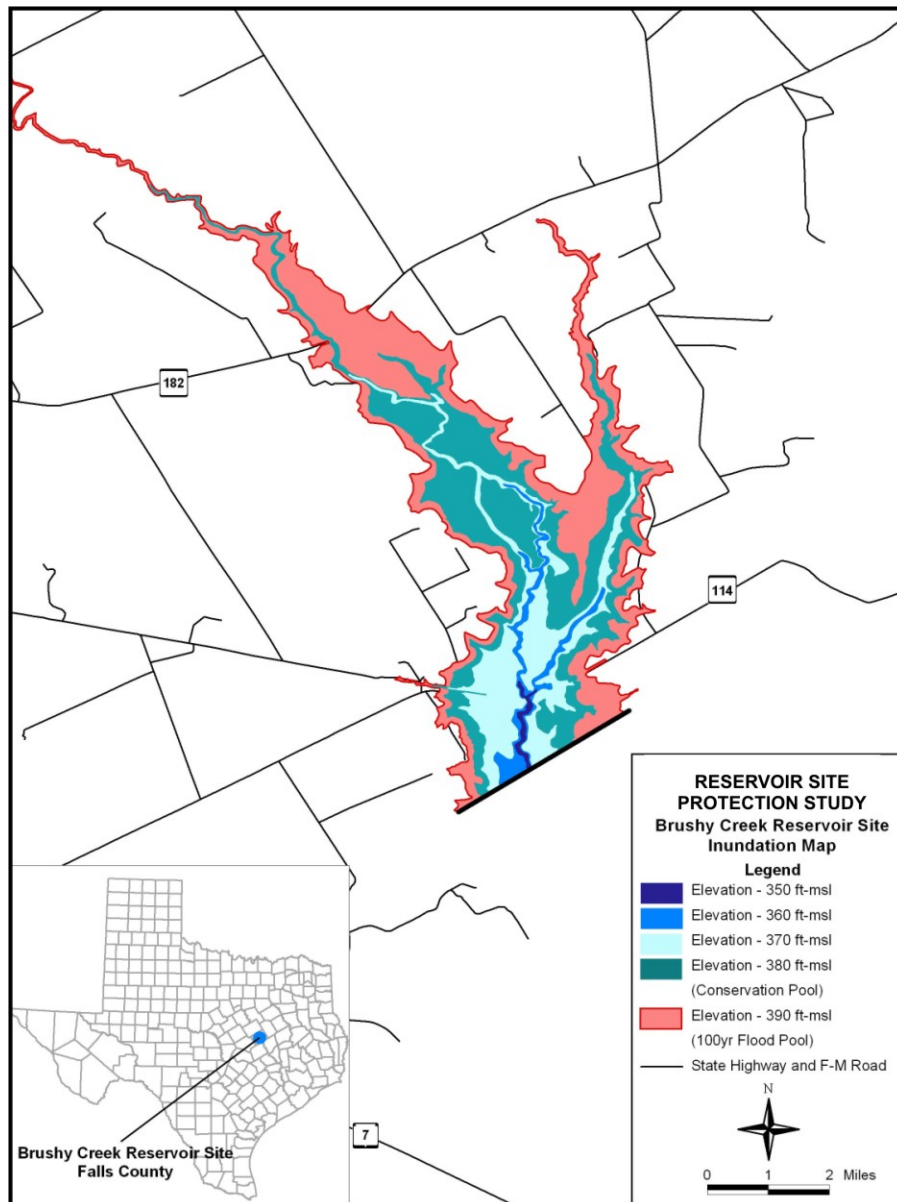
Figure 3.4.3-3. Inundation Map for Brushy Creek Reservoir

The monthly variation in storage in Brushy Creek Reservoir as simulated with the WAM over the 1940-1997 analysis period under firm yield conditions is shown in Figure 3.4.3-4. At the conservation pool elevation of 380.5 ft-msl (6,560 acft of storage capacity), the reservoir would be full about 25 percent of the time and would be below 50 percent of the conservation storage capacity about 12 percent of the time on a monthly basis. A frequency curve for storage content is also shown in Figure 3.4.3-4.
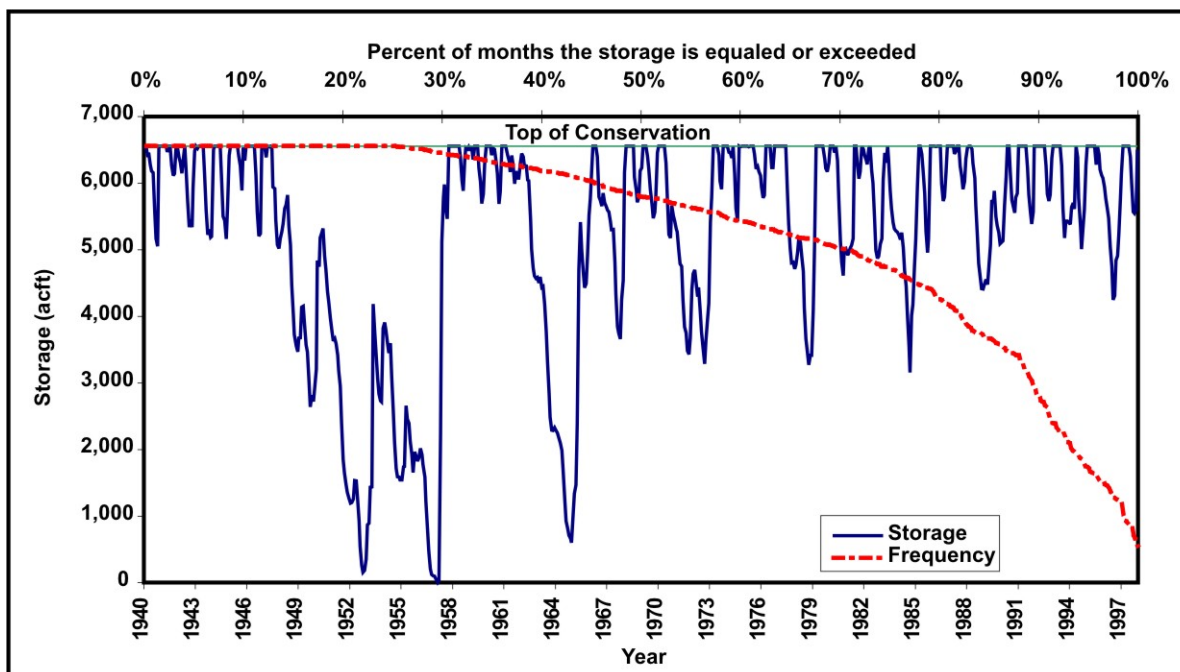
***Figure 3.4.3-4. Simulated Storage in Brushy Creek Reservoir
(Conservation Elevation = 380.5 ft-msl, Diversion = 1,380 acft/yr)***

3.4.3.3   Reservoir Costs

The costs for the Brushy Creek Reservoir includes a rolled earth embankment with a length of approximately 7,740 feet and a height of 50 feet. A principal spillway, consisting of a reinforced concrete drop inlet structure connected to a 7-foot square box conduit through the dam, will control low flows and provide for the passage of environmental flows. The emergency spillway will be an earthen cut spillway with a bottom width of approximately 400 feet.

The conflicts identified at the site include water lines, electrical distribution and transmission lines, and county and FM roads. A list of the potential conflicts as identified by TNRIS is provided in Table 3.4.3-2, and they are shown in Figure 3.4.3-5. The conflict costs represent less than 17 percent of the total construction cost of the reservoir project.

Table 3.4.3-3 shows the estimated capital costs for the Brushy Creek Reservoir, including construction costs, engineering, permitting, and mitigation. Unit costs for the dam and reservoir are based on the cost assumptions used in this study. The total estimated cost of the project is $18.4 million (2005 prices). Assuming an annual yield of 1,380 acft/yr, raw water from the project will cost approximately $931 per acre-foot ($2.86 per 1,000 gallons) during the debt

service period. Without the floodwater component of the project, the unit cost is approximately $484 per acre-foot ($1.48 per 1000 gallons).

Table 3.4.3-2.
List of Potential Conflicts for Brushy Creek Reservoir

Description	Unit	Quantity
Water Lines	Mile	2.5
Electrical Distribution & Transmission	Mile	3.0
County & FM Roads	Mile	1.2

3.4.3.4   *Environmental Considerations*

The Brushy Creek Reservoir site is not located on an ecologically significant stream as identified by the Texas Parks and Wildlife Department (TPWD). The main impacts of this project are significant only in the areas of construction of the dam and inundated areas. The reservoir will experience some sediment loading due to the nature of the soils within the drainage area. Several flood water retarding structures located in the upper part of the basin will act to reduce the loading. Temporary loading will occur immediately after construction of these upstream structures before all disturbed soils are re-vegetated. This effect is expected to greatly diminish as the vegetation matures and the sedimentation and erosion controls are maintained.

No endangered species have been identified in the basin area. Some archeological sites have been identified and ongoing work is scheduled through the sponsors of the project, which are the City of Marlin and the NRCS.

The dam is located on Brushy Creek immediately upstream of its confluence with Big Creek. Big Creek consists of a wide and flat braided stream that has many sloughs and wetlands. Hydraulic and hydrologic analyses of the dam indicate that the reduction of flows caused by storing water behind the dam would not have an adverse impact on the wetlands.

Brushy Creek Reservoir will inundate 697 acres of land at conservation storage capacity. Table 3.4.3-3 and Figure 3.4.3-6 summarize existing landcover for the Brushy Creek Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by upland deciduous forest (44 percent) and agricultural land (39 percent).

Table 3.4.3-3.
Acreage and Percent Landcover for Brushy Creek Reservoir

Landcover Classification	Acreage[1]	Percent
Upland Deciduous Forest	269	44.3%
Grassland	58	9.5%
Shrubland	45	7.3%
Agricultural Land	235	38.7%
Total	607	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
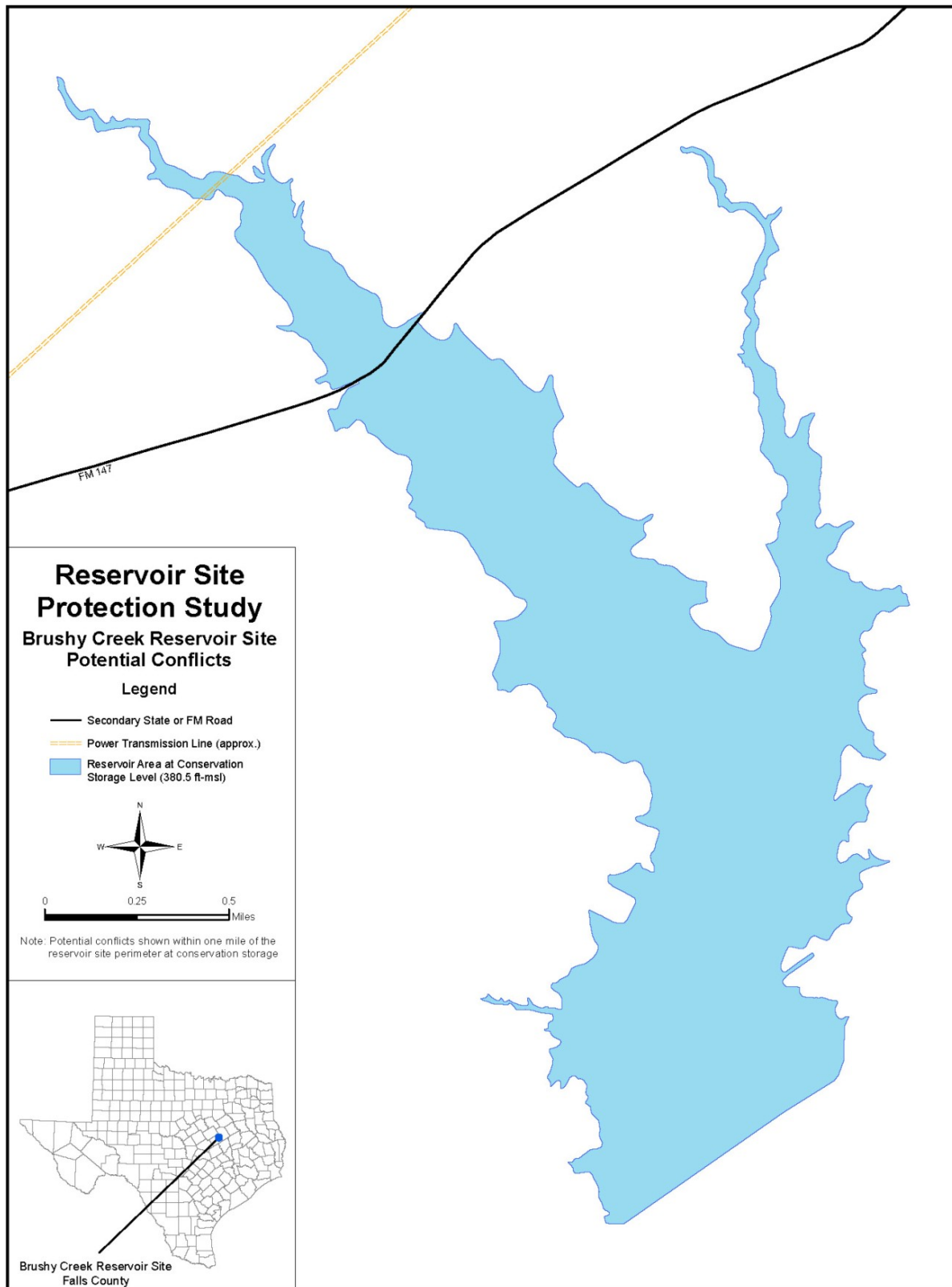
Figure 3.4.3-5. Potential Major Conflicts for Brushy Creek Reservoir

Table 3.4.3-4.
Cost Estimate — Brushy Creek Reservoir @ Elevation 380.5 ft-msl
(page 1 of 2)

	UNIT	QUANTITY	UNIT COST	COST
MOBILIZATION (5%)	LS	1		**$183,340**
FOUNDATION:				
CUTOFF EXCAVATION	CY	61,832	$2.50	$154,580
CHANNEL CLEANOUT EXCAVATION &				
FOUNDATION PREPARATION	CY	29,000	$2.50	$72,500
COMPACTED FILL - CUTOFF TRENCH	CY	61,832	$2.50	$154,580
SUBTOTAL - FOUNDATION CONSTRUCTION				**$381,660**
EMBANKMENT:				
CLEARING AND GRUBBING	AC	40	$2,000.00	$80,000
COMPACTED FILL	CY	579,789	$2.50	$1,449,473
RIP RAP & BEDDING	TON	12,500	$65.00	$812,500
TOPSOIL & GRASSING	AC	50	$4,500.00	$225,000
FENCING	LF	14,190	$4.00	$56,760
SUBTOTAL - EMBANKMENT CONSTRUCTION				**$2,623,733**
EMERGENCY SPILLWAY:				
EXCAVATION -EMERGENCY SPILLWAY	CY	110,000	$2.50	$275,000
SUBTOTAL - EMERGENCY SPILLWAY CONSTRUCTION				**$275,000**
PRINCIPAL SPILLWAY:				
REINFORCED CONCRETE				
7' X 7' BOX CULVERT CONDUIT	CY	290	$400.00	$116,000
ANTI-SEEP COLLARS	CY	39	$400.00	$15,600
RISER	CY	81	$400.00	$32,400
FOOTING	CY	31	$400.00	$12,400
ST. ANTHONY FALLS BASIN	CY	490	$400.00	$196,000
SLIDE GATE	EA	1	$6,000.00	$6,000
TRASH RACK	EA	1	$8,000.00	$8,000
SUBTOTAL - PRINCIPAL SPILLWAY CONSTRUCTION				**$386,400**
SUBTOTAL - DAM CONSTRUCTION				**$3,666,793**
CLEARING RESERVOIR	AC	175	$1,000.00	$175,000
SUBTOTAL - DAM & RESERVOIR CONSTRUCTION				**$4,025,132**
ENGINEERING & CONTINGENCIES (35% DAM & RESERVOIR)				**$1,408,796**
TOTAL - DAM & RESERVOIR CONSTRUCTION				**$5,433,928**
CONFLICTS (RELOCATIONS):				
12.5 kV DISTRIBUTION LINE	LS	1	$30,000.00	$30,000
69 kV TRANSMISSION LINE	LS	1	$270,000.00	$270,000
CLOSE COUNTY ROADS 182 & 182A	LS	1	$150,000.00	$150,000

Table 3.4.3-4.
Cost Estimate — Brushy Creek Reservoir @ Elevation 380.5 ft-msl
(page 2 of 2)

	UNIT	QUANTITY	UNIT COST	COST
WATER LINES	LS	1	$80,000.00	$80,000
TXDOT HIGHWAY 147	LS	1	$2,500,000.00	$2,500,000
SUBTOTAL - CONFLICTS				**$3,030,000**
ENGINEERING & CONTINGENCIES (35% CONFLICTS)				**$1,060,500**
LAND PURCHASE COSTS	AC	1,812	2,009	**$3,640,308**
ENVIRONMENTAL STUDIES & MITIGATION COSTS (100% LAND COSTS)				**$3,640,308**
CONSTRUCTION TOTAL				**$16,805,044**
INTEREST DURING CONSTRUCTION				**$1,608,625**
TOTAL COST				**$18,413,669**
ANNUAL COSTS				
DEBT SERVICE (6% FOR 40 YEARS)				**$1,223,801**
OPERATION & MAINTENANCE (1.5% OF DAM & SPILLWAY COSTS)				**$60,377**
TOTAL ANNUAL COSTS				**$1,284,178**
FIRM YIELD (ACRE-FEET PER ANNUM)				**1,380**
UNIT COST: CITY SHARE (52%) & NRCS SHARE (48%)				
UNIT COST OF WATER With NRCS floodwater component				
PER ACRE-FOOT				**$931**
PER 1,000 GALLONS				**$2.86**
UNIT COST OF WATER Without NRCS floodwater component (City's Share)				
PER ACRE-FOOT				**$484**
PER 1,000 GALLONS				**$1.48**
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.				

Note: The original landcover data provided by TPWD/TNRIS was modified for this figure to show only the area within the reservoir conservation pool (380.5 ft-msl).
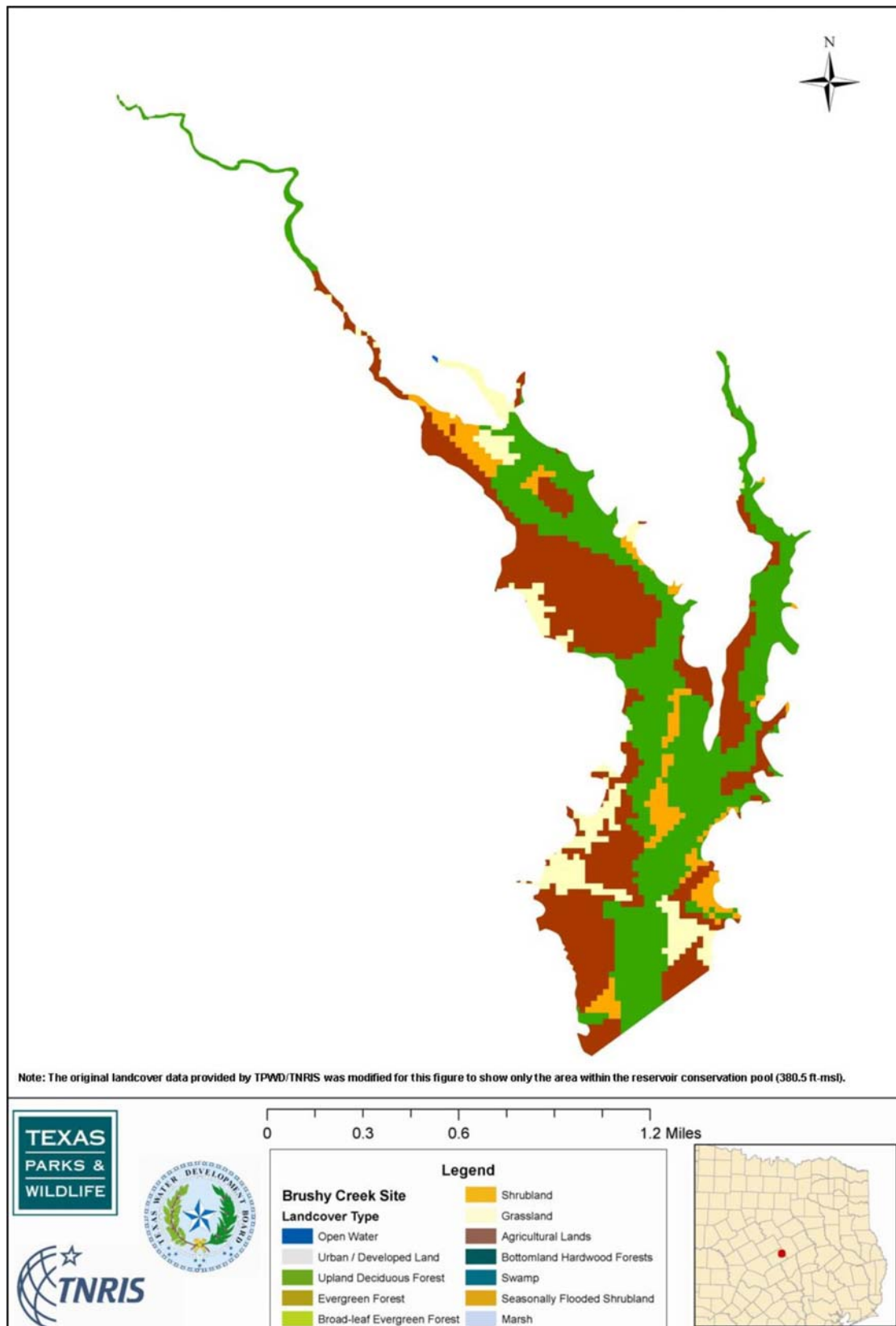
Figure 3.4.3-6. Existing Landcover for Brushy Creek Reservoir

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3.4.4   Cedar Ridge Reservoir (Breckenridge Reservoir)

3.4.4.1   Project Description

The Cedar Ridge Reservoir site, also referred to in past plans as the Breckenridge or Reynolds Bend site, is located in Throckmorton County on the Clear Fork of the Brazos River. This reservoir was first studied in 1971 and most recently in 2004 by HDR Engineering (HDR, September 2004).   The location of this reservoir site differs from the locations in previous reports. A location upstream of the confluence of Paint Creek has been selected in order to minimize conflicts with historic structures in the area as well as to improve water quality by excluding flows from Paint Creek. The selected dam site is located about 5 miles upstream of Paint Creek on the west side of the hill known as Cedar Ridge and is about 50 miles north of the City of Abilene, as shown in Figure 3.4.4-1. The proposed reservoir will impound 310,383 acft and inundate 6,190 acres at the full conservation storage level of 1,430 ft-msl.
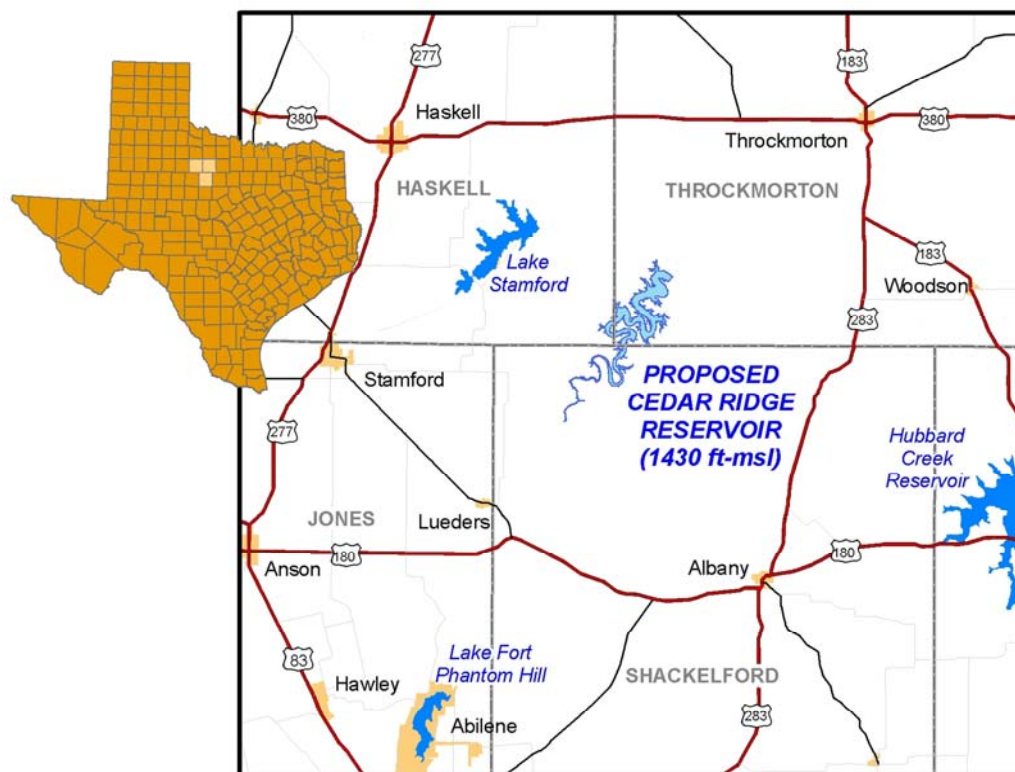
Figure 3.4.4-1. Location Map of Cedar Ridge Reservoir

With the establishment of regional water planning as part of the process for updating the State Water Plan (pursuant to Senate Bill 1 of the 75th Texas Legislature), Cedar Ridge Reservoir was identified as a potentially feasible project in the 2001 Brazos G Regional Water Plan. In the 2006 Brazos G Water Plan (approved by the TWDB on April 18, 2006), Cedar Ridge Reservoir is a recommended water management strategy to meet projected needs for the City of Abilene, the West Central Texas Municipal Water District, and irrigated agriculture in Throckmorton County. The 2007 State Water Plan (TWDB, 2007) recommends Cedar Ridge Reservoir be designated as a unique reservoir site by the legislature. Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply in 2060 total 17,240 acft/yr for counties within a 50-mile radius of the Cedar Ridge Reservoir site. The nearest major population and water demand centers to the Cedar Ridge Reservoir site are Dallas / Fort Worth (146 miles) and Austin (211 miles).

3.4.4.2   *Reservoir Yield Analyses*

The elevation-area-capacity relationship for Cedar Ridge Reservoir is presented in Figure 3.4.4-2 and in Table 3.4.4-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.4-3. At the conservation storage pool elevation of 1,430 ft-msl, Cedar Ridge Reservoir would inundate 6,190 acres and have a capacity of 310,383 acft.

Table 3.4.4-1.
Elevation-Area-Capacity Relationship for Cedar Ridge Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
1,290	0	0
1,300	97	548
1,320	455	5,626
1,340	1,202	21,599
1,360	1,927	52,605
1,380	2,710	98,753
1,390	3,209	128,311
1,400	3,772	163,178
1,410	4,482	204,399
1,420	5,274	253,125
1,430	6,190	310,383
1,440	7,294	377,727
1,460	10,066	550,585
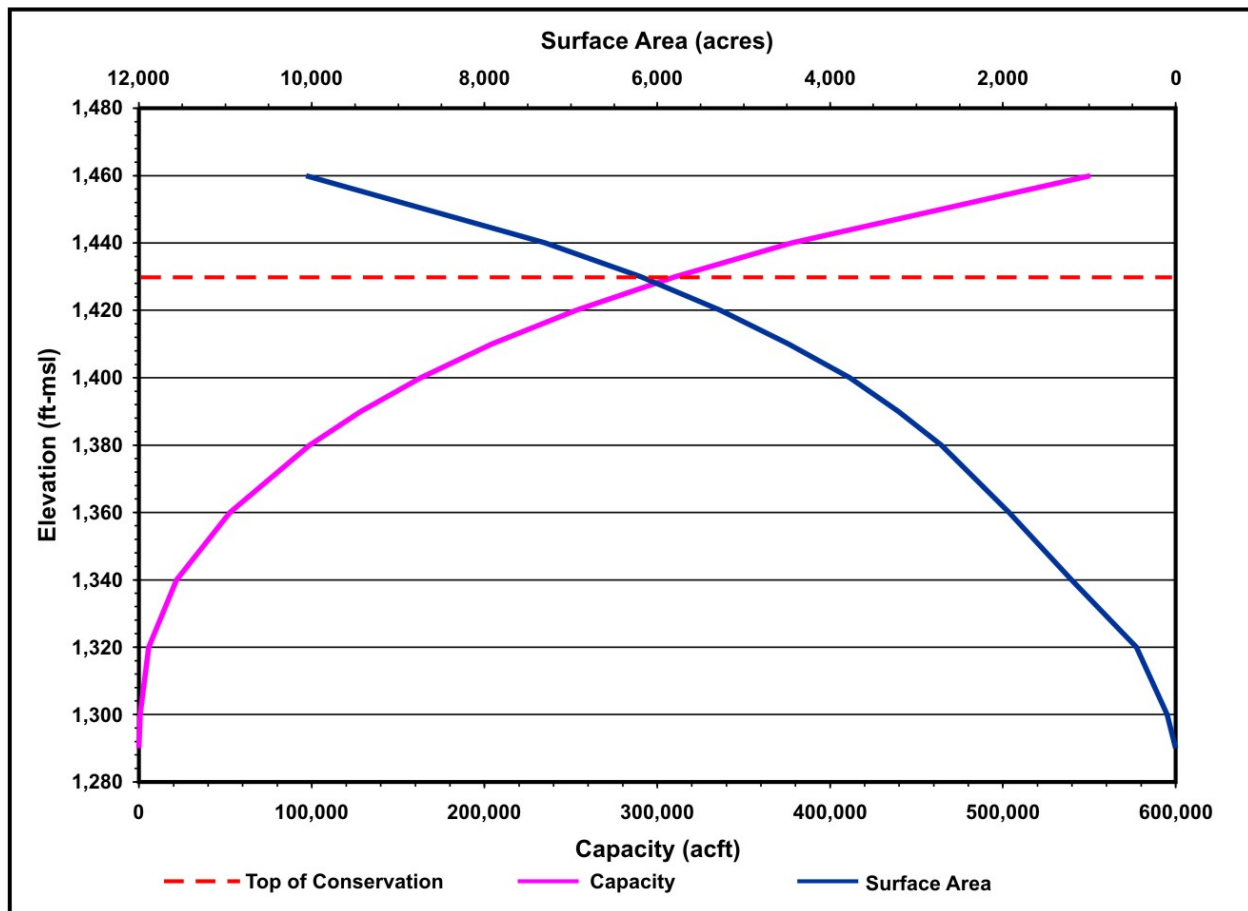
Figure 3.4.4-2. Elevation-Area-Capacity Relationship for Cedar Ridge Reservoir

Median and quartile (25th percentile) streamflows have been calculated for the Cedar Ridge site based on monthly naturalized flows from the Brazos WAM. These monthly naturalized flows were then disaggregated to daily naturalized flows using historical records of the USGS streamflow gaging station on the Clear Fork near Nugent. For each month, daily flows are ranked with median and quartile flows then extracted. The natural median and quartile flows for the Cedar Ridge site are presented in Table 3.4.4-2.
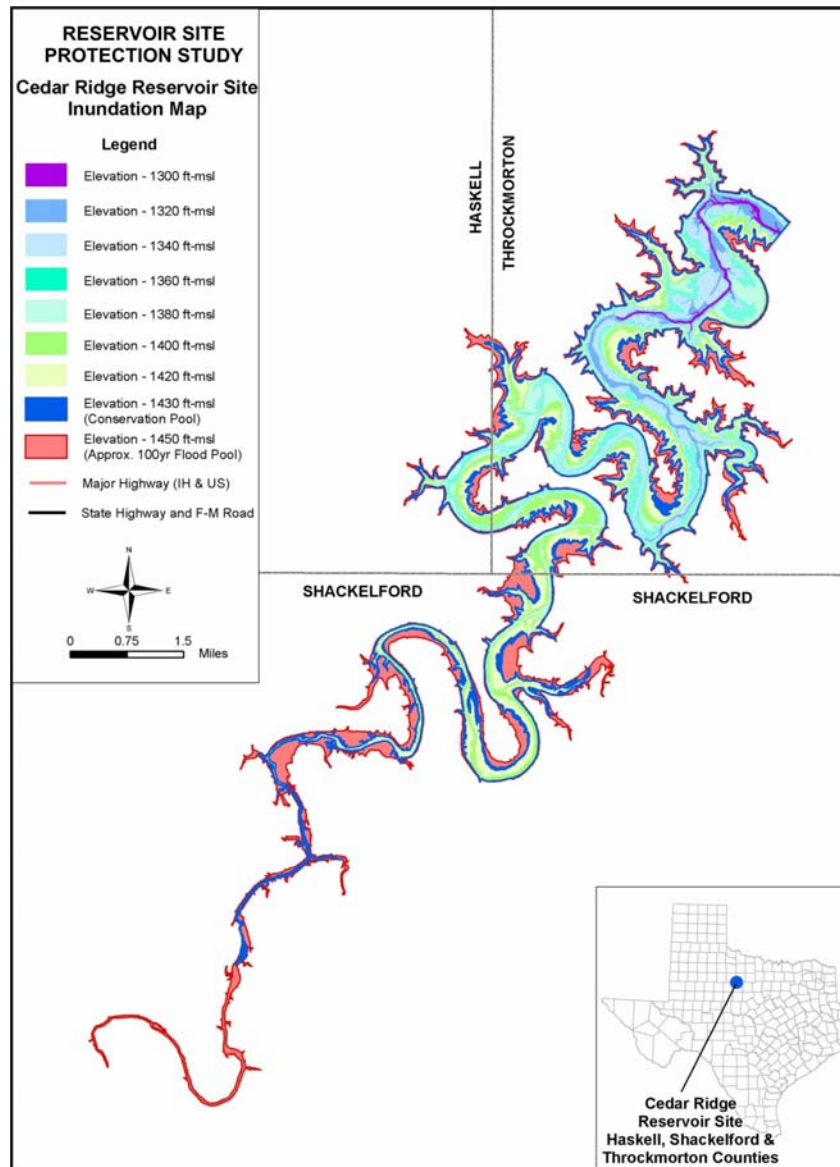
Figure 3.4.4-3. Inundation Map for Cedar Ridge Reservoir

Table 3.4.4-2.
Consensus Criteria for Environmental Flow Needs for Cedar Ridge Reservoir

	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
Median (cfs)	24.6	30.0	34.6	37.2	54.0	53.7	21.3	13.0	21.3	24.1	18.5	16.7
Median (acft/mo)	1,510	1,664	2,125	2,212	3,322	3,192	1,311	799	1,269	1,482	1,099	1,024
Quartile (cfs)	13.5	14.7	17.3	12.8	12.6	16.8	2.7	1.5	1.5	3.8	4.1	7.0
Quartile (acft/mo)	829	815	1,065	760	772	1,000	168	74	57	236	246	432
7Q2 (cfs)	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
7Q2 (acft/mo)	92	83	92	89	92	89	92	92	89	92	89	92
Note: The 7Q2 value is used when the 7Q2 value exceeds the value of the median and/or quartile.												

The Consensus Criteria for Environmental Flow Needs (CCEFN) (TWDB, August 1997), a three-staged criteria that uses percentages of reservoir capacity as triggers for determining the pass-through requirement, is used for modeling of the Cedar Ridge Reservoir. Pass-through flows are the monthly naturalized median flow when reservoir storage is greater than 80 percent of capacity, the monthly naturalized 25th percentile flow when the reservoir is between 50 and 80 percent of capacity, and the published 7Q2 when reservoir capacity is less than 50 percent of conservation capacity. The CCEFN values used include the median and quartile flows in Table 3.4.4-1 and the 7Q2 value of 1.5 cfs published in the Texas Surface Water Quality Standards. Cedar Ridge Reservoir is located well in excess of 200 river miles from the coast, so freshwater inflow needs for bays and estuaries are not explicitly considered herein, but are assumed to be sufficiently addressed by CCEFN.

The firm yield of the Cedar Ridge Reservoir is calculated using the Brazos WAM. The Brazos WAM simulates a repeat of the natural streamflows over the 58-year period of 1940 through 1997 accounting for the appropriated water rights of the Brazos River Basin with respect to location, priority date, diversion amount, diversion pattern, storage, and special conditions including instream flow requirements.

For the purposes of this study, Possum Kingdom Reservoir is assumed to be subordinated to Cedar Ridge Reservoir. Specific terms of such subordination are the subject of negotiations between reservoir sponsors and the Brazos River Authority (BRA). Estimates of Cedar Ridge Reservoir firm yield reported herein include no passage of inflow for senior water rights associated with Possum Kingdom Reservoir.

Four potential conservation storage capacities were modeled for the Cedar Ridge Reservoir. These conservation storage capacities are associated with 1410 ft-msl, 1420 ft-msl, 1430 ft-msl, and 1440 ft-msl conservation pool elevations. Table 3.4.4-2 includes the conservation storage capacities associated with these four conservation elevations.

Firm yield estimates for Cedar Ridge Reservoir for all four conservation pool elevations are shown in Table 3.4.4-3. Current planning initiatives envision a conservation pool elevation of 1430 ft-msl for the Cedar Ridge Reservoir, thereby yielding a firm supply of 36,891 acft/yr. For comparison purposes, the firm yield of the Cedar Ridge Reservoir at conservation pool elevation 1430 ft-msl without an environmental flow requirement is 39,225 acft/yr. Figure 3.4.4-4 shows the relationship between firm yield and conservation storage capacity for Cedar Ridge Reservoir.

Cedar Ridge Reservoir was most recently studied by HDR (HDR, January 2006) for the 2006 Brazos G Water Plan. The safe yield of Cedar Ridge Reservoir as reported therein is 31,910 acft/yr at conservation pool elevation 1430 ft-msl.
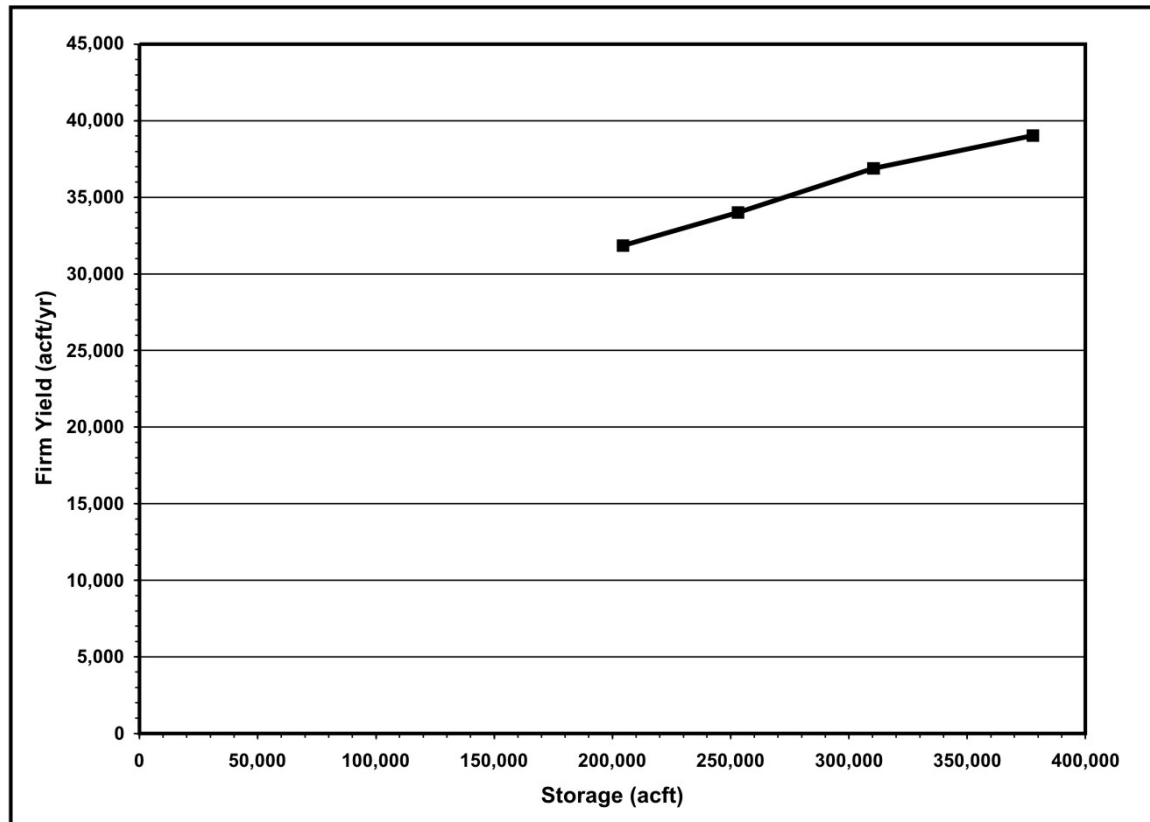
Figure 3.4.4-4. Firm Yield vs. Conservation Storage for Cedar Ridge Reservoir

Table 3.4.4-3.
Firm Yield vs. Conservation Storage for Cedar Ridge Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)
1410.0	204,399	CCEFN	31,860
1420.0	253,125	CCEFN	34,000
1430.0*	310,383	CCEFN	36,891
		None	39,225
1440.0	377,727	CCEFN	39,033
*Proposed conservation storage.			

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Figure 3.4.4-5 illustrates storage fluctuations through time for Cedar Ridge Reservoir subject to firm yield diversions and CCEFN. The reservoir storage frequency curve shown in Figure 3.4.4-5 indicates that the reservoir would be full approximately 4 percent of the time and more than half full about 64 percent of the time.
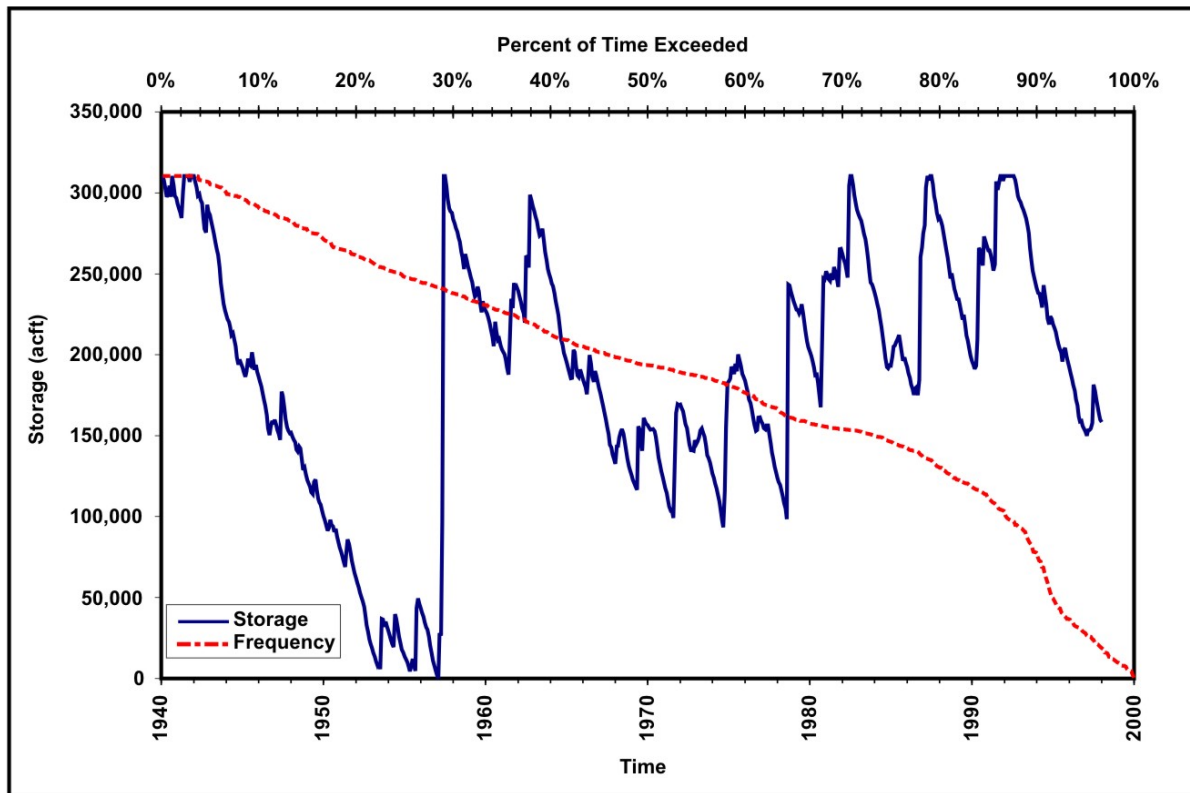
Figure 3.4.4-5. Simulated Storage in Cedar Ridge Reservoir
(Conservation Elevation = 1430 ft-msl, Diversion = 36,891 acft/yr)

3.4.4.3 *Reservoir Project Cost Estimates*

The Cedar Ridge Reservoir includes the construction of an earth dam, principal spillway, emergency spillway, and appurtenant structures. The length of the dam is estimated at approximately 3,500 feet with a maximum height of 175 feet. The service spillway would include a Morning Glory intake; a 14-foot diameter outlet pipe, a stilling basin, and an outlet channel to convey up to 5,000 cfs. A summary cost estimate for Cedar Ridge Reservoir at elevation 1430 ft-msl is shown in Table 3.4.4-4. Dam and reservoir costs total about $62.4 million, while relocations add $18.7 million. Land, which includes mitigation lands, costs an additional $17.1 million. Annual costs for Cedar Ridge Reservoir are approximately

$8.5 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $230/acft ($0.71 per 1,000 gallons).

Figure 3.4.4-6 shows the major conflicts within a 1-mile buffer of Cedar Ridge Reservoir. Major conflicts include oil and gas wells, and a power transmission line. According to TNRIS, there are 65 oil and gas wells within the conservation storage level (1430 ft-msl) of the reservoir. Resolution of facility conflicts represents approximately 17 percent of the total construction cost and could be less if the reservoir is constructed after economical recovery of oil and gas reserves is completed.

Figure 3.4.4-6. Potential Major Conflicts for Cedar Ridge Reservoir

Table 3.4.4-4.
Cost Estimate — Cedar Ridge Reservoir @ Elevation 1,430 ft-msl

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Mobilization (5%)		LS		$2,170,125
Clearing and Grubbing	100	AC	$2,000	$200,000
Care of Water During Construction (1%)		LS		$434,025
Required Excavation	998,000	CY	$2.50	$2,495,000
Borrow Excavation	4,378,000	CY	$2.00	$8,756,000
Random Compacted Fill	5,126,000	CY	$2.50	$12,815,000
Cut-Off Trench	37,000	SF	$15.00	$555,000
Rock Riprap	64,000	SY	$115.00	$7,360,000
Sand Filter Drain	4,900	CY	$35.00	$171,500
Outlet Works Tower and Conduit	1	LS	$6,200,000	$6,200,000
Power Drop	1	LS	$250,000	$250,000
Instrumentation	1	LS	$550,000	$550,000
Emergency Spillway	1	LS	$4,250,000	$4,250,000
Engineering Contingencies (35%)				<u>$16,172,328</u>
Subtotal Dam & Reservoir				**$62,378,978**
Conflicts				
Roads	1	LS	$10,980,000	$10,980,000
Existing Structures	1	LS	$1,250,000	$1,250,000
Oil and gas Wells	65	EA	$25,000	$1,620,000
Engineering Contingencies (35%)				<u>$4,849,500</u>
Subtotal Conflicts				**$18,704,500**
Land				
Land Acquisition	10,066	AC	$850	$8,556,100
Environmental Studies and Mitigation Lands	10,066	AC	$850	<u>$8,556,100</u>
Subtotal Land				**$17,112,200**
CONSTRUCTION TOTAL				**$98,195,428**
Interest During Construction (36 months)				$11,783,451
TOTAL COSTS				**$109,978,879**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$7,309,196
Operations & Maintenance				$935,685
Purchase of Water (BRA)	5,000	acft/yr	45.75	<u>$228,750</u>
Total Annual Costs				**$8,473,631**
Firm Yield (acft/yr)				**36,891**
Unit Costs of Water ($/acft/yr)				**$230**

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

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3.4.4.4   Environmental Considerations

Cedar Ridge Reservoir would inundate a portion of TCEQ classified stream segment Number 1232. This segment is not listed by Texas Parks and Wildlife Department (TPWD) as an Ecologically Significant Stream Segment.

Cedar Ridge Reservoir will inundate 6,190 acres of land at conservation storage capacity. Table 3.4.4-5 and Figure 3.4.4-7 summarize existing landcover for the Cedar Ridge Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by shrubland (42 percent), grassland (31 percent), and upland deciduous forest (21 percent). The remainder of the site is classified as open water (6 percent).

Table 3.4.4-5.
Acreage and Percent Landcover for Cedar Ridge Reservoir

Landcover Classification	Acreage[1]	Percent
Shrubland	2,598	42.0%
Grassland	1,896	30.6%
Upland Deciduous Forest	1,314	21.3%
Open Water	379	6.1%
Total	6,187	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
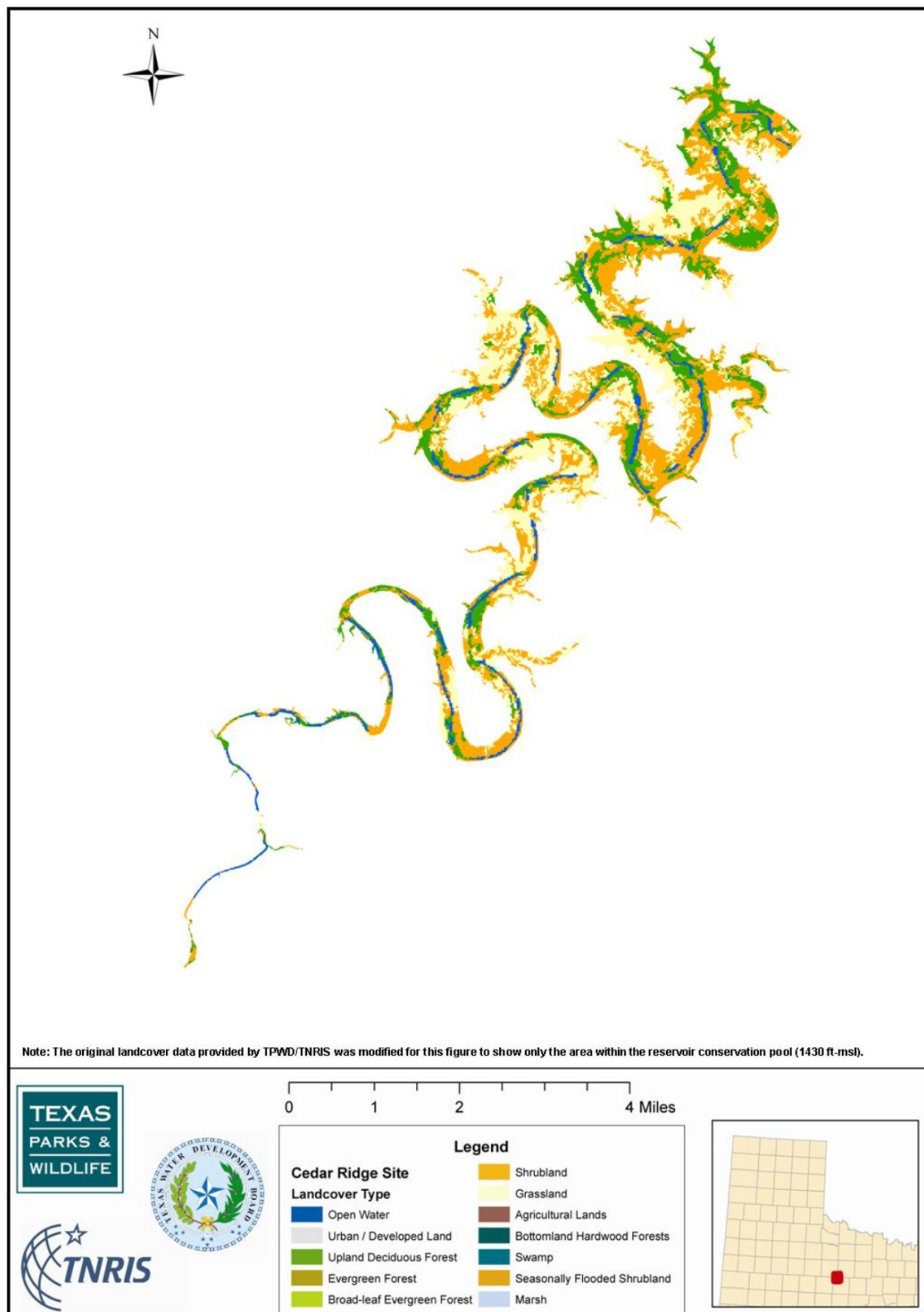
Figure 3.4.4-7. Existing Landcover for Cedar Ridge Reservoir

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3.4.5   Cuero II Reservoir (Sandies Creek Reservoir or Lindenau Reservoir)

3.4.5.1   Project Description

Cuero II Reservoir, also known as Sandies Creek Reservoir or Lindenau Reservoir in previous studies, is a proposed reservoir located on Sandies Creek, a tributary of the Guadalupe River in DeWitt and Gonzales Counties. The project would impound water from the Sandies Creek watershed as well as water diverted from the Guadalupe River during periods of flow in excess of downstream needs. This reservoir was proposed as a water supply for in-basin needs as part of the Texas Basins Project (USBR, February 1965) in the mid-1960s. Subsequent studies of the reservoir were performed (TWDB, July 1966), the latest of which was in the 2001 South Central Texas Regional Water Plan. The reservoir location is shown in Figure 3.4.5-1.
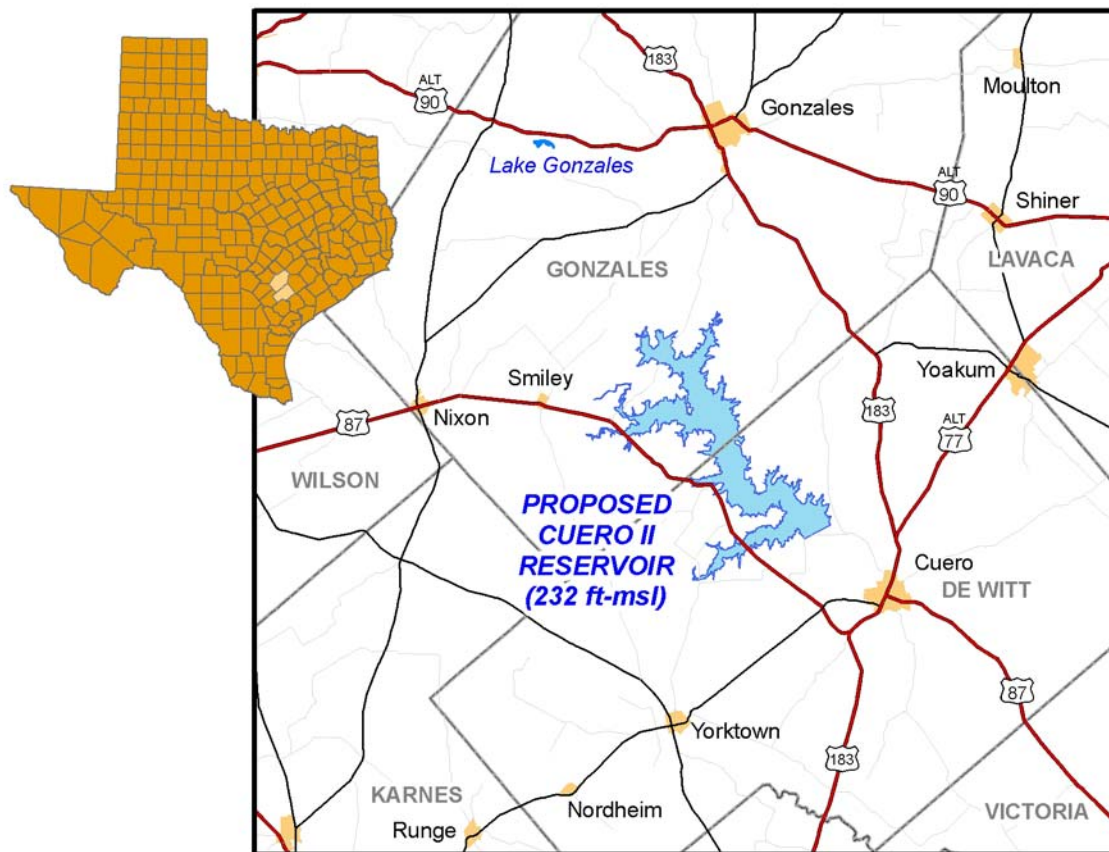
Figure 3.4.5-1. Location Map of Cuero II Reservoir

The dam would be an earthfill embankment with a roller-compacted concrete spillway to impound runoff from the 678 square mile watershed. The dam would extend about 2 miles across the Sandies Creek valley, and provide a conservation storage capacity of 583,975 acft,

inundating 28,154 acres. The spillway design flood elevation would be 240.5 ft-msl and inundate approximately 36,967 acres.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply prior to year 2060 total 346,140 acft/yr for counties within a 50-mile radius of the Cuero II Reservoir site. The nearest major population and water demand centers to the Cuero II Reservoir site are San Antonio (71 miles) and Austin (83 miles).

3.4.5.2   *Reservoir Yield Analyses*

The elevation-area-capacity relationship for Cuero II Reservoir is presented in Figure 3.4.5-2 and Table 3.4.5-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.5-3. Surface areas and capacities associated with 232 ft-msl are computed by linear interpolation between values for 230 ft-msl and 240 ft-msl and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 232 ft-msl, Cuero II Reservoir would inundate 28,154 acres and have a capacity of 583,975 acft.

Table 3.4.5-1.
Elevation-Area-Capacity Relationship for
Cuero II Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
155	0	0
160	67	112
170	295	1,786
180	1,516	10,053
190	2,981	32,134
200	5,927	75,842
210	11,310	160,590
220	17,673	304,326
230	26,080	521,735
232	28,154	583,975
240	36,448	832,937
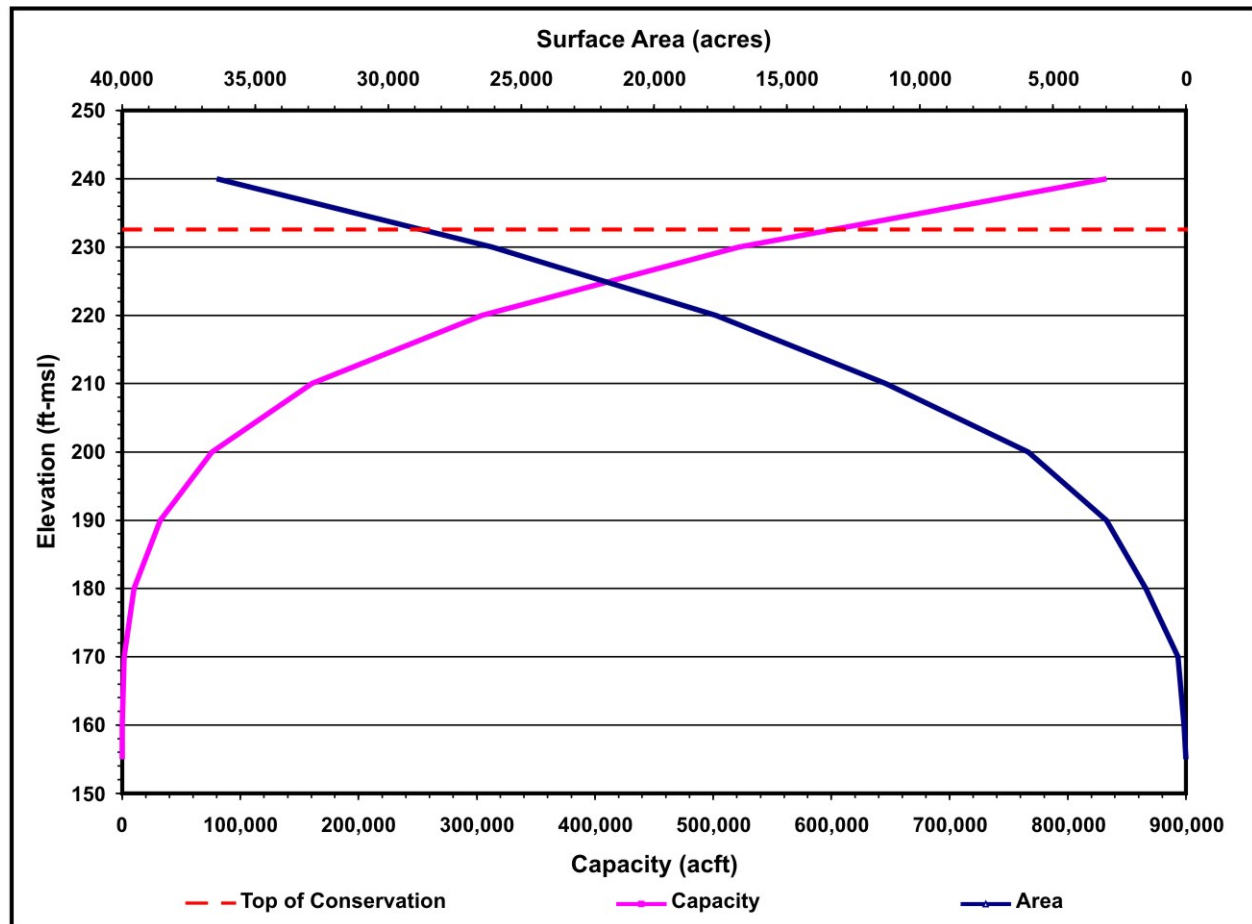
Figure 3.4.5-2. Elevation-Area-Capacity Relationship for Cuero II Reservoir

The Consensus Criteria for Environmental Flow Needs (CCEFN) (TWDB, August 1997), a three-staged criteria that uses percentage of reservoir capacity as a trigger for determining the pass-through requirement, is used for the modeling of Cuero II Reservoir. Pass-through flows are the monthly naturalized median flow when reservoir storage is greater than 80 percent of capacity, the monthly naturalized 25th percentile flow when the reservoir is between 50 and 80 percent of capacity, and the published 7Q2 when reservoir capacity is less than 50 percent of conservation capacity. The CCEFN values used include the median and quartile flows in Table 3.4.5-2 and the 7Q2 value of 3.5 cfs published in the Texas Surface Water Quality standards (Texas Administrative Code).

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Cuero II Reservoir Site Inundation Map

Legend

- Elevation - 160 ft-msl
- Elevation - 170 ft-msl
- Elevation - 180 ft-msl
- Elevation - 190 ft-msl
- Elevation - 200 ft-msl
- Elevation - 210 ft-msl
- Elevation - 220 ft-msl
- Elevation - 230 ft-msl
- Elevation - 232 ft-msl (Conservation Pool)
- Elevation - 240 ft-msl (Approx. 100yr Flood Pool)
- Major Highway (IH & US)
- State Highway and F-M Road

Cuero II Reservoir Site
DeWitt & Gonzales Counties
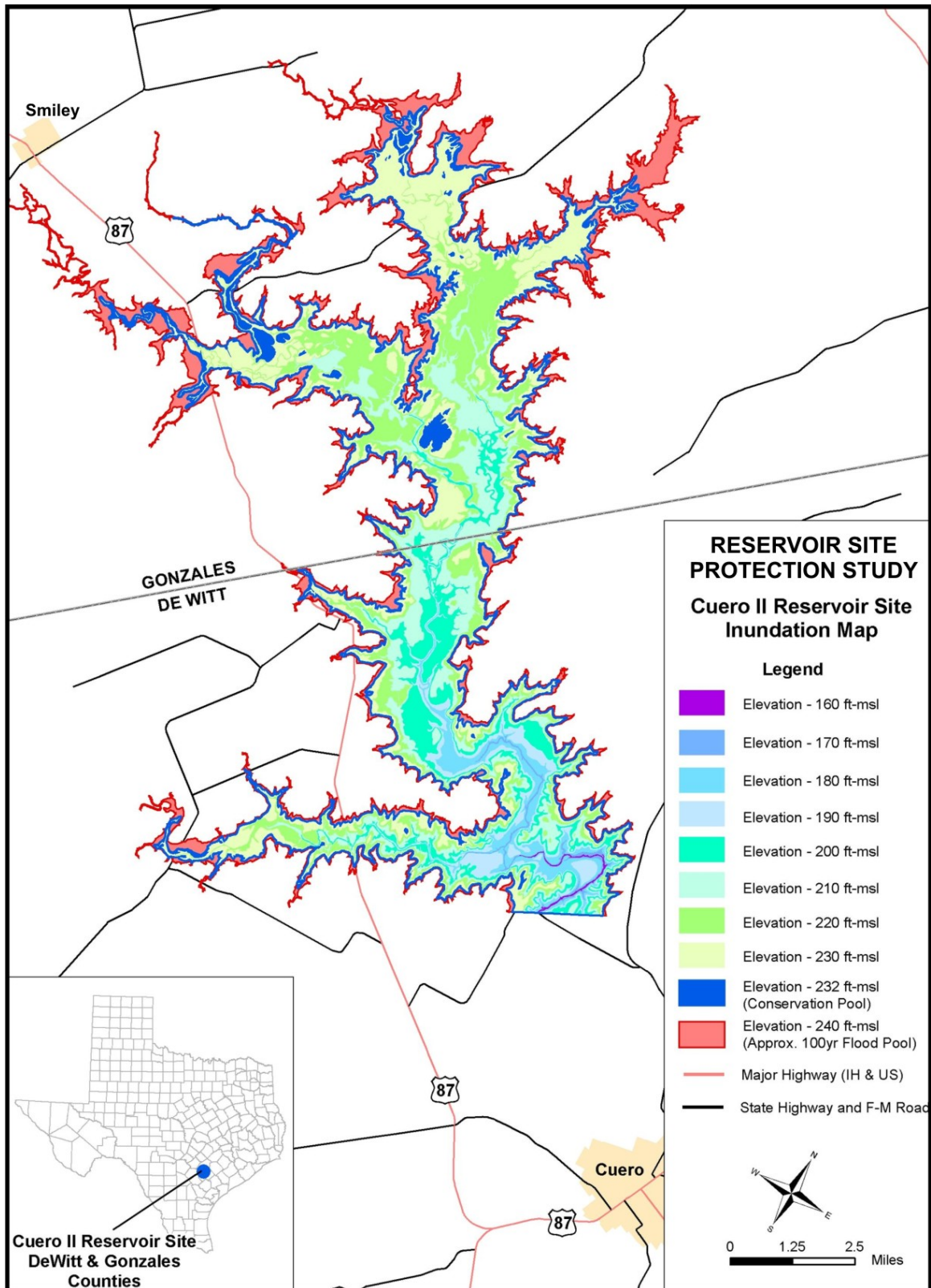
Figure 3.4.5-3. Inundation Map for Cuero II Reservoir

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Table 3.4.5-2.
Consensus Criteria for Environmental Flow Needs for Cuero II Reservoir

	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
Median (cfs)	16.6	19.7	17.1	16.1	20.2	17.1	9.6	7.1	10.6	11.6	14.1	15.1
Median (acft/mo)	1,023	1,092	1,054	960	1,240	1,020	589	434	630	713	840	930
Quartile (cfs)	10.6	11.1	10.6	8.1	7.6	7.1	3.5	3.5	4.0	5.0	7.1	9.1
Quartile (acft/mo)	651	616	651	480	465	420	215	215	240	310	420	558
7Q2 (cfs)	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5	3.5
7Q2 (acft/mo)	215	194	215	208	215	208	215	215	208	215	208	215
Note: The 7Q2 value is used when it exceeds the value of the median and/or quartile												

In addition, the waters diverted from the Guadalupe River to supplement runoff into Cuero II Reservoir are subject to CCEFN. Triggers for run-of-river diversions are based on streamflow passing the diversion point. Table 3.4.5-3 lists the median and quartile flows for the Guadalupe River at Cuero. The 7Q2 value published in the Texas Surface Water Quality Standards for this segment of the Guadalupe River is 317.1 cfs.

Table 3.4.5-3.
Consensus Criteria for Environmental Flow Needs for Guadalupe River Diversions

	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
Median (cfs)	944	1,015	1,015	1,042	1,241	1,120	845	660	729	838	851	881
Median (acft)	58,032	56,392	62,403	62,010	76,291	66,660	51,956	40,610	43,350	51,522	50,640	54,188
Quartile (cfs)	590	641	619	608	671	604	477	349	416	485	536	568
Quartile (acft)	36,301	35,616	38,037	36,150	41,261	35,940	29,326	21,452	24,750	29,822	31,890	34,937
7Q2 (cfs)	317.1	317.1	317.1	317.1	317.1	317.1	317.1	317.1	317.1	317.1	317.1	317.1
7Q2 (acft)	19,498	17,611	19,498	18,869	19,498	18,869	19,498	19,498	18,869	19,498	18,869	19,498

The firm yield of Cuero II Reservoir is estimated using the TCEQ Guadalupe-San Antonio River Basin Water Availability Model (GSA WAM) (HDR, 1999) data sets and the Water Rights Analysis Package (WRAP) (TCEQ, 2004) The GSA WAM simulates a repeat of the natural streamflows over the 56-year period of 1934 through 1989 accounting for the appropriated water rights of the Guadalupe-San Antonio River Basin with respect to location, priority date, diversion amount, diversion pattern, storage, and special conditions including instream flow requirements.

Four potential conservation storage capacities are modeled for Cuero II Reservoir. These conservation storage capacities are associated with 240 ft-msl, 232 ft-msl, 225 ft-msl, and 220 ft-msl conservation pool elevations. Table 3.4.5-4 includes the storage capacities associated with these four conservation pool elevations. For the purposes of this study, one maximum diversion rate of 786 cfs from the Guadalupe River to Cuero II Reservoir has been assumed for all four conservation storage capacities.

Table 3.4.5-4.
Firm Yield vs. Conservation Storage for Cuero II Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)
220.0	304,326	CCEFN	49,418
225.0	413,030	CCEFN	58,367
232.0*	583,975	CCEFN	71,437
		None	83,498
240.0	832,937	CCEFN	85,223
*Proposed conservation storage.			

Cuero II Reservoir is simulated with a priority date junior to all existing water rights in the Guadalupe-San Antonio River Basin. Firm yield estimates for Cuero II Reservoir for all four conservation pool elevations are shown in Table 3.4.5-4. At a conservation pool elevation of 232 ft-msl, the firm yield is 71,437 acft/yr. Figure 3.4.5-4 shows the relationship between firm yield and conservation storage capacity for Cuero II Reservoir.

Cuero II (Sandies Creek) Reservoir was most recently evaluated by Region L in the 2001 South Central Texas Regional Water Plan (HDR et al., 2001). The firm yield of Cuero II Reservoir was reported as 80,836 acft/yr at conservation pool elevation 232 ft-msl. The firm yield estimate in the current study differs from the 2001 Region L Water Plan because SIMDLY (a daily reservoir simulation model) and an alternative Guadalupe-San Antonio River Basin Model were used for regional planning. In addition, the refined elevation-area-capacity relationship in the current study has reduced the conservation capacity at elevation 232 ft-msl from 606,280 acft to 583,975 acft.
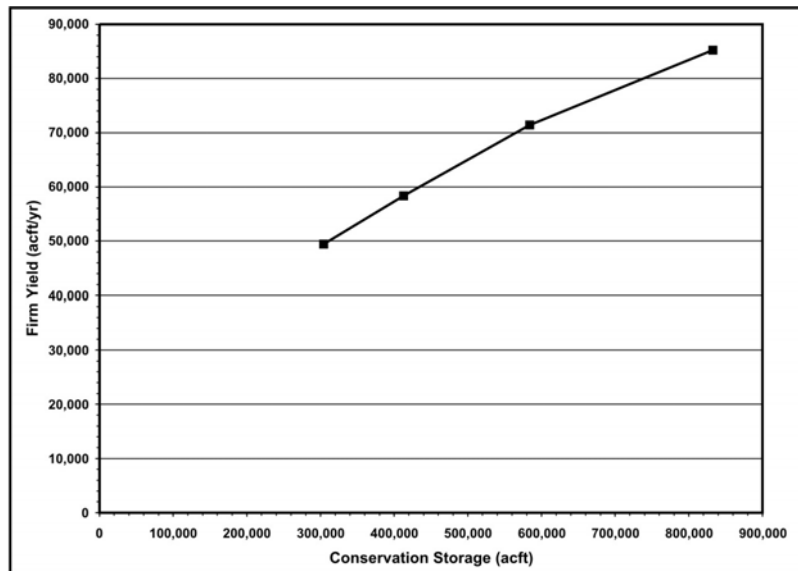
Figure 3.4.5-4. Firm Yield vs. Conservation Storage for Cuero II Reservoir

Figure 3.4.5-5 illustrates storage fluctuations through time for Cuero II Reservoir subject to firm yield diversions and CCEFN. The reservoir storage frequency curve in Figure 3.4.5-5 indicates that the reservoir would be full about 30 percent of the time and more than half full about 94 percent of the time.
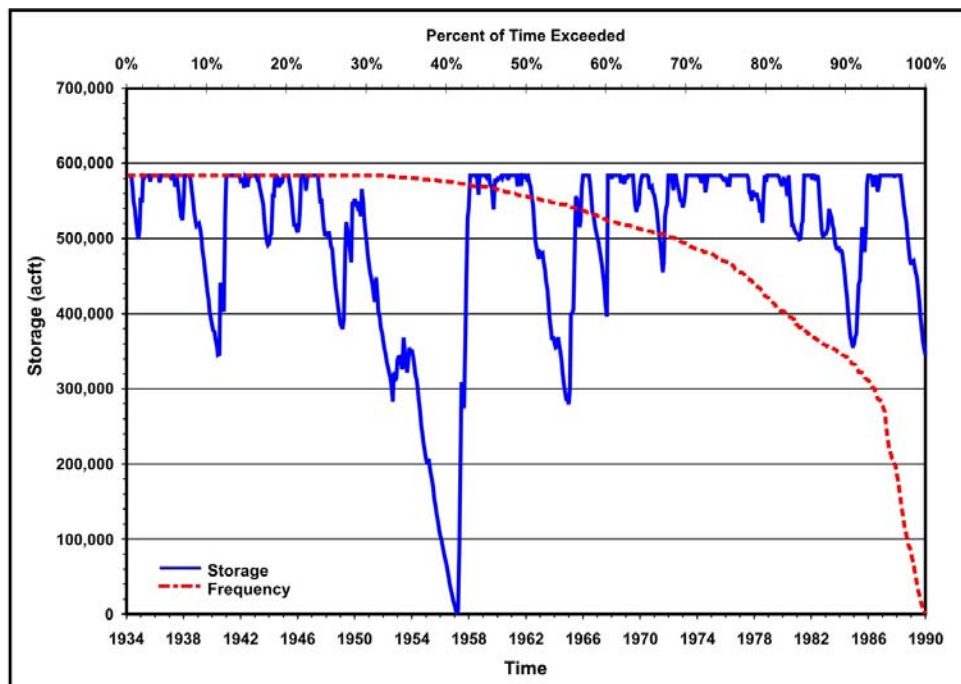
Figure 3.4.5-5. Simulated Storage in Cuero II Reservoir
(Conservation Elevation = 232 ft-msl, Diversion = 71,437 acft/yr)

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3.4.5.3   Reservoir Project Cost Estimates

The Cuero II Reservoir includes the construction of an earth dam, principal spillway, emergency spillway, and appurtenant structures. The length of the dam is estimated at 10,640 feet with a maximum height of 101 feet. The service spillway would include an uncontrolled ogee spillway, a hydraulic jump stilling basin, and 2- 5-foot by 8-foot low flow sluiceway outlets. The diversion from the Guadalupe River near Cuero includes a 510 MGD intake and pump station, two 1.48 mile, 120-inch pipelines, and a stilling basin.

A summary cost estimate for Cuero II Reservoir at elevation 232 ft-msl is shown in Table 3.4.5-5. Detailed quantities for Cuero II Reservoir are from a report entitled Water Availability Study for the Guadalupe and San Antonio River Basins (Espey, Huston & Associates, 1986). Dam and reservoir costs total about $121 million, while relocations total another $34 million. Land, which includes mitigation lands, totals about $229 million. The diversion intake, pump station, and pipeline from the Guadalupe River to Cuero II Reservoir adds another $60 million. Annual costs for Cuero II Reservoir are approximately $35.8 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $501/acft/yr ($1.54 per 1,000 gallons).

Figure 3.4.5-6 shows the major conflicts within the conservation pool of Cuero II Reservoir. Potential major conflicts include oil and gas wells, water wells, product transmission pipelines, power transmission lines, and relocation of State Highway 87, as well as several other minor roads. Resolution of facility conflicts represents approximately 8 percent of the total construction cost.
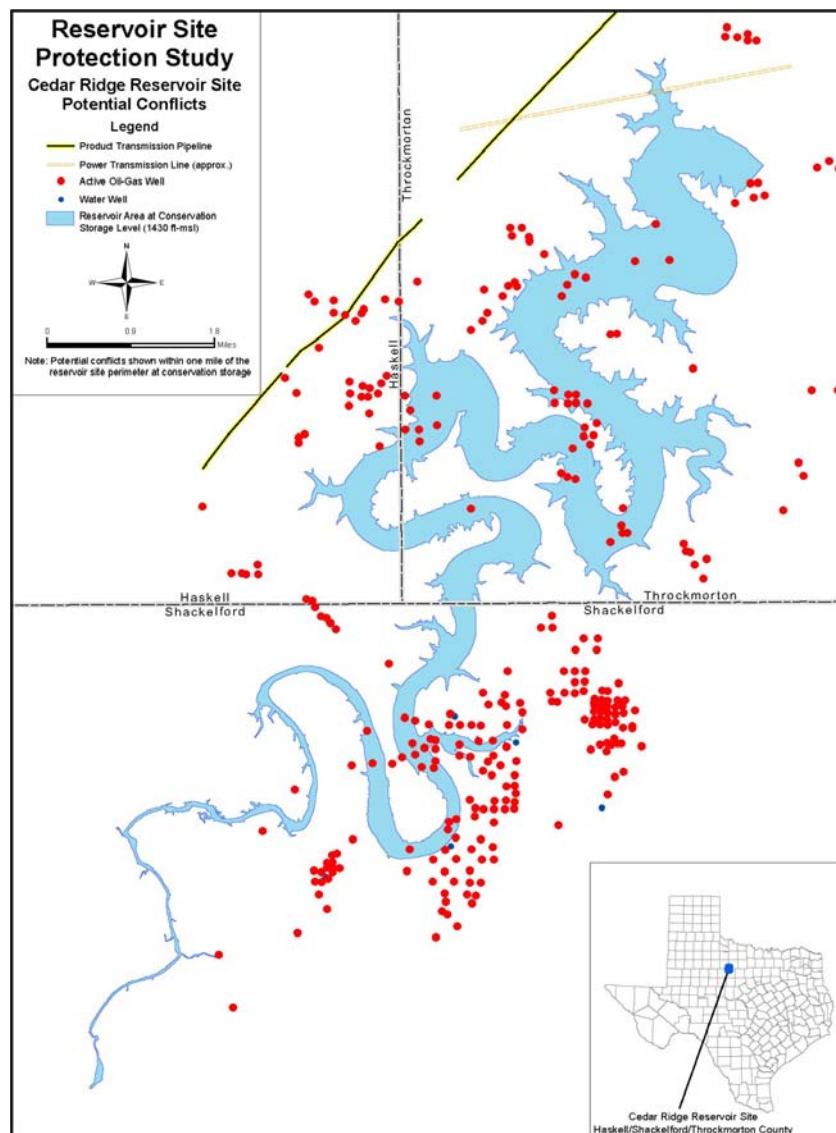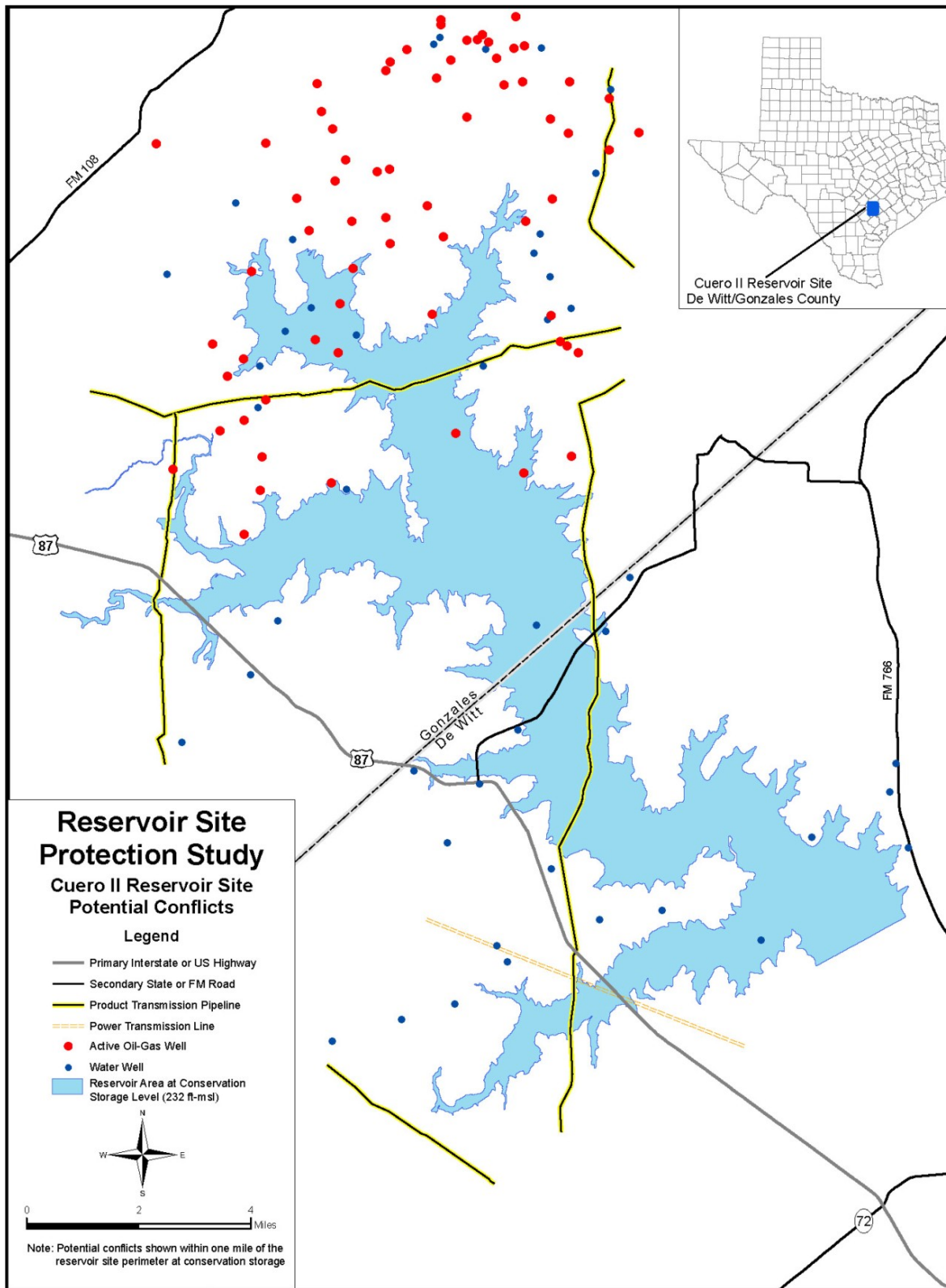
Figure 3.4.5-6. Potential Major Conflicts for Cuero II Reservoir

Table 3.4.5-5.
Cost Estimate — Cuero II Reservoir @ Elevation 232 ft-msl

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Mobilization (5%)		LS		$2,300,329
Clearing and Grubbing	10,066	AC	$4,000	$40,264,000
Care of Water During Construction (1%)		LS		$1,380,197
Random Compacted Fill	2,761,000	CY	$2.50	$6,902,500
Core Compacted Fill (Impervious)	653,500	CY	$3.00	$1,960,500
Soil Cement	112,000	CY	$65.00	$7,280,000
Roller Compacted Concrete	175,831	CY	$75.00	$13,187,325
Mass Concrete	3,891	CY	$150.00	$583,650
Rock Riprap	6,253	SY	$115.00	$719,106
Sand Filter Drain	323,300	CY	$35.00	$11,315,500
Outlet Works Tower and Conduit	1	LS	$2,858,000	$2,858,000
Power Drop	1	LS	$250,000	$250,000
Instrumentation	1	LS	$550,000	$550,000
Spillway Low Flow System	1	LS	$400,000	$400,000
Engineering Contingencies (35%)				$31,482,888
Subtotal Dam & Reservoir				**$121,433,995**
Pump & Pipeline				
Pump Station & Intake (510 MGD)	1	LS	$28,688,730	$28,688,730
Pipeline (2-120-inch)	15,629	LF	$870	$13,597,230
Stilling Basin (786 cfs)	1	LS	$2,377,650	$2,377,650
Engineering Contingencies (35%)				$15,632,264
Subtotal Pump & Pipeline				**$60,295,874**
Conflicts				
Oil & Gas Pipeline	7,597	LF	$48	$364,679
Power Transmission Line	7,170	LF	$450	$3,226,541
Roads	45,322	LF		
Major	18,480	LF	$900	$16,632,000
Minor	26,842	LF	$150	$4,026,271
H20 Drill	4	EA	$25,000	$100,000
H20 Well	14	EA	$25,000	$350,000
Oil & Gas Well	23	EA	$25,000	$575,000
Engineering Contingencies (35%)				$8,846,072
Subtotal Conflicts				**$34,120,564**
Land				
Land Acquisition	36,967	AC	$3,100	$114,597,700
Environmental Studies and Mitigation Lands	36,967	AC	$3,100	$114,597,700
Subtotal Land				**$229,195,400**
CONSTRUCTION TOTAL				**$445,045,832**
Interest During Construction (36 months)				$53,405,500
TOTAL COSTS				**$498,451,332**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$33,127,076
Operations & Maintenance				$2,698,477
Pumping Energy				$3,771,987
Total Annual Costs				**$35,825,553**
Firm Yield (acft/yr)				**71,437**
Unit Costs of Water ($/acft/yr)				**$501**

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

3.4.5.4   Environmental Considerations

Cuero II Reservoir would inundate portions of TCEQ unclassified stream segments 1803A (Elm Creek) and 1803B (Sandies Creek). Neither these segments nor the Guadalupe River near Cuero are listed by Texas Parks and Wildlife Department (TPWD) as Ecologically Significant Stream Segments.

Cuero II Reservoir will inundate 28,154 acres of land at conservation storage capacity. Table 3.4.5-6 and Figure 3.4.5-7 summarize existing landcover for the Cuero II Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (47 percent) with sizeable areas of shrubland (21 percent), broad-leaf evergreen forest (18 percent), and upland deciduous forest (12 percent). Only about 2 percent of the site is classified as bottomland hardwood forest.

Table 3.4.5-6.
Acreage and Percent Landcover for Cuero II Reservoir

| Landcover Classification	Acreage[1]	Percent
Grassland	13,134	46.6%
Shrubland	5,903	20.9%
Broad Leaf Evergreen Forest	5,128	18.2%
Upland Deciduous Forest	3,329	11.8%
Bottomland Hardwood Forest	619	2.2%
Seasonally Flooded Shrubland	65	0.2%
Marsh	34	0.1%
Total	28,212	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
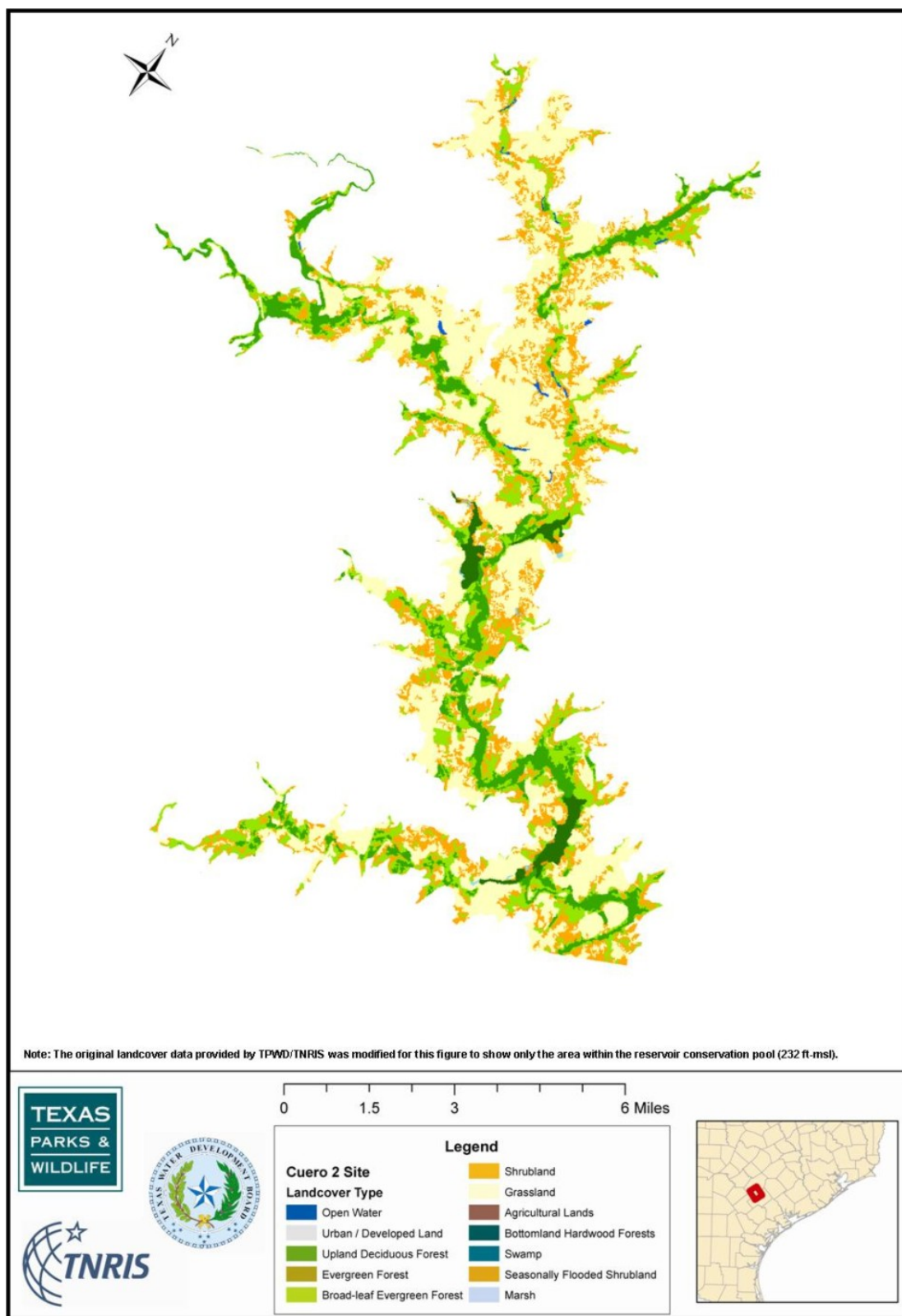
Figure 3.4.5-7. Existing Landcover for Cuero II Reservoir

3.4.6 Fastrill Reservoir (Weches Reservoir)

3.4.6.1 Project Description

The Fastrill Reservoir Project, in Anderson and Cherokee Counties, was first identified and evaluated in the Report on Master Plan for Water Supply Reservoirs prepared for the Upper Neches River Municipal Water Authority in 1961 (Forrest & Cotton, 1961). In this plan, Fastrill Reservoir was identified as one among three potential reservoir projects (including Ponta Reservoir and substantial enlargement of Lake Palestine) for development of new water supplies in the Neches River Basin. The proposed dam location below SH 294, with a conservation storage pool level of 274 ft-msl and flood pool level of approximately 280 ft-msl, is shown in Figure 3.4.6-1.
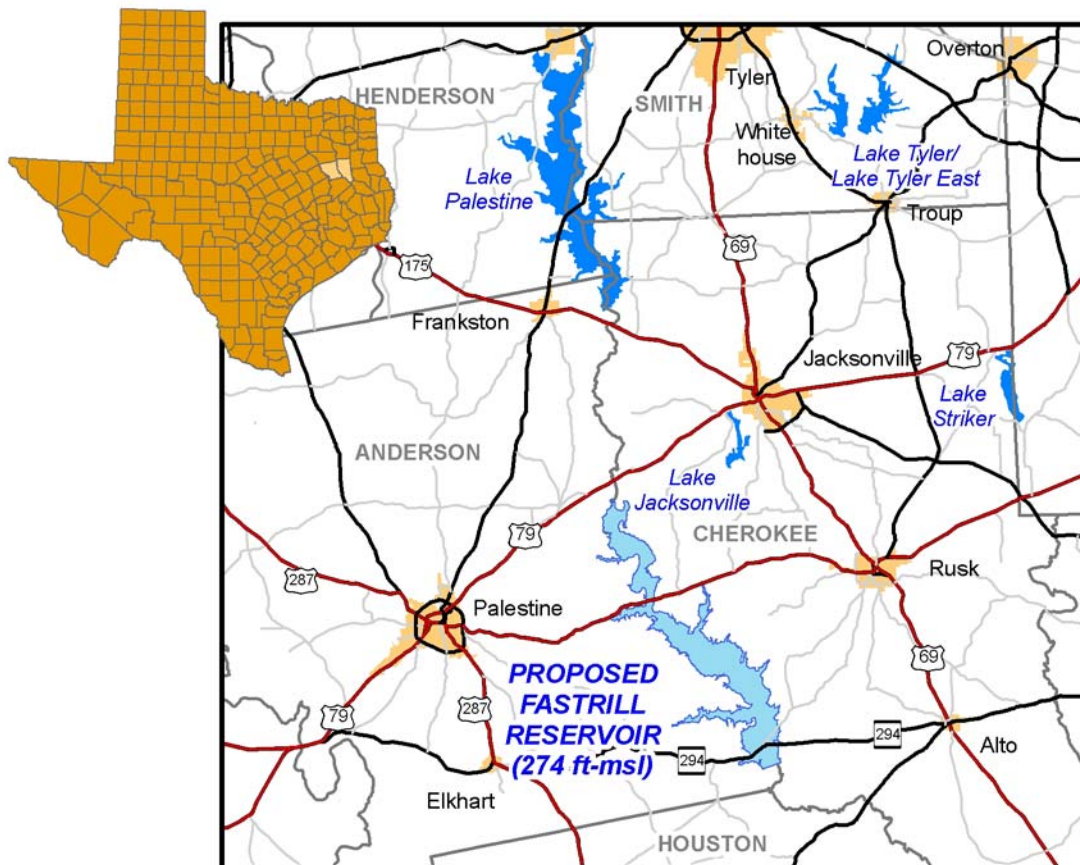
Figure 3.4.6-1. Location Map of Fastrill Reservoir

The Fastrill Reservoir site lies completely within the Weches Reservoir site recommended in the 1968 and 1984 State Water Plans. Although the Weches dam site is about 10 river miles downstream of the Fastrill dam site, available information indicates that the Weches Reservoir, if constructed at the conservation pool elevation once considered (282 ft-msl), would inundate the entire Fastrill Reservoir area. Conservation storage capacity for Weches Reservoir (~1,402,000 acft) was to have been about 2.8 times that of Fastrill Reservoir (~500,000 acft).
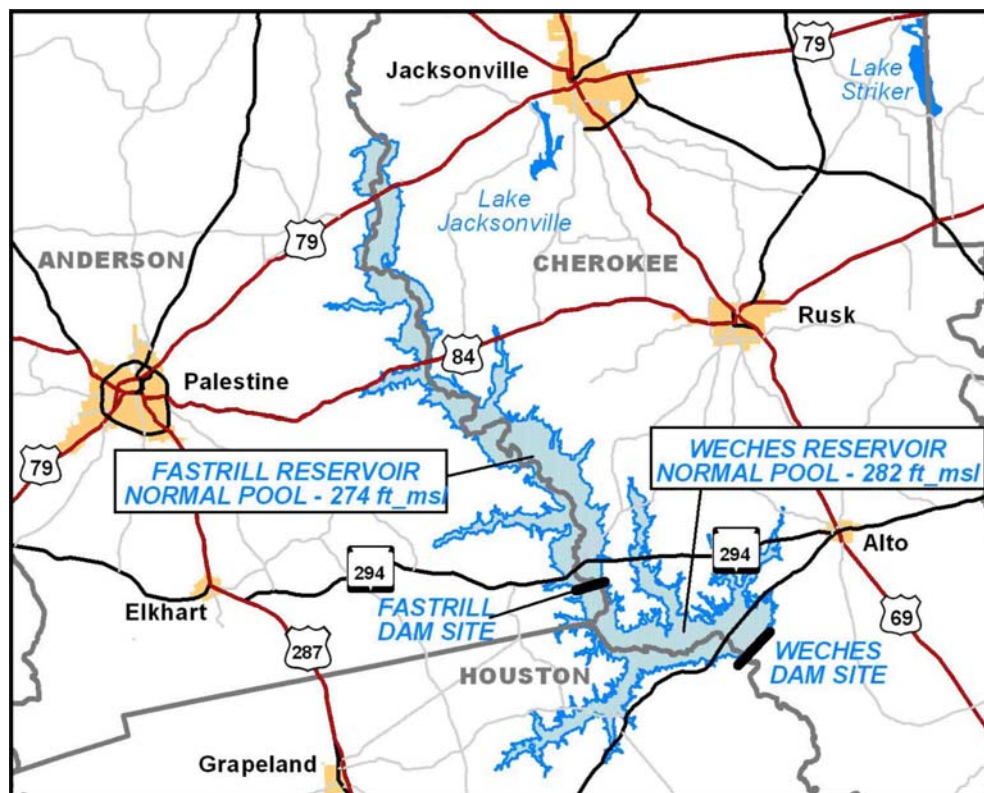
Figure 3.4.6-2. Location Map of Weches Reservoir

With the establishment of regional water planning as part of the process for updating the State Water Plan (pursuant to Senate Bill 1 of the 75th Texas Legislature), Fastrill Reservoir emerged as a potentially feasible project identified in the 2001 East Texas (Region I) Regional Water Plan. In the 2006 Region C Water Plan (approved by the TWDB on April 18, 2006), Fastrill Reservoir is a recommended water management strategy to meet projected needs for Dallas as well as water user groups in Anderson, Cherokee, Henderson, and Smith Counties in Region I. The 2006 Region C Water Plan further recommends Fastrill as a unique site for

reservoir construction citing its location and geologic, hydrologic, topographic, water availability, water quality, and current development characteristics as making it uniquely suited to provide water supply for Region C. The 2006 East Texas Regional Water Plan (approved by the TWDB on May 16, 2006) also recognizes Fastrill Reservoir as an alternative water management strategy to meet projected needs in Region I. The 2007 State Water Plan (TWDB, 2007) includes a recommendation for legislative designation of the Fastrill site as one of unique value for the construction of a reservoir.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply prior to year 2060 total 136,476 acft/yr for counties within a 50-mile radius of the Fastrill Reservoir site. The nearest major population and water demand centers to the Fastrill Reservoir site are Dallas / Fort Worth (127 miles) and Houston (130 miles).

3.4.6.2   Reservoir Yield Analyses

The elevation-area-capacity relationship for Fastrill Reservoir is presented in Figure 3.4.6-3 and Table 3.4.6-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.6-4. Surface areas and capacities associated with 274 ft-msl are computed by linear interpolation between values for 270 ft-msl and 280 ft-msl and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 274 ft-msl, Fastrill Reservoir would inundate 24,948 acres and have a capacity of 503,563 acft.

Table 3.4.6-1.
Elevation-Area-Capacity Relationship for Fastrill Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
219	0	0
220	29	10
230	539	2,318
240	3,614	20,812
250	10,529	88,518
260	15,524	217,977
270	21,134	400,548
274	24,948	503,563
280	30,668	658,086
290	39,247	1,006,781
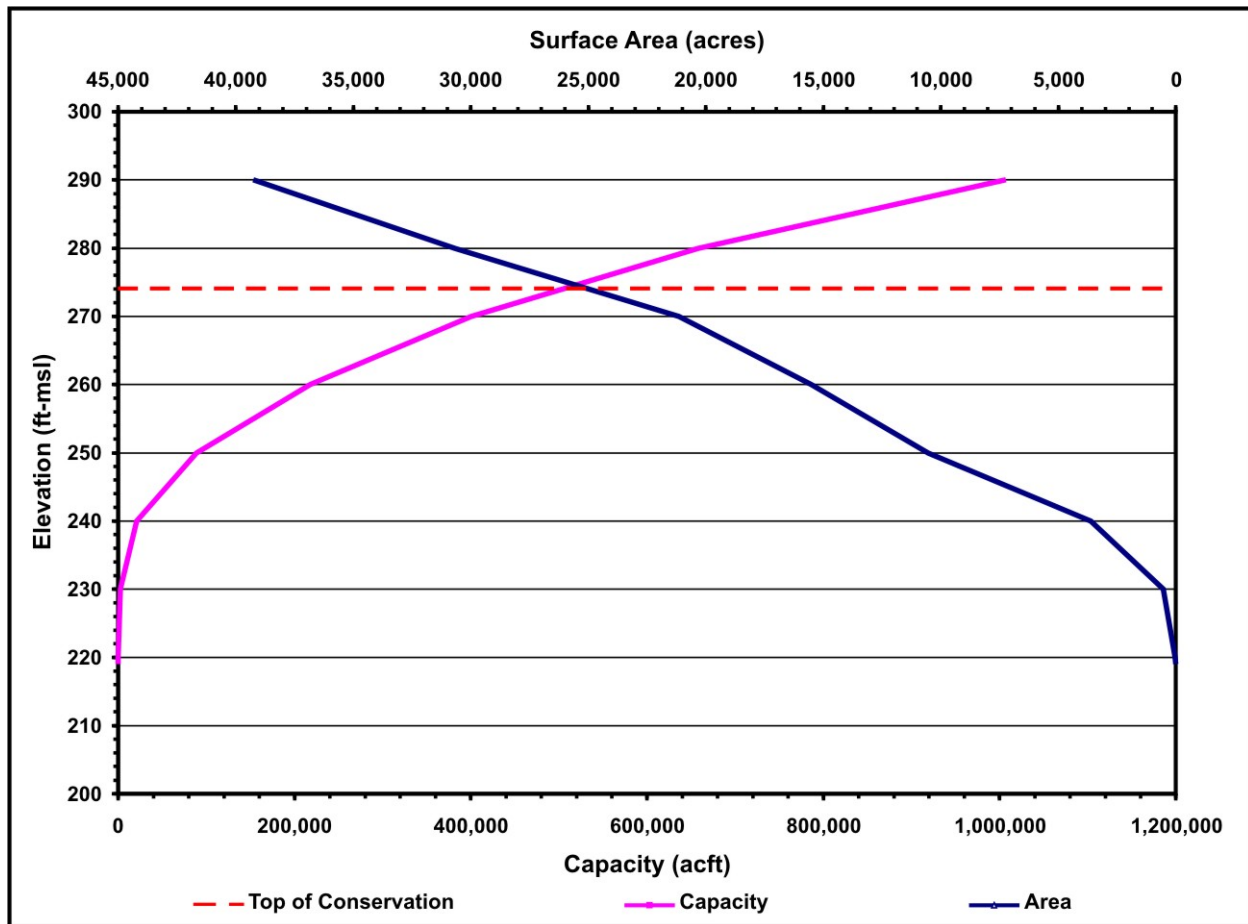
Figure 3.4.6-3. Elevation-Area-Capacity Relationship for Fastrill Reservoir
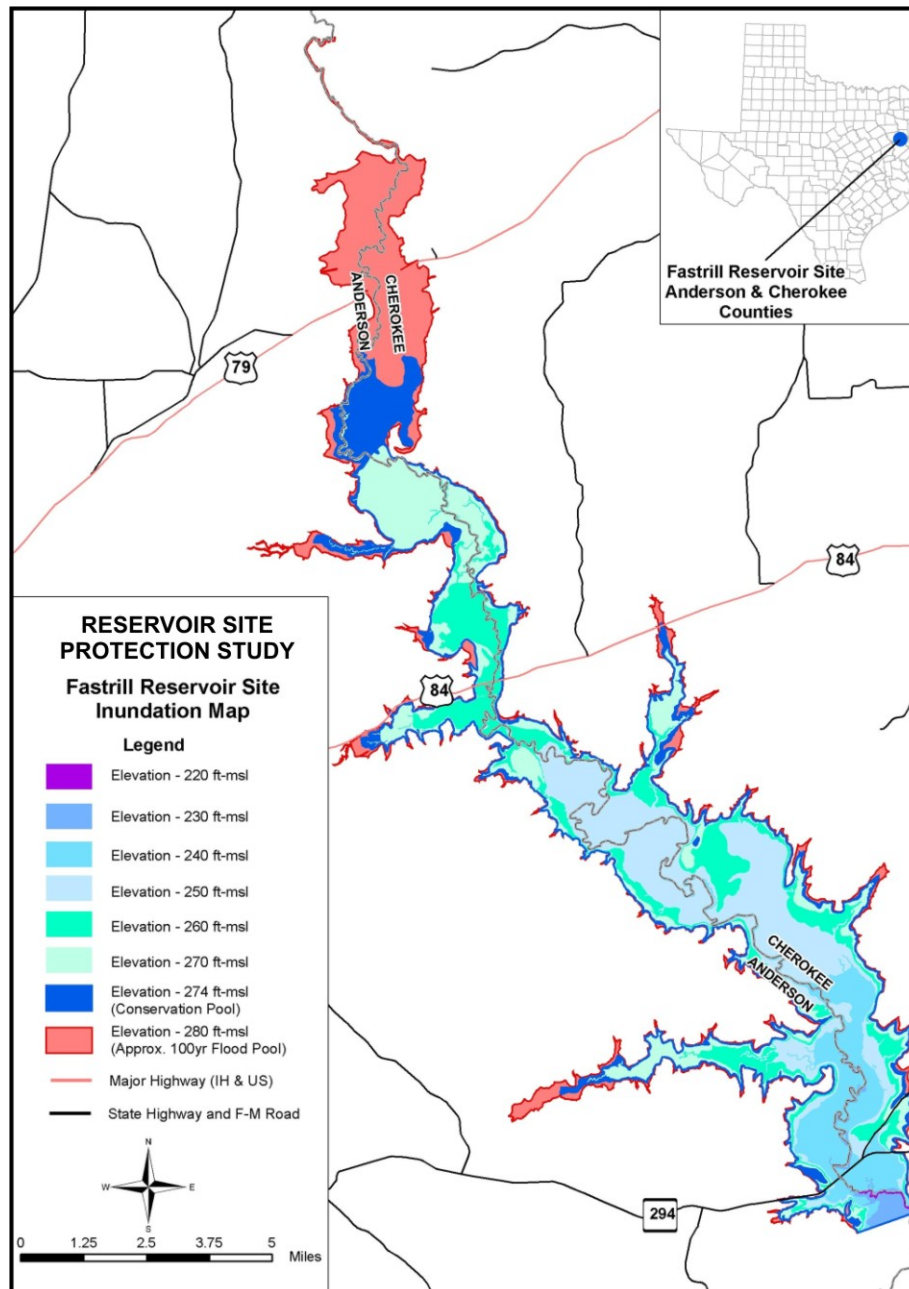
Figure 3.4.6-4. Inundation Map for Fastrill Reservoir

Median and quartile (25th percentile) streamflows have been calculated for the Fastrill Dam site based on monthly naturalized flows from the Neches River Basin Water Availability Model (Neches WAM) (Brown & Root Services, et. al., 2000). These monthly naturalized flows are then disaggregated to daily naturalized flows using historical records of streamflow for the USGS Neches River near Neches gaging station. For each month, daily flows are ranked and

median and quartile flows are then extracted. The natural median and quartile flows for the Fastrill Dam site are presented in Table 3.4.6-2.

Table 3.4.6-2.
Consensus Criteria for Environmental Flow Needs for Fastrill Reservoir

	JAN	*FEB*	*MAR*	*APR*	*MAY*	*JUN*	*JUL*	*AUG*	*SEP*	*OCT*	*NOV*	*DEC*
Median (cfs)	942	1,288	1,347	1,095	1,083	496	161	67	83	139	336	628
Median (acft/mo)	57,920	71,542	82,807	65,132	66,571	29,492	9,930	4,148	4,945	8,551	20,015	38,599
Quartile (cfs)	432	647	636	566	464	205	67	67	67	67	166	313
Quartile (acft/mo)	26,571	35,916	39,124	33,659	28,551	12,218	4,145	4,145	4,011	4,145	9,865	19,267
7Q2 (cfs)	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4	67.4
7Q2 (acft/mo)	4,145	3,744	4,145	4,011	4,145	4,011	4,145	4,145	4,011	4,145	4,011	4,145
Note: The 7Q2 value is used when it exceeds the value of the median and/or quartile.												

The Consensus Criteria for Environmental Flow Needs (CCEFN) (TWDB, August 1997), a three-staged criteria that uses percentage of reservoir capacity as a trigger for determining the pass-through requirement, is used for the modeling of Fastrill Reservoir. Pass-through flows are the monthly naturalized median flow when reservoir storage is greater than 80 percent of capacity, the monthly naturalized 25th percentile flow when the reservoir is between 50 and 80 percent of capacity, and the published 7Q2 when reservoir capacity is less than 50 percent of conservation capacity. The CCEFN values used include the median and quartile flows in Table 3.4.6-2 and the 7Q2 value of 67.4 cfs published in the Texas Surface Water Quality Standards. Fastrill Reservoir is located well in excess of 200 river miles from the coast, therefore freshwater inflow needs for bays and estuaries are not explicitly considered herein, but are assumed to be sufficiently addressed by CCEFN.

The firm yield of Fastrill Reservoir is estimated by using the TCEQ Neches WAM data sets and a modified version of the Water Rights Analysis Package (WRAP) (TCEQ, 2004) which specifically incorporates the special condition in Certificate of Adjudication No. 06-4411 regarding subordination of the BA Steinhagen - Sam Rayburn Reservoir System.   A Daily Operations Model (DOM) developed by HDR is used to determine the monthly pass-through amounts to meet environmental flow requirements for Fastrill Reservoir subject to CCEFN. The DOM uses monthly inflow and availability quantities from the Neches WAM to determine the flow to be passed for downstream senior water rights.   The total monthly inflow is then

distributed to daily values using historical data from nearby streamflow gages. The daily pass-through for senior water rights is determined through an iterative calculation and is taken uniformly throughout the month to the extent that sufficient inflow occurs on a daily basis. Next, the daily pass-through required for downstream senior water rights is compared to the environmental flow pass-through requirement. The greater of the two becomes the daily pass-through amount. An alternative pass-through amount is calculated for each of three potential reservoir storage zones defined by percentage of capacity. Finally, daily pass-through amounts are summed to a time-series of monthly pass-through amounts and added to the Neches WAM data file.

The firm yield of Fastrill Reservoir is calculated using the Neches WAM. The Neches WAM simulates a repeat of the natural streamflows over the 57-year period of 1940 through 1996 accounting for the appropriated water rights of the Neches River Basin with respect to location, priority date, diversion amount, diversion pattern, storage, and special conditions including instream flow requirements.

Four potential conservation storage capacities are modeled for Fastrill Reservoir. These conservation storage capacities are associated with 280 ft-msl, 274 ft-msl, 270 ft-msl, and 265 ft-msl conservation pool elevations. Table 3.4.6-3 includes the conservation storage capacities associated with these four conservation elevations.

For the purposes of this study, Fastrill Reservoir is modeled as an independent reservoir, not relying upon makeup water from Lake Palestine. Fastrill Reservoir is simulated with a junior priority date, independent of Lake Palestine. Firm yield estimates for Fastrill Reservoir for all four conservation pool elevations are shown in Table 3.4.6-3. Current planning initiatives envision a conservation elevation of 274 ft-msl for Fastrill Reservoir, thereby yielding a firm water supply of 134,038 acft/yr. For comparison purposes, the firm yield of Fastrill Reservoir at conservation elevation 274 ft-msl without an environmental flow requirement is 179,441 acft/yr, meaning that about 45,000 acft/yr (25 percent) of the firm yield potential of Fastrill Reservoir is dedicated to environmental flows. Figure 3.4.6-5 shows the relationship between firm yield and conservation capacity for Fastrill Reservoir.

In a recent study for the Upper Neches River Municipal Water Authority (UNRMWA) and the City of Dallas (HDR, September 2006), the firm yield of Fastrill Reservoir under an independent operations scenario was reported as 137,843 acft/yr at conservation elevation 274 ft-msl. The firm yield estimate in the current study is less than that in the September 2006 study in

that the September 2006 study because treated effluent discharges upstream of Lake Palestine and Fastrill Reservoir have been excluded.
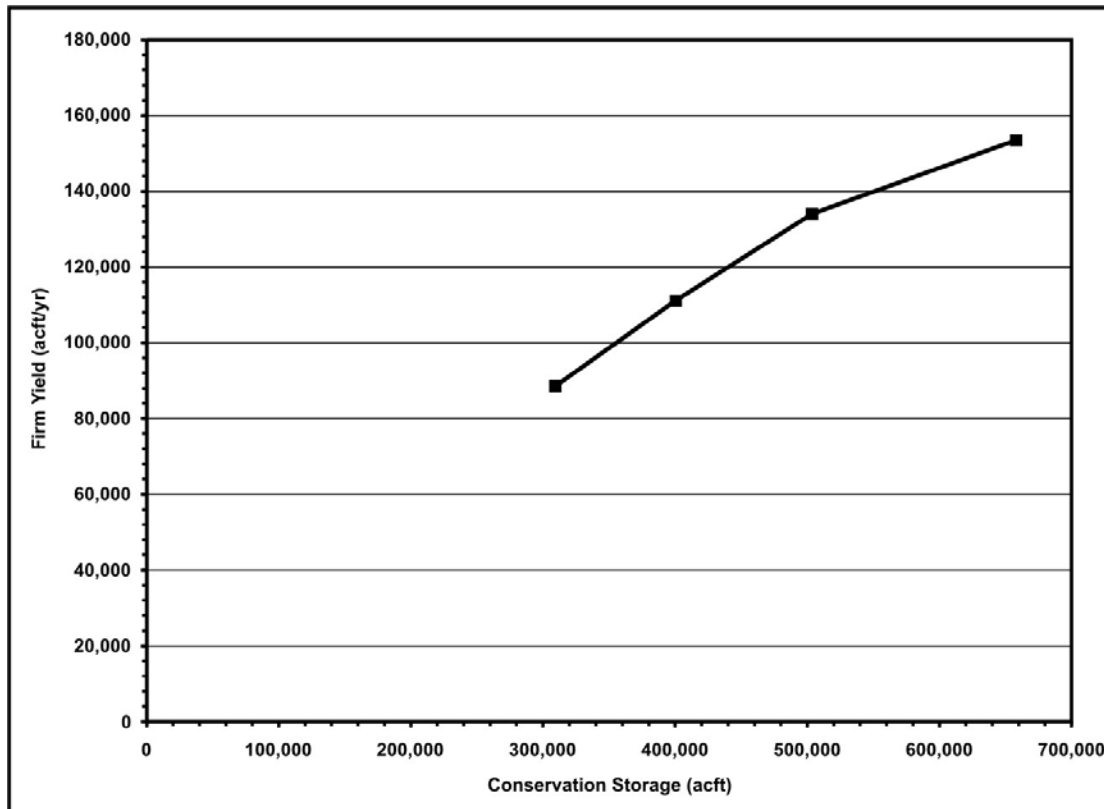
Figure 3.4.6-5. Firm Yield vs. Conservation Storage for Fastrill Reservoir

Table 3.4.6-3.
Firm Yield vs. Conservation Storage for Fastrill Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)
265.0	309,263	CCEFN	88,589
270.0	400,548	CCEFN	111,097
274.0*	503,563	CCEFN	134,038
		None	179,441
280.0	658,086	CCEFN	153,476
*Proposed conservation storage.			

Figure 3.4.6-6 illustrates storage fluctuations through time for Fastrill Reservoir under independent operations subject to firm yield diversions and CCEFN. The reservoir storage frequency curve in Figure 3.4.6-6 indicates that the reservoir would be full about 13 percent of the time and more than half full about 80 percent of the time.
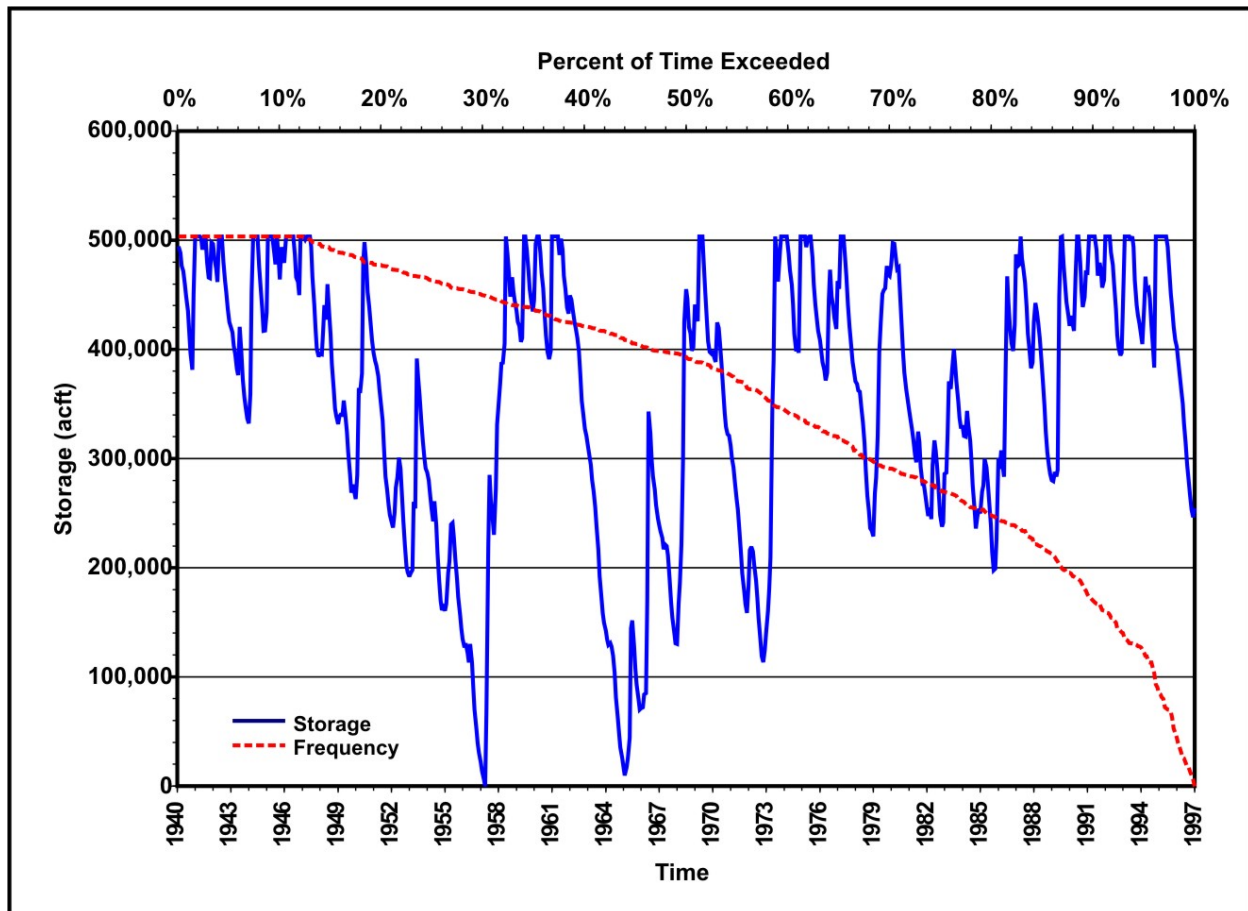
Figure 3.4.6-6. Simulated Storage in Fastrill Reservoir
(Conservation Elevation = 274 ft-msl, Diversion = 134,038 acft/yr)

3.4.6.3   *Reservoir Project Cost Estimates*

The geology at the Fastrill Reservoir dam site is conducive to an earthfill dam similar in nature to the existing Blackburn Crossing Dam, which impounds Lake Palestine. More specifically, a zoned earthfill dam that maximizes the use of locally available materials is proposed to impound Fastrill Reservoir. The length of the dam is estimated at approximately 6,800 feet with a maximum height of 74.4 feet. The service spillway would include a gated intake tower, two 72-inch conduits through the dam, and a conventional St. Anthony Falls outlet

structure. Flood flows would be passed through a 700-foot wide, uncontrolled, concrete ogee emergency spillway.

Figure 3.4.6-7 shows the major conflicts within the conservation pool of Fastrill Reservoir. Potential conflicts include three major roadways (SH 294, US 84, and US 79), minor roadways, two railways (including the Texas State Railroad), power transmission lines, a natural gas pipeline, and oil and gas wells. Resolution of facility conflicts represents approximately 32 percent of the total capital cost.
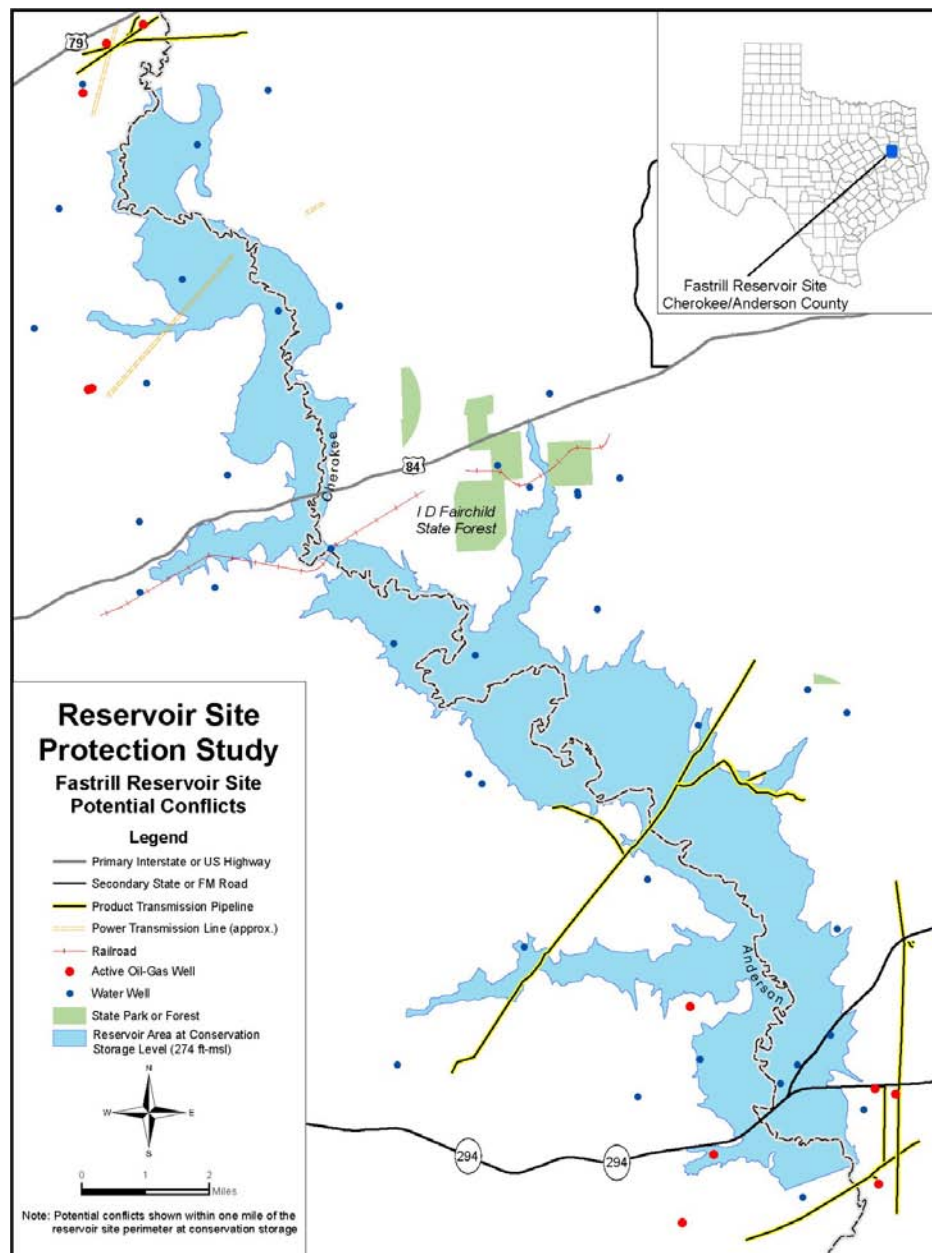
Figure 3.4.6-7. Potential Major Conflicts for Fastrill Reservoir

A summary cost estimate for Fastrill Reservoir at elevation 274 ft-msl is shown in Table 3.4.6-4. Quantities and relocation costs are based upon detailed information from the Fastrill Reservoir Preliminary Yield & Feasibility Study (HDR, September 2006). Dam and reservoir costs total about $56 million, while relocations total another $93.5 million. Land, which includes mitigation lands, totals about $112 million. Annual costs for Fastrill Reservoir are approximately $20.3 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $152/acft ($0.47 per 1,000 gallons).

Table 3.4.6-4.
Cost Estimate – Fastrill Reservoir @ Elevation 274 ft-msl
(page 1 of 2)

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Mobilization (5%)	1	LS		$1,907,907
Clearing and Grubbing	78	AC	$4,000	$310,771
Care of Water During Construction (3%)	1	LS		$1,144,744
Required Excavation	176,679	CY	$2.50	$441,698
Random Compacted Fill	2,471,688	CY	$2.50	$6,179,219
Core Compacted Fill (Impervious)	1,109,594	CY	$3.00	$3,328,782
Soil Bentonite Slurry Trench	379,500	SF	$15.00	$5,692,493
Soil Cement	156,173	CY	$65.00	$10,151,223
Reinforced Concrete	21,033	CY	$400.00	$8,413,032
Gates Hoist and Operating System	1	EA	$250,000	$250,000
Spillway Bridge	199	LF	$1,300	$258,960
Flex Base Roadway	4,264	SY	$20.00	$85,282
Sand Filter Drain	75,218	CY	$35.00	$2,632,633
Grassing	39	AC	$4,500	$174,808
Instrumentation	1	LS	$550,000	$550,000
Engineering Contingencies (35%)				<u>$14,532,543</u>
Subtotal Dam & Reservoir				**$56,054,095**
Conflicts				
Existing Structures	22	EA	$50,000	$1,100,000
Roadways				
FM 23	1	LS		$2,075,000
SH 294	1	LS		$12,484,000
US 84	1	LS		$8,243,000
US 79	1	LS		$5,490,000
Railways				
Texas State RR	1	LS		$16,294,000
Missouri Pacific RR	1	LS		$13,267,000
Power Transmission	1	LS		$3,562,000

Table 3.4.6-4.
Cost Estimates – Fastrill Reservoir @ Elevation 274 ft-msl
(page 2 of 2)

Natural Gas Lines				
6.63"	5,600	LF		$560,000
16"	6,300	LF		$1,260,000
10.75"	18,100	LF		$3,620,000
Oil & Gas Wells	54	EA	$25,000	$1,350,000
Engineering Contingencies (35%)				<u>$24,256,750</u>
Subtotal Conflicts				**$93,561,750**
Land				
Land Acquisition	30,668	AC	$1,825	$55,969,100
Environmental Studies and Mitigation Lands	30,668	AC	$1,825	<u>$55,969,100</u>
Subtotal Land				**$111,938,200**
CONSTRUCTION TOTAL				**$261,554,045**
Interest During Construction (36 months)				$31,386,485
TOTAL COSTS				**$292,940,530**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$19,468,828
Operations & Maintenance				<u>$840,811</u>
Total Annual Costs				**$20,309,639**
Firm Yield (acft/yr)				**134,038**
Unit Costs of Water ($/acft/yr)				**$152**
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.				

3.4.6.4   *Environmental Considerations*

Fastrill Reservoir would inundate a portion of TCEQ classified stream segment 0604. Texas Parks and Wildlife Department (TPWD, 1999) listed the entire length of the Neches River below Lake Palestine as ecologically significant. Inundation by or operations of Fastrill Reservoir could have effects relevant to three TPWD criteria, as follows:

(1) <u>Biological Function</u> — Texas Natural Rivers System nominee for outstandingly remarkable fish and wildlife values; priority bottomland hardwood habitat displays significant overall habitat value

(2) <u>High Water Quality/Exceptional Aquatic Life/High Aesthetic Value</u> — National Forest Service wilderness-type area, exceptional aesthetic value

(3) <u>Threatened or Endangered Species/Unique Communities</u> — unique, exemplary, and unusually extensive natural community; Paddlefish; Creek chubsucker, Blue sucker; Neches River rose-mallow

Fastrill Reservoir will inundate 24,948 acres of land at conservation storage capacity. Table 3.4.6-5 and Figure 3.4.6-8 summarize existing landcover for the Fastrill Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by bottomland hardwood forest (32 percent) with sizeable areas of evergreen forest (21.5 percent), and upland deciduous forest (18 percent). Marsh, swamp, and open water total about 12 percent of the reservoir area.
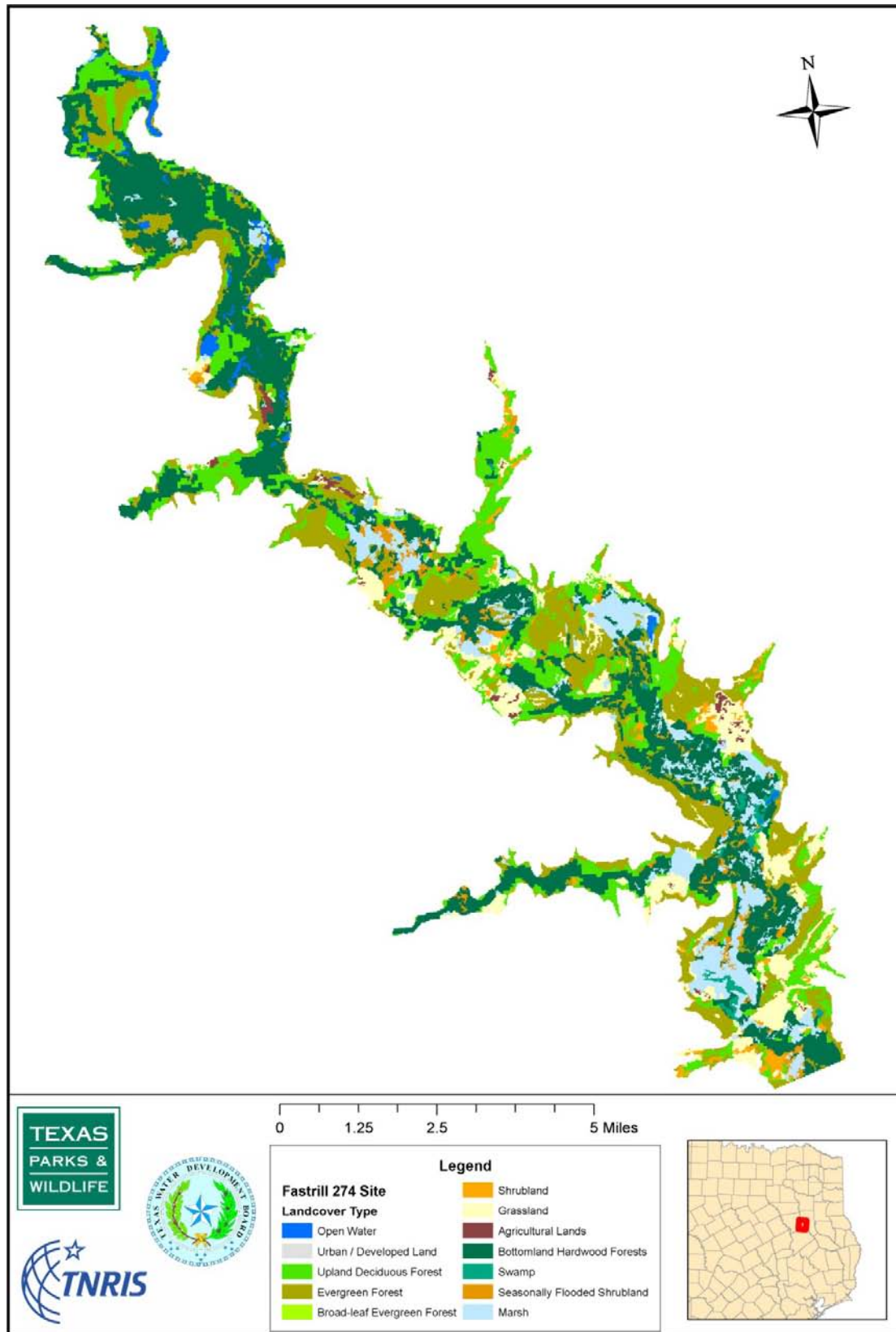
Figure 3.4.6-8. Existing Landcover for Fastrill Reservoir

Table 3.4.6-5.
Acreage and Percent Landcover for Fastrill Reservoir

Landcover Classification	Acreage[1]	Percent
Bottomland Hardwood Forest	7,781	32.2%
Evergreen Forest	5,202	21.5%
Upland Deciduous Forest	4,432	18.3%
Grassland	2,446	10.1%
Marsh	2,377	9.8%
Shrubland	562	2.3%
Seasonally Flooded Shrubland	554	2.3%
Open Water	410	1.7%
Swamp	224	0.9%
Agricultural Land	213	0.9%
Total	24,201	100%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		

The U.S. Fish & Wildlife Service (USFWS) has formally created the Neches River National Wildlife Refuge (NRNWR) with the purposes of protecting habitat for migratory birds, bottomland hardwood forests, and wetlands and providing for compatible wildlife-dependent recreation opportunities (US Fish & Wildlife Service, March 2005). The NRNWR includes a segment of the Neches River and its floodplain as well as surrounding upland areas that are coincident with the proposed location of Fastrill Reservoir. This refuge site was one among 14 Priority 1 sites identified by the USFWS in their Texas Bottomland Hardwood Preservation Program report (USFWS, May 1985). Priority 1 areas are considered to be excellent quality bottomlands and high value to key waterfowl species including mallards and wood ducks.   The Fastrill Reservoir site is also located immediately upstream of a Priority 1 site bottomland preservation site identified as Middle Neches River (N-4).

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3.4.7 Lower Bois d'Arc Creek Reservoir

3.4.7.1 *Description*

Lower Bois d'Arc Creek Reservoir is a proposed reservoir on Bois d'Arc Creek, a tributary of the Red River. Figure 3.4.7-1 shows the location of the project, which is in Fannin County in North-Central Texas. A reservoir at this site (then called the Bonham Reservoir) was included in the Red River Compact (Red River Compact Commission, 1979). The project has been studied previously for the Red River Authority and the North Texas Municipal Water District (Freese and Nichols, 1984 and 1996) and was recommended as a water supply for the North Texas Municipal Water District in the 2001 and 2006 Region C Water Plans (Freese and Nichols et al., 2001 and 2006a) and the 2002 and 2007 Texas State Water Plan (Texas Water Development Board, 2002 and 2006).
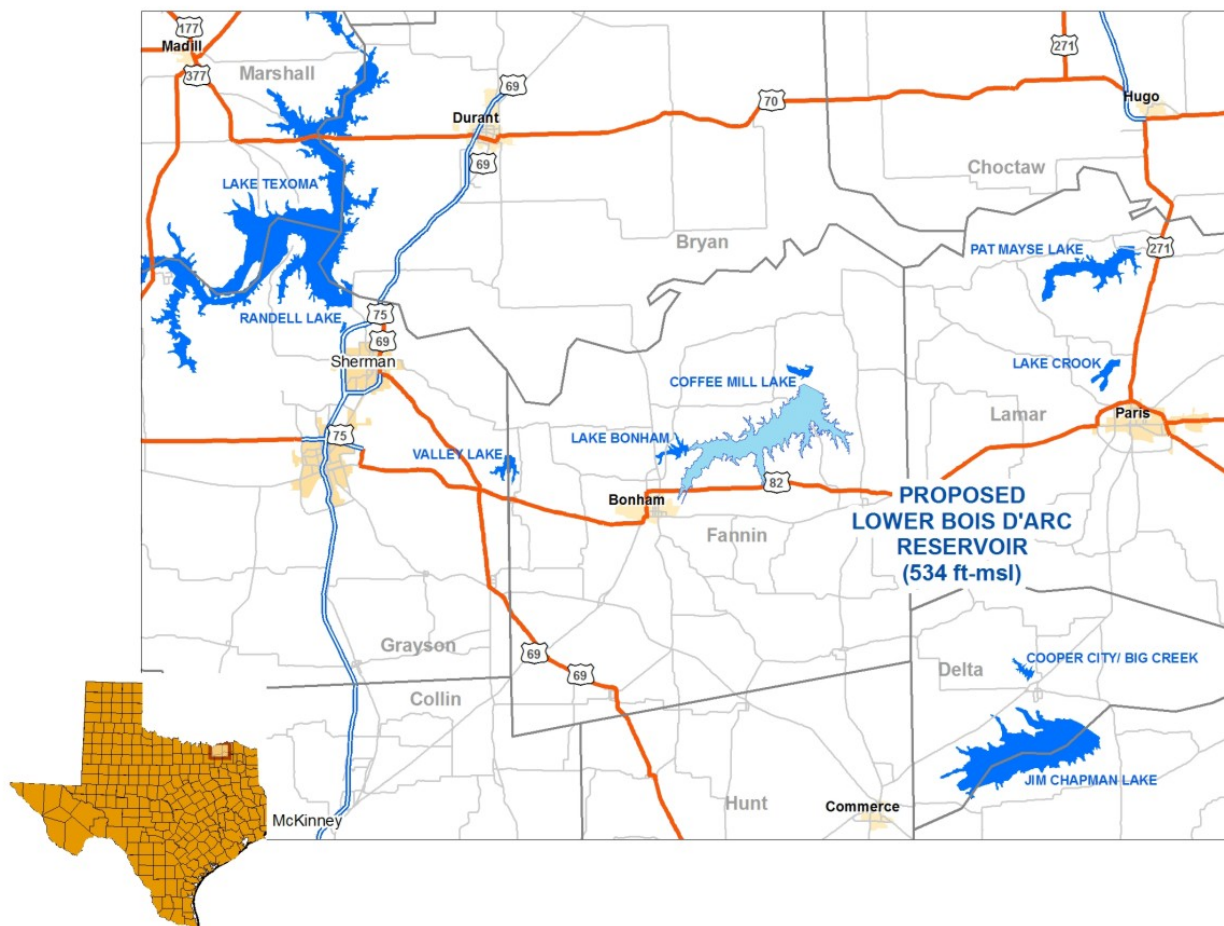
Figure 3.4.7-1. Location Map of Lower Bois d'Arc Creek Reservoir

Lower Bois d'Arc Creek Reservoir is recommended as a unique reservoir site in both the 2001 and 2006 Region C Water Plans. The reservoir is planned to provide water to the North Texas Municipal Water District, which serves water to customers over an eight-county area in north central Texas. The projected needs of the District for additional supply are 113,000 acft/yr in 2010, increasing to over 545,000 acft/yr by 2060 (Freese and Nichols et al, 2006a). The projected needs for additional water supply within 50 miles of the proposed reservoir site by 2060 are 728,028 acft/yr. The nearest major demand center is the Dallas-Fort Worth area, which is located approximately 60 miles southwest of the reservoir site.

3.4.7.2   *Reservoir Yield Analysis*

The reservoir area capacity data was developed from USGS topographic data and aerial photography that was flown in March 2004. The aerial photography provided 2-foot contour data at the reservoir site up to elevation 540 ft-msl. Table 3.4.7-1 shows the area-capacity-elevation (ACE) data for Lower Bois d'Arc Creek Reservoir. Figures 3.4.7-2 and 3.4.7-3 show the ACE curves and inundation at 10-foot contours.

The firm yields for Lower Bois d'Arc Creek Reservoir were performed using a modified version of the February 8, 2006 Red River WAM (Espey et al. 2002 and TCEQ 2006) Yields were calculated at elevations 530, 534, 536, and 538 ft-msl. The conservation elevation for the proposed reservoir is 534 ft-msl. The yield at this elevation is 126,280 acft/yr.

The hydrology at the Lower Bois d'Arc Creek dam site was calculated outside the WAM and input directly to the model. This adjustment was made because the original WAM underestimates the flows in the Bois d'Arc Creek watershed. From December 1962 to September 1985, the USGS operated the Bois d'Arc Creek near Randolph gage, which measured flows from about 22 percent of the proposed reservoir watershed. There were no known diversions or return flows above this gage, so the flows are representative of natural conditions. A recent study of the proposed reservoir compared these historical flows to naturalized flows in adjacent watersheds (Freese and Nichols, 2006b). This study concluded that naturalized flows in the Sulphur River Basin were probably a better estimator of flows in the Bois d'Arc Creek watershed than incremental flows in the main stem of the Red River, which is the default method used in the TCEQ Red River WAM. The study recommended adding a new primary control

Table 3.4.7-1.
Elevation-Area-Capacity Relationship for Lower Bois d'Arc Creek Reservoir

Elevation (feet)	Area (acre)	Capacity (acft)
464.0	5	4
470.0	19	76
480.0	378	1,197
490.0	2,001	15,109
500.0	4,288	50,684
510.0	6,987	99,108
520.0	10,601	180,995
530.0	14,724	302,570
534.0	16,526	367,609
540.0	19,616	467,767
550.0	23,967	678,337
560.0	29,670	954,617
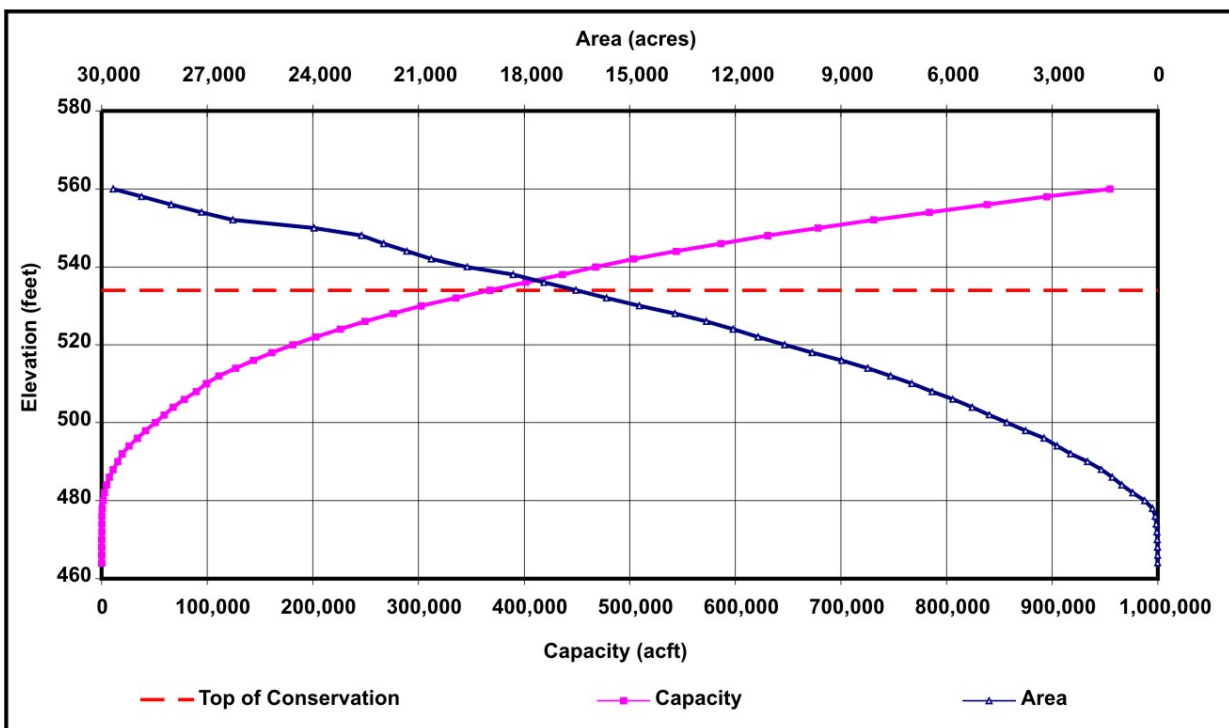
Figure 3.4.7-2. Elevation-Area-Capacity Relationship for
Lower Bois d'Arc Creek Reservoir
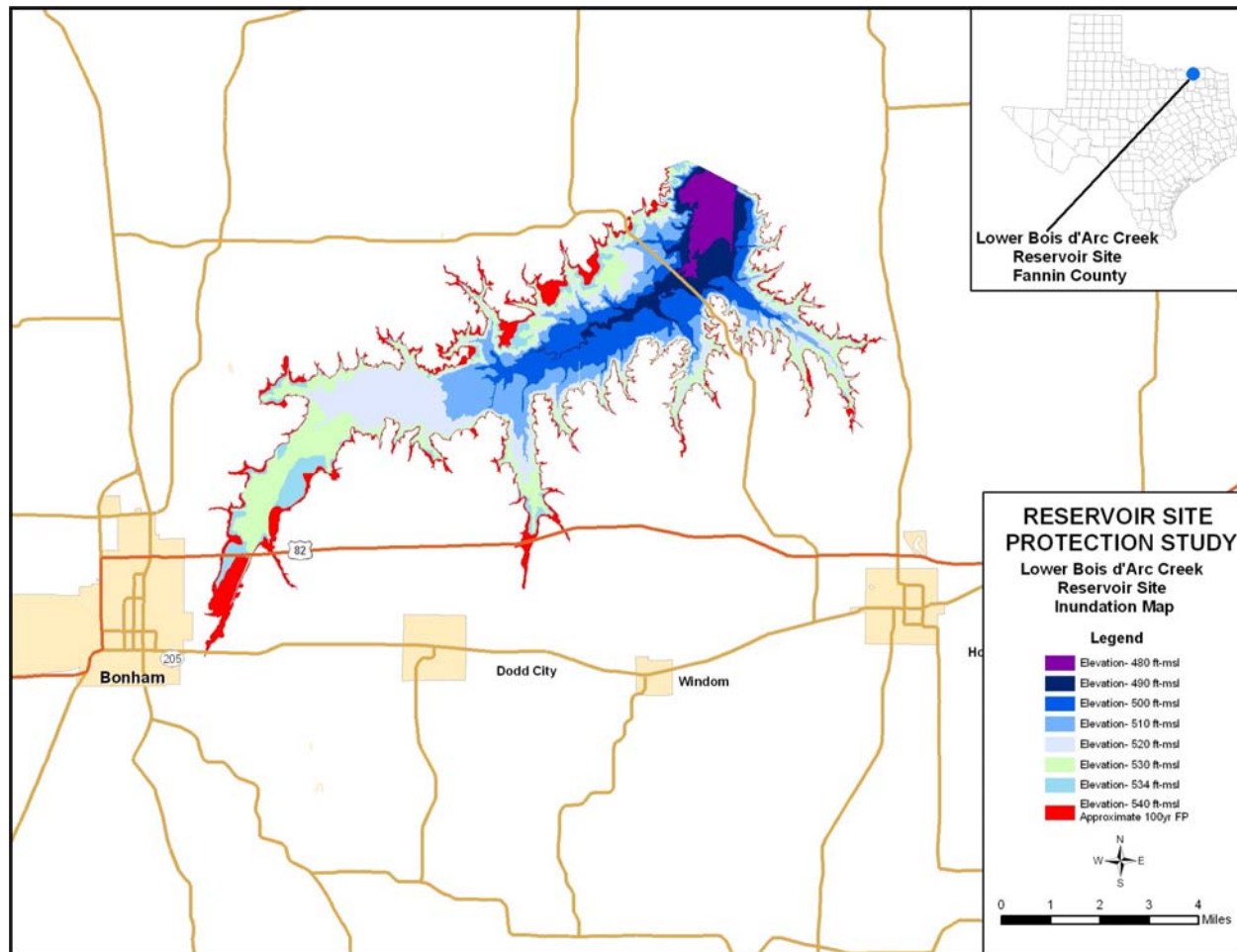
Figure 3.4.7-3. Inundation Map for Lower Bois d'Arc Creek Reservoir

point at the proposed reservoir site using flows based on data from the Randolph gage on Bois d'Arc Creek and naturalized flows in the Sulphur Basin. This method was adopted for the current yield evaluations. More information can be found in the *Report Supporting an Application for a Texas Water Right for Lower Bois d'Arc Creek Reservoir* (Freese and Nichols, 2006b).

For the hydrologic analyses, a new control point was added to the Red River WAM between secondary control points X10200 and X10260. This control point has a drainage area of 327 square miles. A standard firm yield was calculated assuming that water was passed to downstream senior water rights as determined in the WAM Run 3.

The yield studies used the Consensus Criteria for Environmental Flow Needs (CCEFN) bypass criteria developed in the 2006 study of the reservoir. The CCEFN criteria may be found

in Table 3.4.7-2. At the recommended conservation elevation, the bypass criteria reduce the yield of the reservoir by 880 acft/yr.

Table 3.4.7-2.
Consensus Criteria for Environmental Flow Needs for Lower Bois d'Arc Creek Reservoir

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Median	acft/mo	1,568	2,515	2,348	1,873	1,779	706	105	12	30	103	467	1,201
	cfs	25.5	44.9	38.2	31.5	28.9	11.9	1.7	0.2	0.5	1.7	7.8	19.5
25th	acft/mo	447	884	827	664	520	100	4	0	0	0	47	144
	cfs	7.3	15.8	13.4	11.2	8.5	1.7	0.1	0.0	0.0	0.0	0.8	2.3
7Q2	acft/mo	0	0	0	0	0	0	0	0	0	0	0	0

Table 3.4.7-3 and Figure 3.4.7-4 show the results of the yield studies. Note that in Figure 3.4.7-4 the yield of the reservoir per acre-foot of increased conservation storage is higher at a conservation elevation of 538 feet. However, the proposed reservoir is immediately downstream of Lake Bonham and the City of Bonham. Increasing the elevation of the reservoir would impact the existing dam for Lake Bonham and increase the potential for flooding in the City of Bonham. The storage trace for the recommended conservation pool elevation and the storage frequency curve are shown in Figure 3.4.7-5. This figure shows that at the proposed conservation elevation of 534 feet, the reservoir would be full about 13 percent of the time and below 50 percent full (183,805 acft) less than 20 percent of the months.

Table 3.4.7-3.
Firm Yield vs. Conservation Storage for Lower Bois d'Arc Creek Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)	Critical Period
530.0	302,570	CCEFN	117,190	7/75 - 8/80
534.0*	367,609	CCEFN	126,280	7/75 - 2/81
		None	127,160	7/75 - 2/81
536.0	401,647	CCEFN	130,820	7/75 - 2/81
538.0	436,333	CCEFN	139,570	7/51 - 2/57
*Proposed conservation storage.				
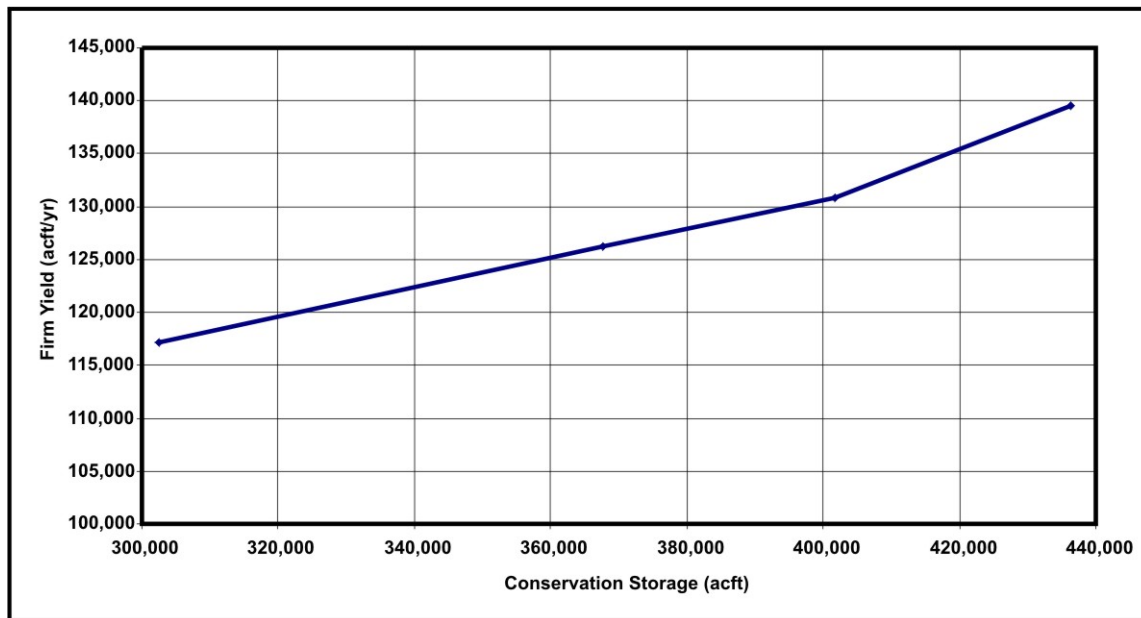
Figure 3.4.7-4. Firm Yield vs. Conservation Storage for Lower Bois d'Arc Creek Reservoir

3.4.7.3   Reservoir Costs

Costs for the Lower Bois d'Arc Creek Reservoir Dam assume a zoned earthen embankment and uncontrolled spillway. The length of the dam is estimated at 10,400 feet with a maximum height of 90 feet. The service spillway would include an approach channel; a 150-foot uncontrolled concrete weir, chute, hydraulic jump stilling basin, and outlet channel.
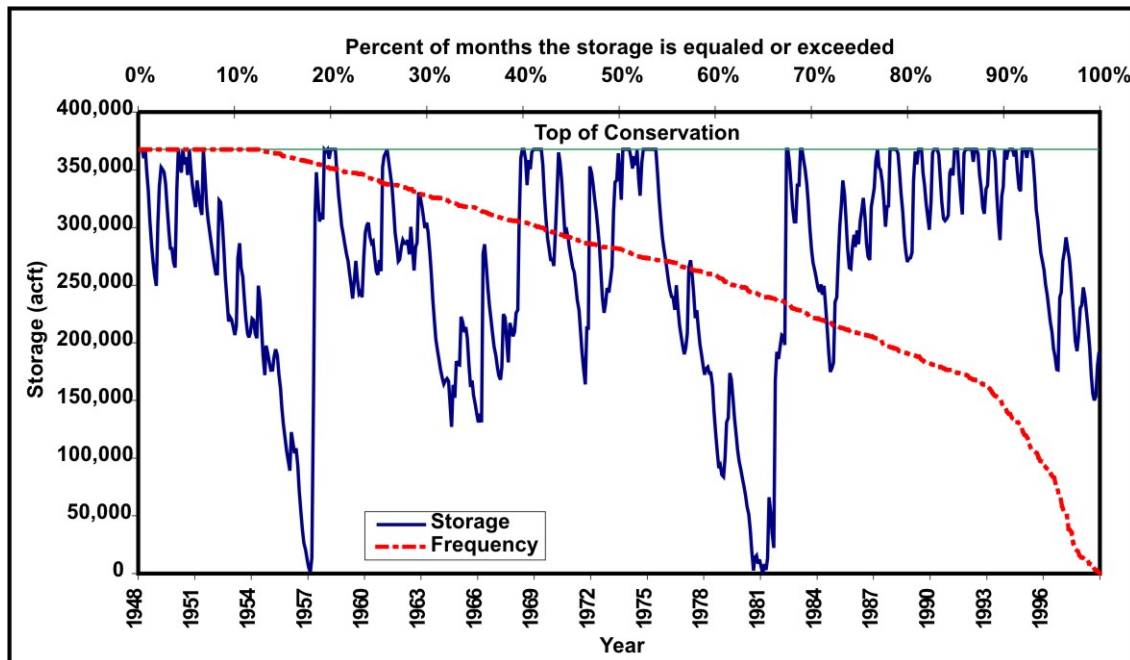
***Figure 3.4.7-5. Simulated Storage in Lower Bois d'Arc Creek Reservoir
(Conservation Elevation = 534 ft-msl, Diversion = 126,280 acft/yr)***

Conflicts identified at the site include a cemetery, electrical lines, several roads (including U.S. Highway 82 and F.M. 1396), a 10-inch gas line and several other structures. A list of the potential conflicts is provided in Table 3.4.7-4. In addition to these conflicts, the cost estimate includes protection of the downstream slope of the Lake Bonham Dam, which will abut the upper reaches of the Lower Bois d'Arc Creek Reservoir. Costs for these conflict resolutions were developed from data provided by TNRIS and from the study report in support of the water right permit application for Lower Bois d'Arc Creek Reservoir (Freese and Nichols, 2006b). The conflict costs represent less than 10 percent of the total construction cost of the reservoir project. Figure 3.4.7-6 shows the conflicts as mapped by TNRIS.

Table 3.4.7-4.
List of Potential Conflicts for Lower Bois d'Arc Creek Reservoir

Gas Pipeline	Power Transmission Lines
Roads	Cemetery
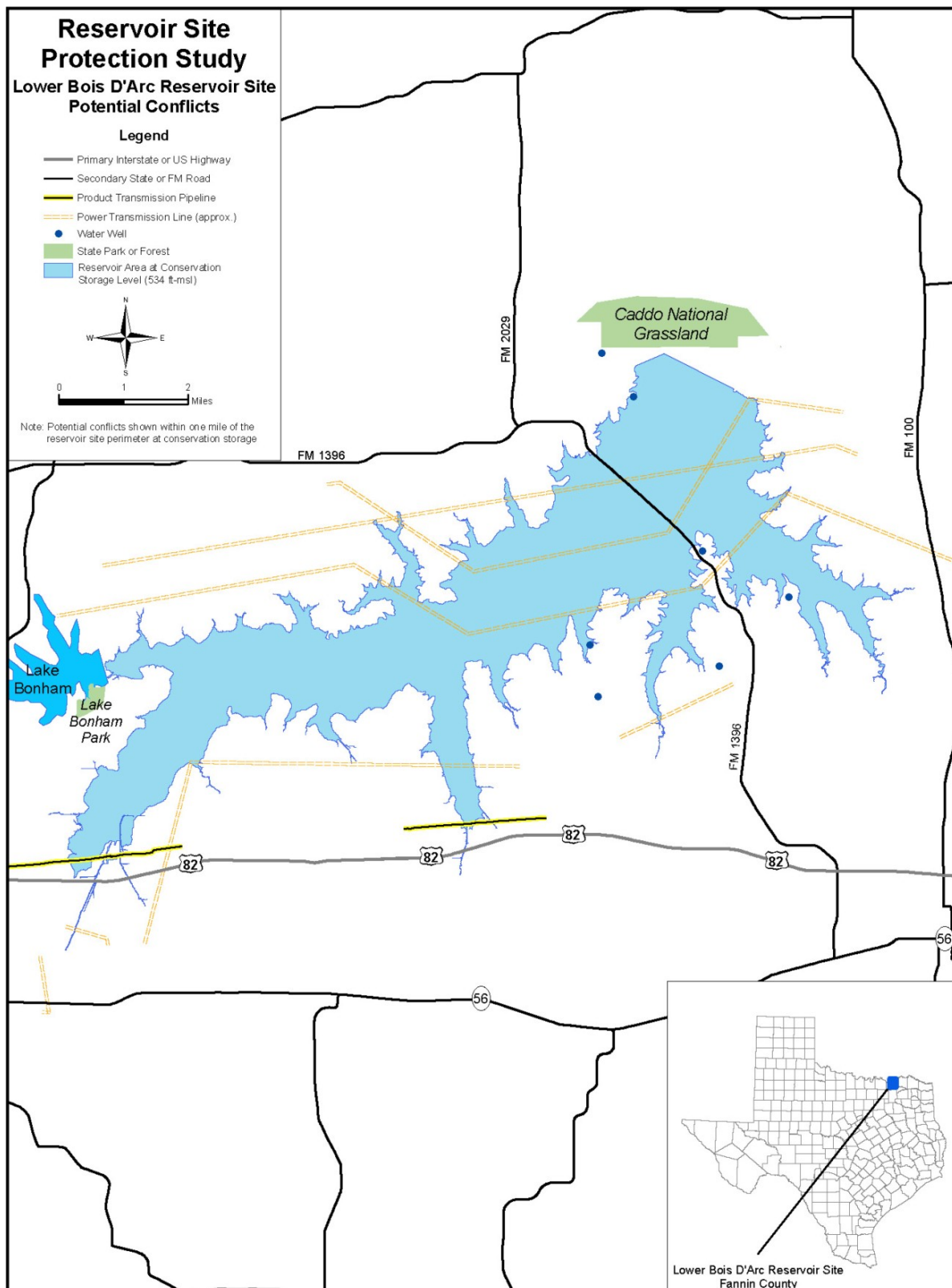
Figure 3.4.7-6. Potential Major Conflicts for Lower Bois d'Arc Creek Reservoir

Table 3.4.7-5 shows the estimated capital costs for the Lower Bois d'Arc Creek Reservoir Project, including construction costs, engineering, permitting and mitigation. Unit costs for the dam and reservoir are based on the unit cost assumptions used in this study. Local costs could vary. Utilizing these unit costs, the total estimated cost of the project is $248 million (2005 prices). Assuming a yield of 126,200 acft/yr, raw water from the project will cost approximately $140 per acre-foot ($0.43 per 1,000 gallons) during the debt service period.

3.4.7.4 *Environmental Considerations*

Lower Bois d'Arc Creek Reservoir is located on an ecologically significant stream as identified by the Texas Parks and Wildlife Department. The designation is based on biological function, hydrologic function, and the presence of a riparian conservation area. The Region C Water Planning Group did not identify this stream segment as ecologically unique in the 2006 water plan. Portions of the creek that would be impacted by the reservoir were altered (straightened and widened) approximately 80 years ago to reduce localized flooding. The site is located immediately upstream of the Caddo National Grasslands, but would have minimal impacts to these lands. The U.S. Fish and Wildlife Service has identified Priority 4 bottomland hardwoods considered "moderate quality bottomlands with minor waterfowl benefits" (USFWS, 1985) in the vicinity of the project.

Lower Bois d'Arc Creek Reservoir will inundate 16,526 acres of land at conservation storage capacity. Table 3.4.7-6 and Figure 3.4.7-7 summarize existing landcover for the Lower Bois d'Arc Creek Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by upland deciduous forest (42 percent) with sizeable areas of grassland (28 percent) and agricultural land (17 percent). Bottomland hardwood forest comprises only about 2.2 percent of the reservoir area while marsh, swamp, and open water total about 3.5 percent of the reservoir area.

Table 3.4.7-5.
Cost Estimate — Lower Bois d'Arc Creek Reservoir @ Elevation 534 ft-msl

	Quantity	*Unit*	*Unit Price*	*Cost*
Dam & Reservoir				
Mobilization (5%)	1	LS	$2,976,100	$2,976,000
Clearing and Grubbing	85	AC	$4,000	$340,000
Care of Water During Construction (1%)	1	LS	$589,300	$589,000
Required Excavation	2,339,400	CY	$2.50	$5,849,000
Borrow Excavation	2,030,000	CY	$2.00	$4,060,000
Random Compacted Fill	3,261,000	CY	$2.50	$8,153,000
Core Compacted Fill	711,200	CY	$3.00	$2,134,000
Soil Bentonite Slurry Trench	497,700	SF	$15.00	$7,466,000
Soil Cement	114,900	CY	$65.00	$7,469,000
Flex Base Roadway	29,200	SY	$20.00	$584,000
Sand Filter Drain	293,000	CY	$35.00	$10,255,000
Grassing	41	AC	$4,500	$185,000
Intake Tower for Low-Flow Outlet	527	CY	$750	$395,000
Conduit for Low-Flow Outlet	660	CY	$500	$330,000
Impact Basin for Low-Flow Outlet	160	CY	$500.00	$80,000
Gates and Miscellaneous for Low-Flow Outlet	1	LS	$200,000	$200,000
Electrical System and Instrumentation for Low-Flow Outlet	1	LS	$195,000	$195,000
Spillway Structure and Reinforced Concrete	19,700	CY	$375	$7,388,000
Roller Compacted Concrete	49,900	CY	$60	$2,994,000
Bridge	3,000	SF	$150	$450,000
Barrier and Warning System	1	LS	$50,000	$50,000
Embankment Instrumentation	1	LS	$250,000	$250,000
Timber Guard Posts and Guard Rail	1	LS	$55,000	$55,000
Misc. Internal Drainage	1	LS	$50,000	$50,000
Engineering and Contingencies				$21,874,000
Subtotal for Dam & Reservoir				**$84,371,000**
Conflicts				
Utilities				
10-in Gas Pipeline	3,720	LF	$27	$100,000
138 KV Line	1	LS	N/A	$1,500,000
345 KV line	1	LS	N/A	$3,735,000
Other structures	1	LS	N/A	$3,000,000
Cemeteries	27	EA	$6,000	$162,000
Major Roads (raised)	5,000	LF	$900	$4,500,000
Other roads	7,200	LF	$150	$1,080,000
Lake Bonham (protection)	1	LS	$175,000	$175,000
Engineering and Contingencies at 35%				$4,988,000
Land Acquisition - Conservation Pool plus 10%	22,000	AC	$2,675.00	$58,850,000
Environmental Studies and Mitigation Lands	22,000	AC	$2,675.00	$58,850,000
CONSTRUCTION TOTAL				**$221,311,000**
Interest During Construction (36 months)				**$26,927,000**
TOTAL COST				**$248,238,000**
ANNUAL COSTS				
Debt Service (6% for 40 years)				$16,498,000
Operation & Maintenance				$1,125,000
Total Annual Costs				**$17,623,000**
UNIT COSTS				
Per Acre-Foot				$140
Per 1,000 Gallons				$0.43

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.
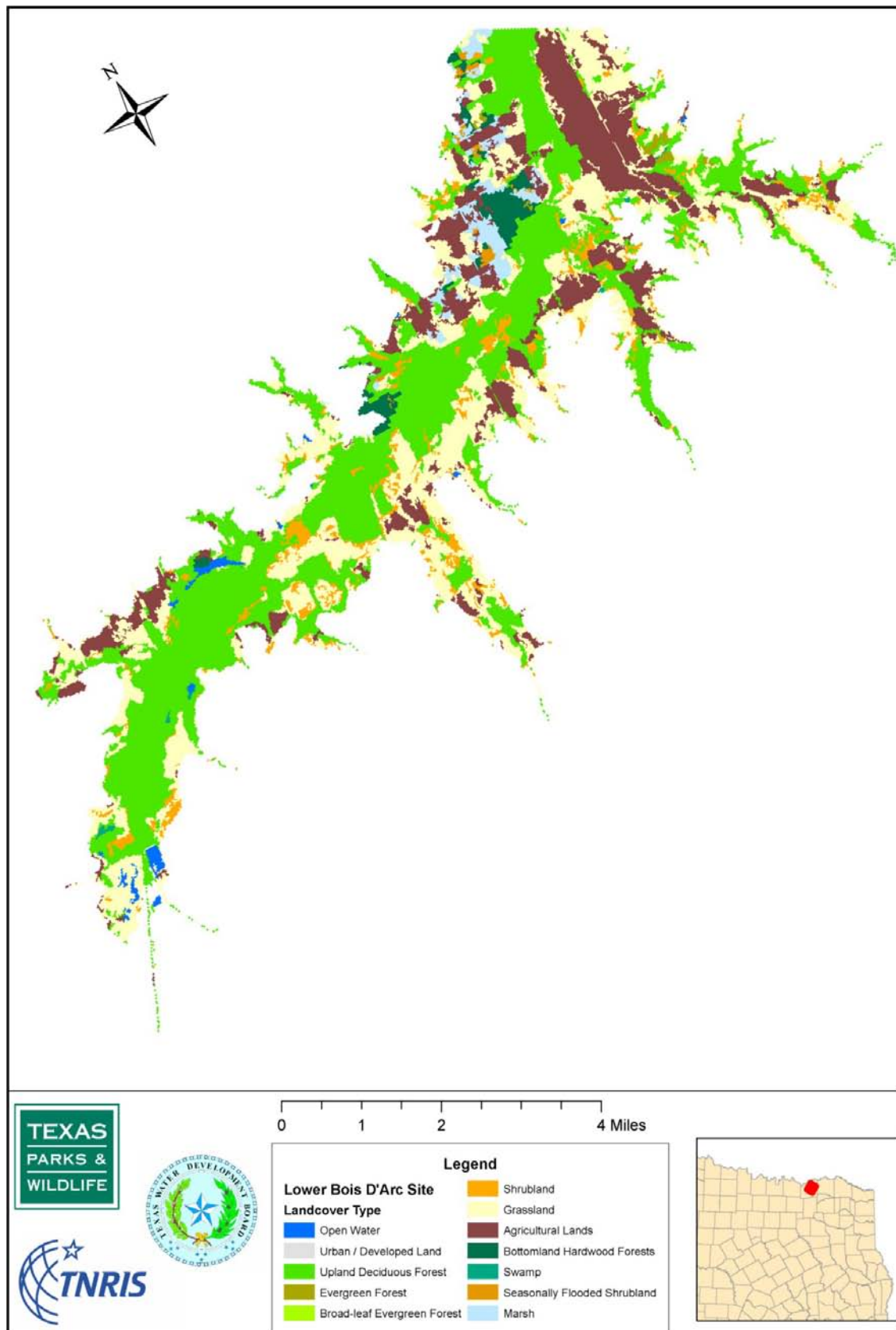
Figure 3.4.7-7. Existing Landcover for Lower Bois d'Arc Creek Reservoir

Table 3.4.7-6.
Acreage and Percent Landcover for Lower Bois d'Arc Creek Reservoir

Landcover Classification	Acreage[1]	Percent
Bottomland Hardwood Forest	373	2.2%
Marsh	407	2.5%
Seasonally Flooded Shrubland	73	0.4%
Swamp	29	0.2%
Evergreen Forest	61	0.4%
Upland Deciduous Forest	6,936	41.9%
Grassland	4,671	28.2%
Shrubland	1,038	6.3%
Agricultural Land	2,826	17.1%
Open Water	135	0.8%
Total	16,549	100.0%
[1] *Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.*		

3.4.8   Marvin Nichols Reservoir (Site IA)

3.4.8.1   Description

Marvin Nichols Reservoir (Site IA) would be located on the Sulphur River in Red River and Titus Counties. Figure 3.4.8-1 shows the location of the reservoir at the proposed conservation pool elevation of 328 ft-msl, with a conservation capacity of 1,562,669 acft. The inundated area at the top of conservation pool is 67,392 acres. The reservoir has a total drainage area of 1,889 square miles, of which 479 square miles are above Lake Chapman.
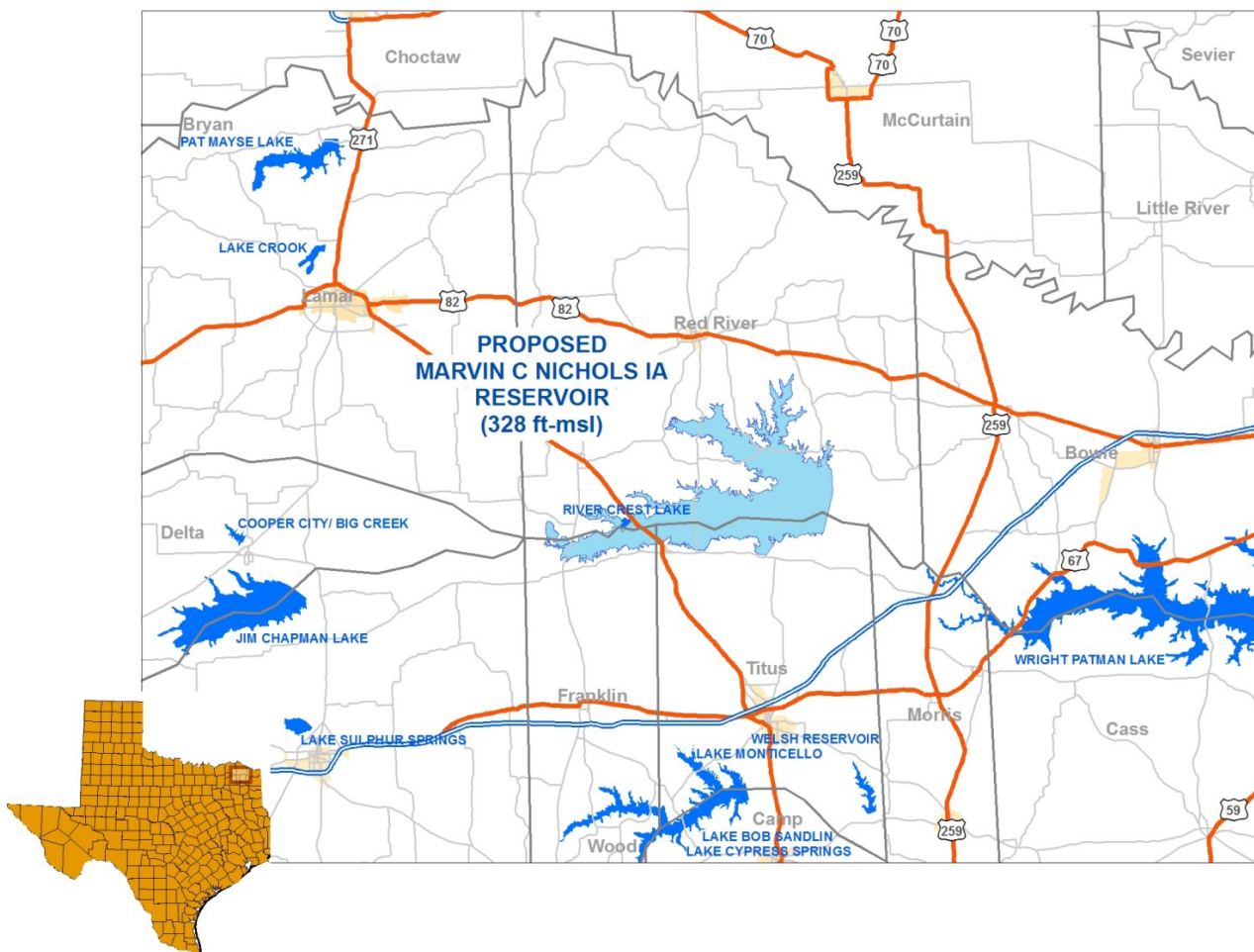
Figure 3.4.8-1. Location Map for Marvin Nichols Reservoir (Site IA)

This reservoir has been previously studied at various dam locations on the Sulphur River since the 1960s. It was first included in a state water plan in 1968 and has been included in each state plan since. More recently, this site was studied by Freese and Nichols in 1990, 1996, 2000,

and 2006, and it is a recommended water management strategy for the North Texas Municipal Water District, Tarrant Regional Water District, and the Upper Trinity River Water District in the 2006 Region C Water Plan (Freese and Nichols *et al*., 2006) and the 2007 Texas State Water Plan (TWDB, 2006). It is also an alternate strategy for the City of Dallas.

Marvin Nichols Reservoir is a recommended unique reservoir site in the 2001 and 2006 *Region C Water Plans*. The reservoir would provide water to several major water providers in the greater Dallas-Fort Worth area in the Region C water planning area. The need for additional water supply for the Region C planning area is expected to exceed 1.9 million acft/yr by 2060 (Freese and Nichols *et al*, 2006a). The projected water shortages within 50 miles of the proposed reservoir site by 2060 are 53,141 acft/yr. The nearest major demand center is the Dallas-Fort Worth area, which is located approximately 115 miles southwest of the reservoir site.

3.4.8.2   *Reservoir Yield Analysis*

The elevation-area-capacity relationship for Marvin Nichols Reservoir is included in Table 3.4.8-1 and Figure 3.4.8-2. The data in Table 3.4.8-2 were developed by Freese and Nichols (2000) by measurement from U.S. Geological Survey topographic quadrangle maps with scale 1:24,000 and 10-foot contour intervals. Figure 3.4.8-3 shows the reservoir inundation at different elevations in a 10-foot interval, including the elevation with the probable maximum flood at 335 feet.

The reservoir will be subject to regulatory bypass to meet environmental needs. For this study, the Consensus Criteria for Environmental Flow Needs (TWDB, 1997) were adopted and are shown in Table 3.4.8-2.

The firm yield of Marvin Nichols Reservoir was calculated with the full authorization scenario (Run 3) of the Water Availability Model of the Sulphur River Basin (dated July 15, 2004) obtained from TCEQ (R.J. Brandes, 1999 and TCEQ, 2006). A control point was added on the North Sulphur River at the dam location.

In the WAM Models, flows at ungaged locations are usually calculated using the drainage area ratio method with known flows at gaged locations. The drainage areas of the Sulphur WAM were calculated by the University of Texas Center of Research in Water Resources (CRWR). These areas are different from values published from U.S. Geological Survey. In some cases, the difference is more than 10 percent.

Table 3.4.8-1.
Elevation-Area-Capacity Relationship for Marvin Nichols Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
260.0	0	0
265.0	96	235
270.0	192	954
275.0	3,435	9,944
280.0	6,678	35,207
285.0	10,690	78,612
290.0	14,703	142,084
295.0	20,072	229,008
300.0	25,441	342,780
305.0	30,778	483,319
310.0	36,114	650,543
315.0	43,726	850,130
320.0	51,337	1,087,776
325.0	61,372	1,369,531
328.0	67,392	1,562,669
330.0	71,406	1,701,463
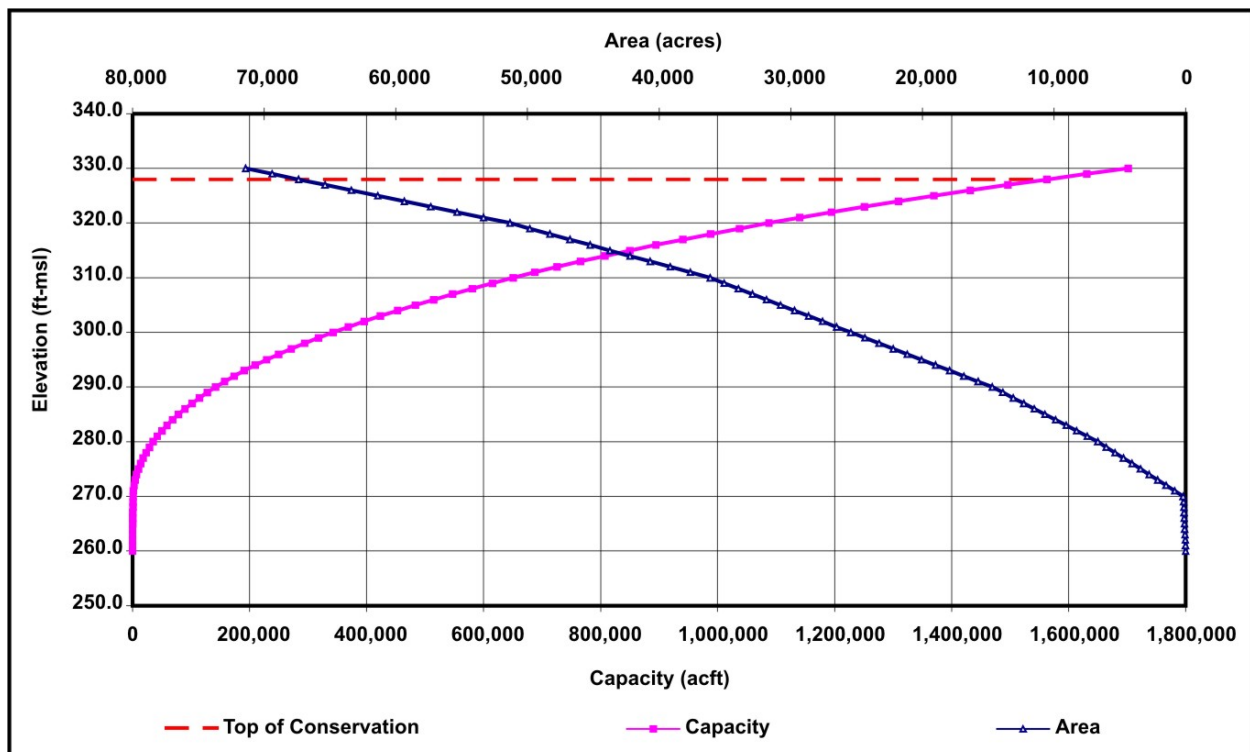
Figure 3.4-8-2. Elevation-Area-Capacity Relationship for Marvin Nichols Reservoir

Table 3.4.8-2.
Consensus Criteria for Environmental Flow Needs for Marvin Nichols Reservoir

	Median		*25th Percentile*		*7Q2*	
	acft/mo	*cfs*	*acft/mo*	*cfs*	*acft/mo*	*cfs*
Jan	13,845	225.1	3,419	55.6	69	1.1
Feb	21,947	391.6	6,659	118.8	63	1.1
Mar	31,133	506.2	8,975	145.9	69	1.1
Apr	19,656	330.2	6,143	103.2	67	1.1
May	32,113	522.1	6,092	99.0	69	1.1
Jun	11,994	201.5	3,110	52.3	67	1.1
Jul	2,564	41.7	552	9.0	69	1.1
Aug	911	14.8	220	3.6	69	1.1
Sep	1,011	17.0	123	2.1	67	1.1
Oct	1,562	25.4	251	4.1	69	1.1
Nov	5,055	84.9	1,083	18.2	67	1.1
Dec	11,641	189.3	2,201	35.8	69	1.1
Total	153,432		38,827		814	
Average	12,786	212.5	3,236	54.0	68	1.1

Figure 3.4.8-3. Inundation Map for Marvin Nichols Reservoir

Preliminary yield studies conducted in this study determined that the flows calculated using the Sulphur WAM with the drainage area ratio method are different from previous hydrologic studies because of differences in the drainage areas. The USGS values are widely accepted and are more accurate than the CRWR values as developed for the Sulphur Basin WAM. Therefore, for purposes of estimating the firm yields of the proposed reservoirs in the Sulphur Basin, naturalized flows at the reservoir sites were calculated using the drainage area ratio method with drainage areas obtained from the USGS rather then CRWR. For Marvin Nichols Reservoir, naturalized flows were calculated using the South Sulphur River near Talco (WAM Control Point C10), the White Oak Creek near Talco (WAM Control Point D10), and the Sulphur River near Darden (WAM Control Point E10).

The scope of work of this study does not include a verification or modification of the drainage areas of the Sulphur WAM Model. However, entering the naturalized flow at the reservoir sites is sufficient to produce accurate estimates of firm yield.

Net evaporation rates were calculated from TWDB quadrangle data of precipitation and lake evaporation. Evaporation at the Marvin Nichols Reservoir site was calculated as the average of Quadrangles 412 and 413. Net evaporation rates entered in the Sulphur WAM were adjusted to remove the portion of the precipitation in the reservoir surface area that was already accounted for in the natural inflow.

Yields were calculated for elevations 330, 328, 323, and 318 ft-msl, subject to bypass for Consensus Criteria for Environmental Flow Needs and assuming stand-alone reservoir operations with no minimum reserve content. Results of firm yield at these elevations are included in Table 3.4.8-3 and Figure 3.4.8-4. At the conservation pool level of 328 feet, the firm yield is 602,000 acft/yr. Environmental flow requirements reduce the yield of the reservoir by 12,800 acft/yr.

An evaluation of the impacts of the construction of other reservoir sites in the Sulphur River Basin on the yield of each of the reservoirs was conducted and the findings are included in Appendix A of this report. Based on this evaluation, the yield of Marvin Nichols Reservoir will decrease if one or more of the proposed reservoirs in the Sulphur Basin (Ralph Hall, Parkhouse I, and/or Parkhouse II) are built, assuming that Marvin Nichols has a junior priority to any of these reservoirs. As of November 2006, Ralph Hall Lake is in the permitting process, and likely would be senior to Marvin Nichols. Yield analysis determined that Ralph Hall Lake would reduce the firm yield of Marvin Nichols IA by 17,900 acft/yr, which is 3 percent of the stand-alone yield. If all of the other proposed reservoirs in the Sulphur Basin are built, the yield of Marvin Nichols would be 460,800, which is 141,200 acft/yr less than the stand-alone yield (or a reduction of 23 percent).

Figure 3.4.8-5 presents a simulated storage trace derived using the Sulphur WAM. A frequency curve for storage content is also shown in Figure 3.4.8-5. At the conservation pool elevation of 328 ft-msl, the reservoir would be full about 17 percent of the time and would be below 50 percent of the conservation storage about 10 percent of the months.

Table 3.4.8-3.
Firm Yield vs. Conservation Storage for Marvin Nichols Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)	Critical Period
318.0	988,151	CCEFN	465,300	5/53-1/57
323.0	1,250,808	CCEFN	527,800	5/53-1/57
328.0*	1,562,669	CCEFN	602,000	5/53-1/57
		None	614,800	5/53-1/57
330.0	1,701,463	CCEFN	635,200	5/53-1/57
*Proposed conservation storage.				
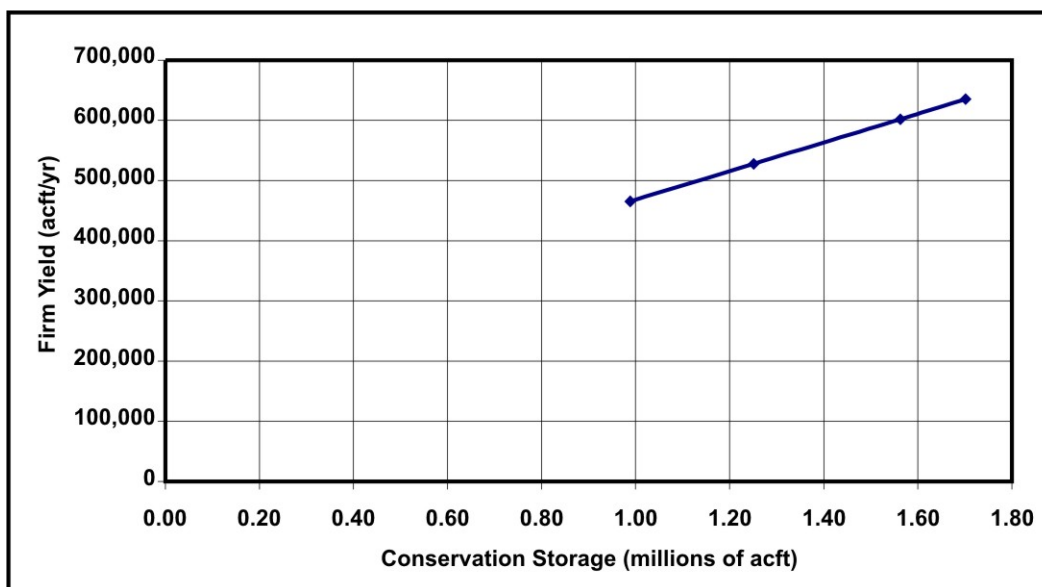
Figure 3.4.8-4. Firm Yield vs. Conservation Storage for
Marvin Nichols Reservoir
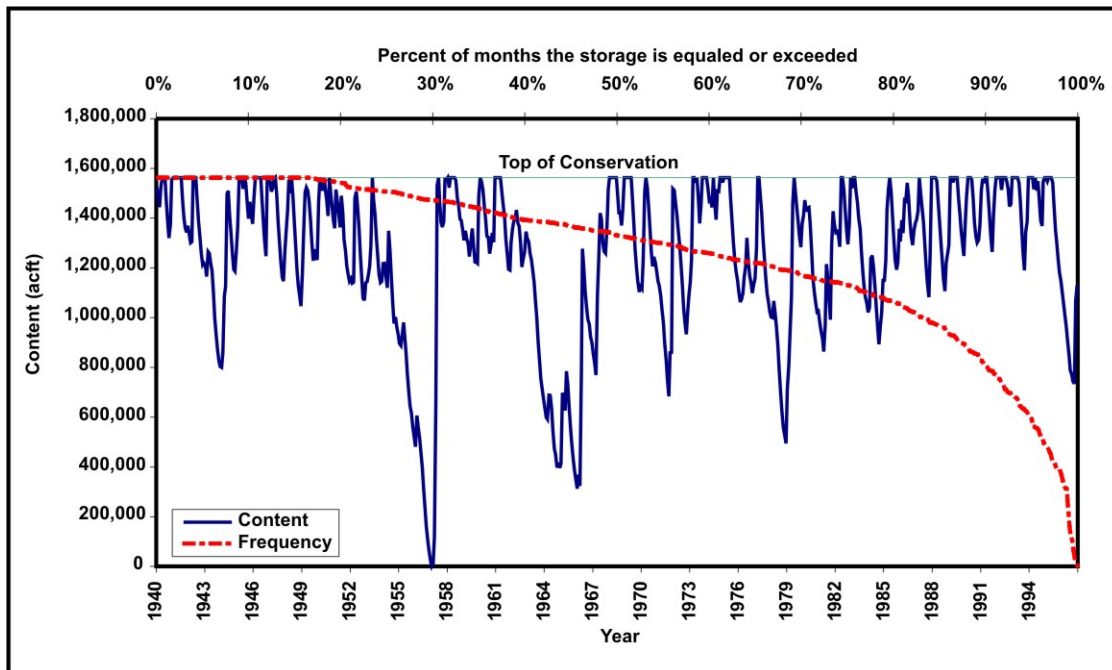
**Figure 3.4.8-5. Simulated Storage in Marvin Nichols Reservoir
(Conservation Elevation = 328 ft-msl, Diversion = 602,000 acft/yr)**

3.4.8.3   Reservoir Cost

The costs for the Marvin Nichols IA Dam are based on data developed for the Sulphur River Basin Reservoir Study (Freese and Nichols, 2000) and used in the 2006 *Region C Water Plan*. The dam and spillway costs assume an earthen embankment with a gated spillway structure. The length of the dam is estimated at approximately 40,400 feet, with a top of dam elevation at 337 ft-msl. The service spillway includes a gated ogee-type weir constructed of concrete, thirteen tainter gates, a stilling basin, and discharge channel.

Figure 3.4.8-6 shows potential conflicts as mapped by TNRIS. The conflicts identified at the site include several cemeteries, electrical lines, roads (including U.S. Highway 271 and State Highway 37), oil and gas pipelines, oil and gas wells and water wells. A list of the potential conflicts is provided in Table 3.4.8-4. Costs and quantities for these conflict resolutions were developed from data provided by TNRIS and from the Region C Water Plan (Freese and Nichols, 2006a). The conflict costs represent approximately 10 percent of the total construction cost of the reservoir project.

Table 3.4.8-4.
List of Potential Conflicts for Marvin Nichols Reservoir

Oil & Gas Pipelines	Power Transmission Lines
Roads	Cemeteries
Oil & Gas Wells	Water Wells
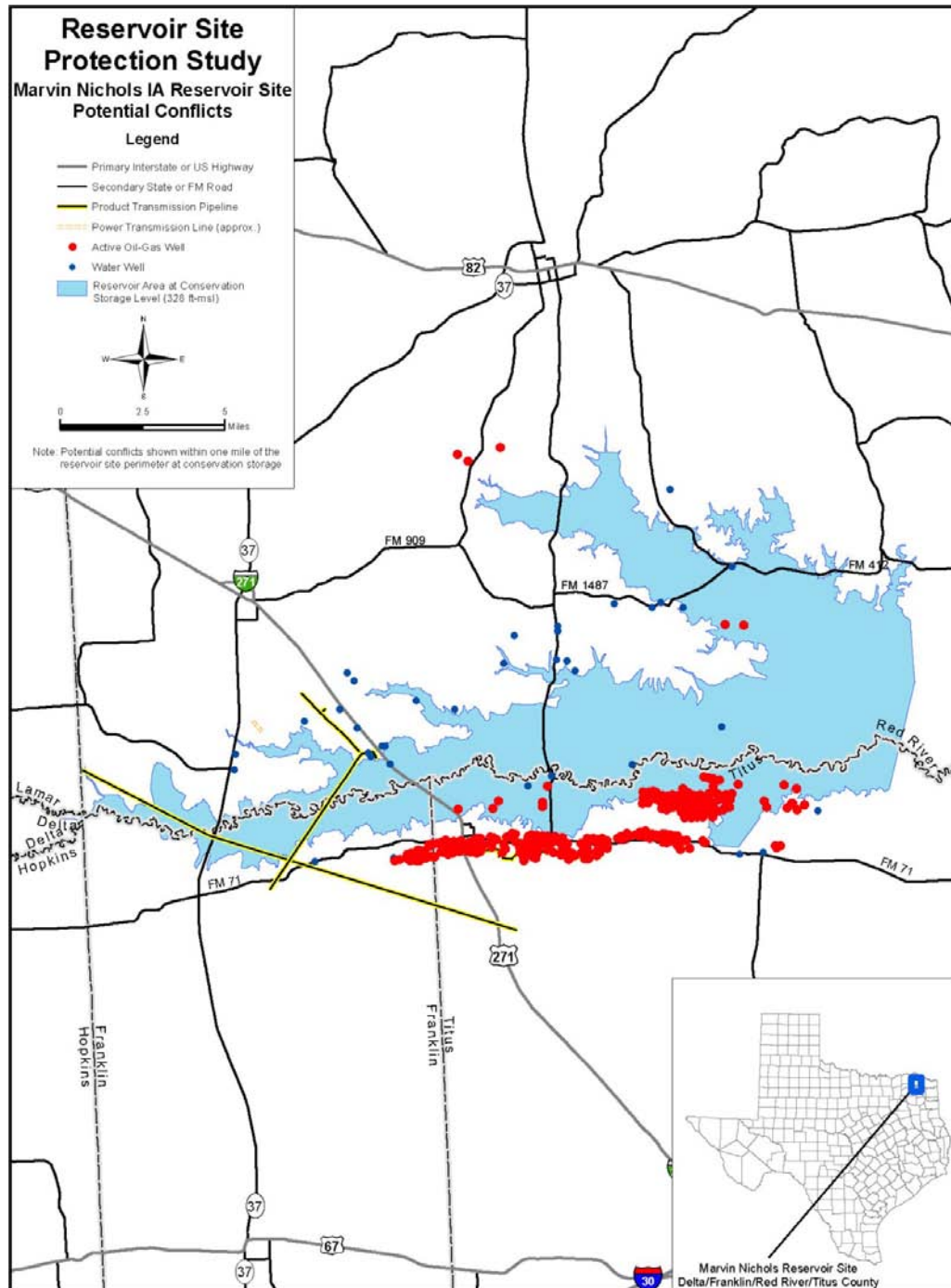
Figure 3.4.8-6. Potential Major Conflicts for Marvin Nichols Reservoir

Table 3.4.8-5 shows the estimated capital costs for the Marvin Nichols Reservoir Project, including construction costs, engineering, permitting and mitigation. Costs for the dam and reservoir are based on the unit cost assumptions used in this study. The total estimated cost of the project is $510 million (2005 prices). Assuming a yield of 602,000 acft/yr, raw water from the project will cost approximately $61 per acft ($0.19 per 1,000 gallons) during the debt service period.

3.4.8.4   *Environmental Considerations*

The Marvin Nichols IA Reservoir is located approximately 29 river miles upstream of an ecologically significant stream segment as identified by the Texas Parks and Wildlife Department (TPWD, 1999). The reservoir itself is not located on an ecologically significant stream segment. The Sulphur River downstream of the IH-30 bridge in Morris County is considered an ecologically significant stream based on biological function associated with bottomland hardwood forests and the presence of the paddlefish, which is a state-listed threatened species. The Region D Water Planning Group did not identify Sulphur River as ecologically unique in the 2006 regional water plan.

Marvin Nichols Reservoir would inundate approximately 67,300 acres. The U.S. Fish and Wildlife Service has classified some of this acreage as Priority 1 bottomland hardwoods, which are considered "excellent quality bottomlands of high value to key waterfowl species" (USFWS, 1985). Previous studies have also identified surface lignite deposits within the project area. At this time, there are no lignite mining areas.

Table 3.4.8-6 and Figure 3.4.8-7 summarize existing landcover for the Marvin Nichols Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by largely contiguous bottomland hardwood forest (39 percent) with sizeable areas of upland deciduous forest (20 percent) and grassland (19 percent). Marsh, swamp, and open water total about 13 percent of the reservoir area.

Table 3.4.8-5.
Cost Estimate — Marvin Nichols Reservoir @ Elevation 328 ft-msl
(page 1 of 2)

	Quantity	Unit	Unit Price	Cost
DAM & RESERVOIR				
Mobilization (5%)	1	LS	$8,183,300	$8,183,000
Spillway Construction				
Mass Concrete	87,300	CY	$150	$13,095,000
Reinforced Concrete	26,800	CY	$400	$10,720,000
Soil Cement	3,600	CY	$65.00	$234,000
Spillway Bridge	640	LF	$1,300	$832,000
Gates, Including Anchoring System	14,040	SF	$275	$3,861,000
Gate Hoist and Operating System	13	EA	$250,000	$3,250,000
Stop Gate and Lift Beam	640	LF	$2,000	$1,280,000
Instrumentation	640	LF	$700	$448,000
Excavation	2,894,000	CY	$3	$7,235,000
Structural Fill	121,000	CY	$12	$1,452,000
Subtotal of Spillway Construction				**$42,407,000**
Embankment Construction				
Random Fill	6,049,600	CY	$2.50	$15,124,000
Impervious Core	1,455,000	CY	$3.00	$4,365,000
Borrow	4,731,600	CY	$2.00	$9,463,000
Foundation Drain (Filter Material)	502,500	CY	$35.00	$17,588,000
Soil Cement	337,800	CY	$65.00	$21,957,000
Slurry Trench Cutoff	1,770,000	SF	$15.00	$26,550,000
Asphalt Paving on Embankment Crest	68,350	SY	$20.00	$1,367,000
Containment Levee	79,100	CY	$2.50	$198,000
Subtotal of Embankment Construction				**$96,612,000**
Other Items				
Barrier Warning System	640	LF	$100	$64,000
Electrical System	1	LS	$550,000	$550,000
Power Drop	1	LS	$250,000	$250,000
Spillway Low-Flow System	1	LS	$400,000	$400,000
Stop Gate Monorail System	640	LF	$1,000	$640,000
Grassing	100	AC	$4,500	$450,000
Clearing and Grubbing/ Site Preparation	321	AC	$4,000	$1,284,000
Care of Water (3%)	1	LS	$4,209,100	$4,209,000
Reservoir Land Clearing	16,800	AC	$1,000	$16,800,000
Subtotal of Other Items				**$24,647,000**
Engineering and Contingencies - Dam & Reservoir				$57,283,000
Conflicts				
Roads				
Federal Highway	16,300	LF	$900	$14,670,000
State Highway	6,000	LF	$900	$5,400,000
F.M	33,400	LF	$150	$5,010,000
Oil & Gas Pipelines				
30-inch	27,000	LF	$98	$2,646,000
16-inch	28,000	LF	$42	$1,176,000
8-inch	20,000	LF	$23	$460,000
6-inch	42,000	LF	$20	$840,000
Power Lines	3,600	LF	$450	$1,620,000
Cemeteries				
Wims	25	EA	$6,000	$150,000
Singleton	10	EA	$6,000	$60,000
Evergreen	75	EA	$6,000	$450,000

Table 3.4.8-5.
Cost Estimate — Marvin Nichols Reservoir @ Elevation 328 ft-msl
(page 2 of 2)

	Quantity	*Unit*	*Unit Price*	*Cost*
Wells (each)				
Oil and Gas Wells	94	EA	$25,000	$2,350,000
Water Wells	9	EA	$49,000	$441,000
Engineering and Contingencies - Conflicts				$12,346,000
Land Purchase Costs	77,427	AC	$1,201	$92,990,000
Environmental Studies and Mitigation Lands	77,427	AC	$1,201	$92,990,000
CONSTRUCTION TOTAL				**$454,548,000**
Interest During Construction (36 months)				**$55,305,000**
TOTAL COST				**$509,853,000**
ANNUAL COSTS				
Debt Service (6% for 40 years)				$33,886,000
Operation & Maintenance				$2,946,000
Total Annual Costs				**$36,832,000**
UNIT COSTS				
Per Acre-Foot				$61
Per 1,000 Gallons				$0.19

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

Table 3.4.8-6.
Acreage and Percent Landcover for Marvin Nichols Reservoir

Landcover Classification	*Acreage[1]*	*Percent*
Bottomland Hardwood Forest	26,309	39.2%
Marsh	6,259	9.3%
Seasonally Flooded Shrubland	1,198	1.8%
Swamp	565	0.8%
Evergreen Forest	27	0.0%
Upland Deciduous Forest	13,667	20.4%
Grassland	13,069	19.5%
Shrubland	1,027	1.5%
Agricultural Land	3,169	4.7%
Urban / Developed Land	8	0.0%
Open Water	1,847	2.8%
Total	67,145	100.0%

[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.
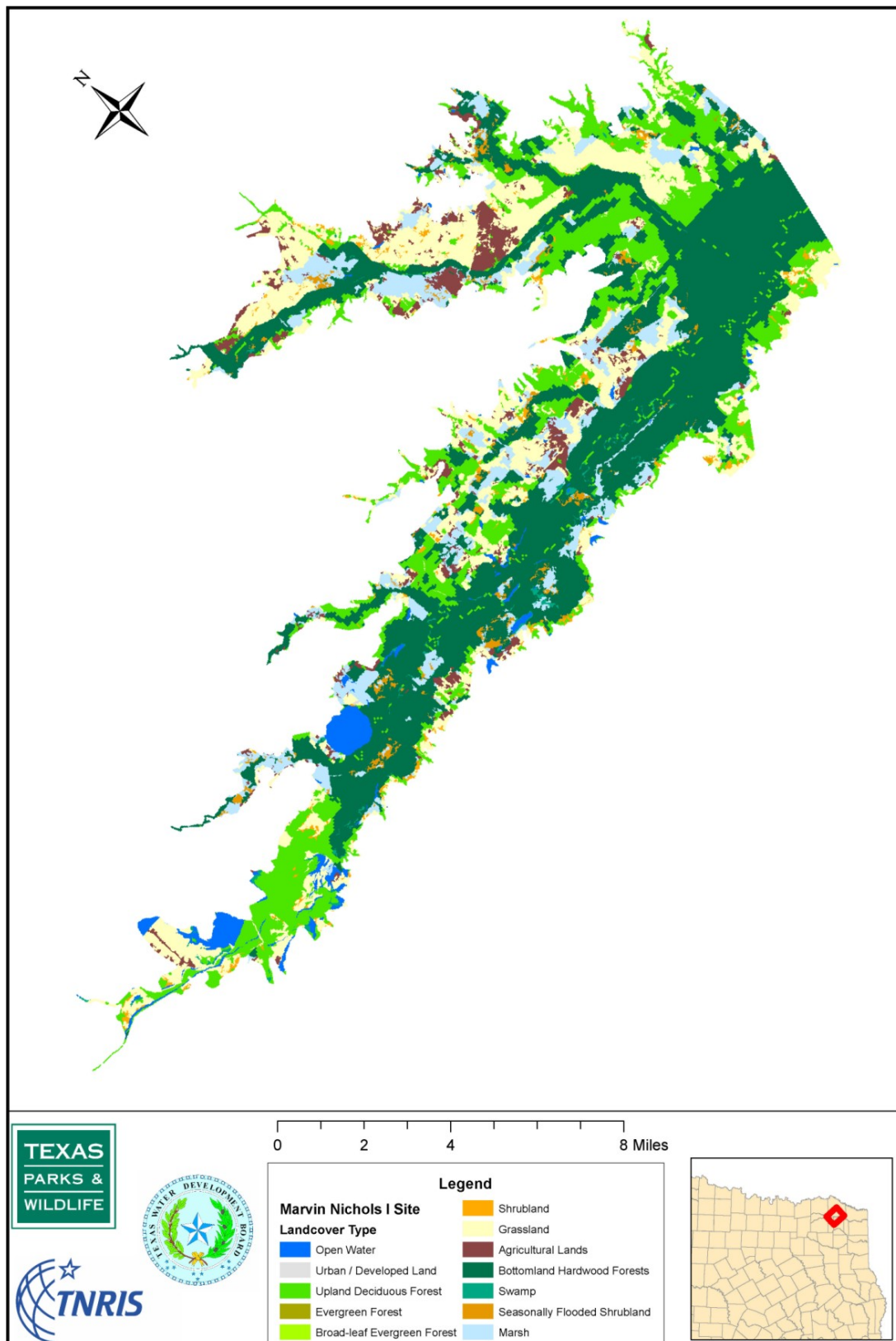
Figure 3.4.8-7. Existing Landcover for Marvin Nichols Reservoir

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3.4.9   Nueces Off-Channel Reservoir

3.4.9.1   *Project Description*

The Nueces Off-Channel Reservoir is recommended in the 2006 Coastal Bend Regional Water Plan (HDR, 2006) as a strategy to increase the firm yield of the Choke Canyon Reservoir/Lake Corpus Christi (CCR/LCC) System and potentially provide ecosystem restoration benefits.   Choke Canyon Reservoir has a storage capacity of approximately 695,000 acft and a contributing drainage of approximately 5,500 square miles. Lake Corpus Christi has a storage capacity of approximately 257,000 acft and a contributing drainage of approximately 16,500 square miles.   This configuration creates a situation where the smallest reservoir has the largest potential for capturing storm flows because of the larger contributing drainage area.   The yield of the CCR/LCC System is affected by the limited storage capacity of Lake Corpus Christi and its limited ability to impound major storm events that travel down the Nueces River.   Since Lake Corpus Christi has the smaller capacity, many times it fills and spills flow to Nueces Bay when there is available capacity in Choke Canyon Reservoir.   Water pumped from Lake Corpus Christi into the Nueces Off-Channel Reservoir will result in more water in storage and enhance the system yield.

The Nueces Off-Channel Reservoir site is shown in Figure 3.4.9-1.   The reservoir is located near the upper western section of Lake Corpus Christi.   The Nueces Off-Channel Reservoir will require an intake and pump station at Lake Corpus Christi to pump available water from Lake Corpus Christi.
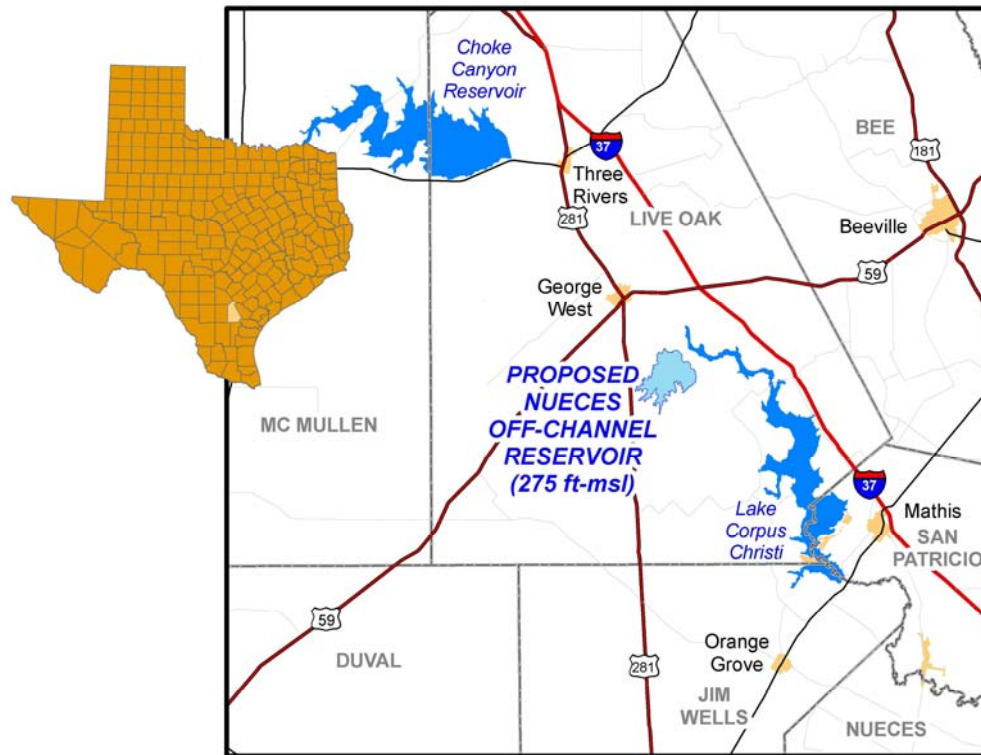
Figure 3.4.9-1. Location Map of Nueces Off-Channel Reservoir

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply prior to year 2060 total 159,640 acft/yr for counties within a 50-mile radius of the Nueces Off-Channel Reservoir site. The 50-mile radius encompasses all or parts of Atascosa, Bee, Duval, Goliad, Jim Wells, Karnes, Kleberg, La Salle, Live Oak, McMullen, Nueces, Refugio, San Patricio, Webb, and Wilson Counties. The nearest major population and water demand center to the Nueces Off-Channel Reservoir site is Corpus Christi (56 miles).

3.4.9.2   *Reservoir Yield Analyses*

The elevation-area-capacity relationship for Nueces Off-Channel Reservoir is presented in Figure 3.4.9-2 and Table 3.4.9-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.9-3. At the conservation storage pool elevation of 275.3 ft-msl, Nueces Off-Channel Reservoir would inundate 5,294 acres and have a capacity of 250,000 acft.
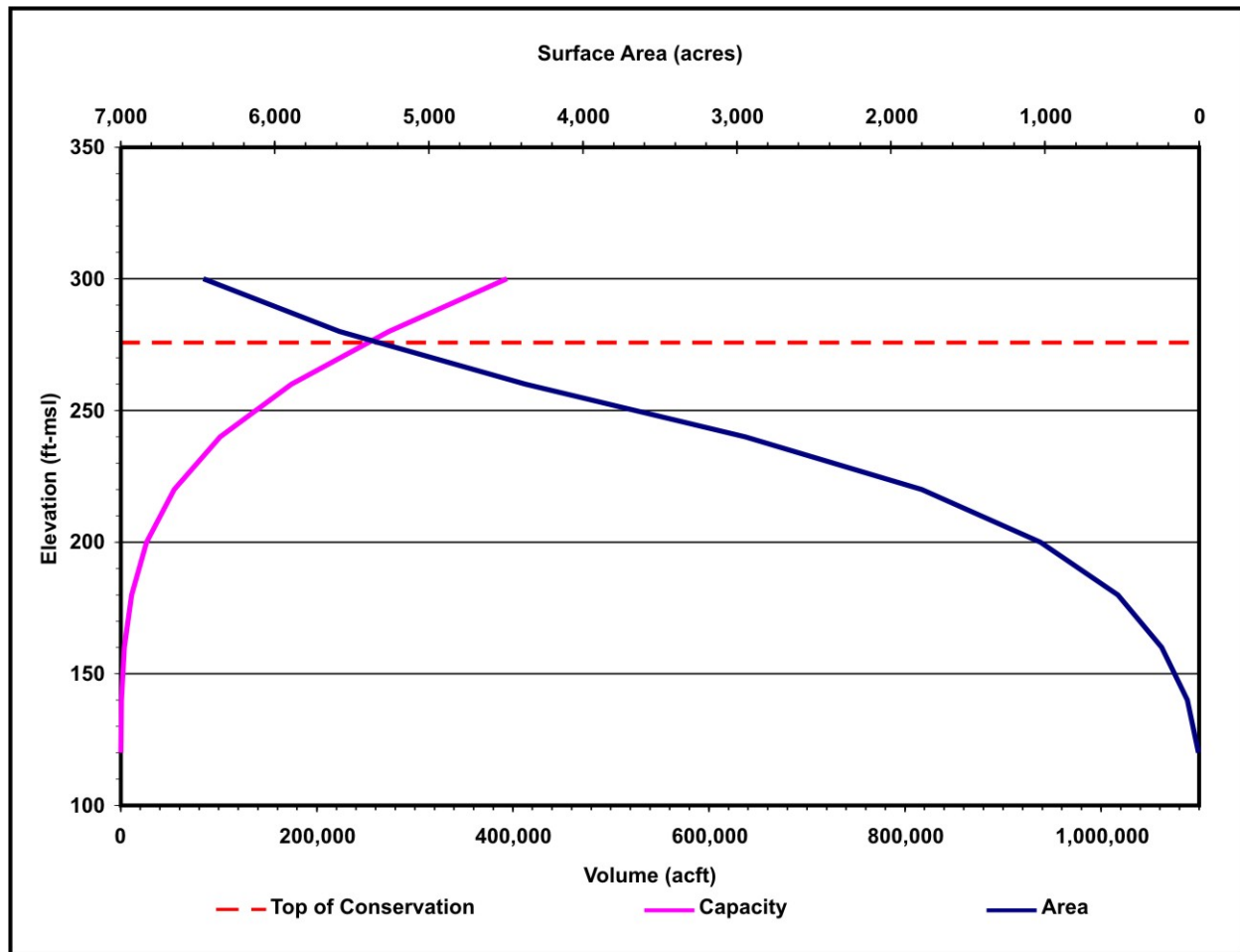
Figure 3.4.9-2. Elevation-Area-Capacity Relationship for Nueces Off-Channel Reservoir

Table 3.4.9-1.
Elevation-Area-Capacity Relationship for Nueces Off-Channel Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
120	4	0
140	76	645
160	243	3,678
180	528	11,209
200	1,029	26,503
220	1,800	54,437
240	2,946	101,432
260	4,374	174,169
275.3	5,294	250,000
280	5,579	273,455
300	6,465	393,787
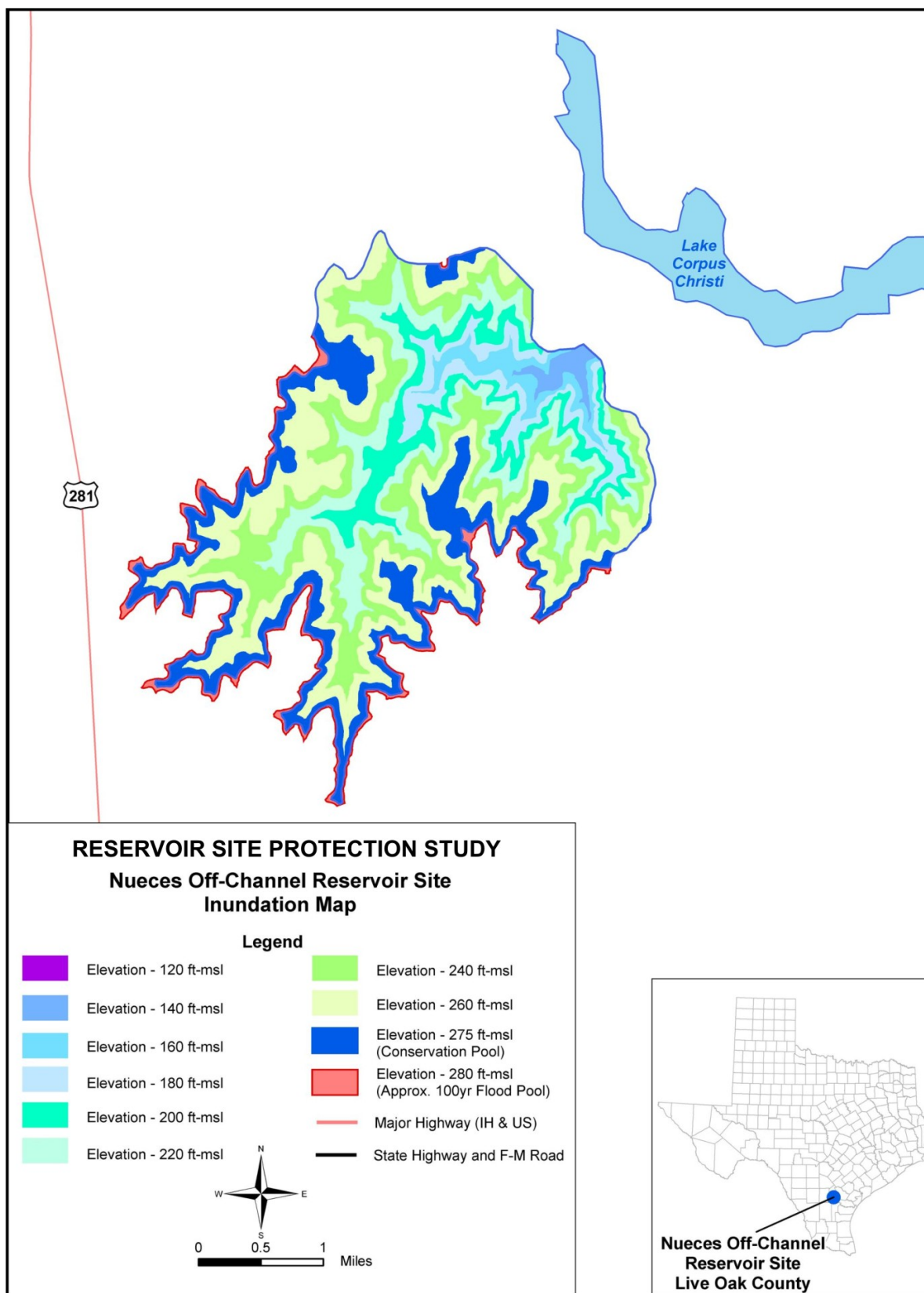
Figure 3.4.9-3. Inundation Map for Nueces Off-Channel Reservoir

Firm yield simulations were made for the historical period from 1934 to 2003 using the City of Corpus Christi's Phase IV Operations Plan (Naismith Engineering, 1999), the 2001 TCEQ Agreed Order (TCEQ, April 2001), and 2010 reservoir sedimentation conditions. It is assumed that Consensus Criteria for Environmental Flow Needs are not applicable because diversions are made from Lake Corpus Christi and the entire system is operated under the current Agreed Order. These simulations were performed using an updated version of the City of Corpus Christi's Lower Nueces River Basin and Estuary (NUBAY) Model (HDR, January 2006) that includes the capability to simulate the Nueces Off-Channel Reservoir. Operating guidelines for the reservoirs and the pump station and pipeline are detailed below.

Operational guidelines for the reservoir, pump station, and pipeline operations for the Nueces Off-Channel Reservoir were developed to identify the optimum set of Lake Corpus Christi elevation triggers, pipeline capacity, and Nueces Off-Channel Reservoir storage capacity with due consideration of firm yield enhancement, freshwater inflow to the Nueces Estuary, and recreation at Lake Corpus Christi. After several combinations were evaluated, the Nueces Off-Channel Reservoir, Choke Canyon Reservoir, and Lake Corpus Christi were operated in the following manner:

1. Water would be pumped from Lake Corpus Christi to fill the Nueces Off-Channel Reservoir, up to the capacity of the pump station and pipeline, any time the elevation in Lake Corpus Christi was 93 ft-msl or greater and storage was available in the Nueces Off-Channel Reservoir. The conservation pool elevation of Lake Corpus Christi is 94 ft-msl.
2. The Nueces Off-Channel Reservoir would release to Lake Corpus Christi any time the elevation in Lake Corpus Christi was less than or equal to 80 ft-msl.
3. Releases from Choke Canyon Reservoir were triggered when Lake Corpus Christi elevation level was less than or equal to 74 ft-msl.

Nueces Off-Channel Reservoir was most recently studied by Region N in the 2006 Regional Water Plan. In the Region N plan, Nueces Off-Channel was evaluated at four conservation storage capacities — 100,000 acft, 200,000 acft, 300,000 acft, and 400,000 acft. It was determined that the optimal size for the Nueces Off-Channel Reservoir is most likely somewhere between 200,000 acft and 300,000 acft.

Four potential conservation storage capacities are modeled herein for Nueces Off-Channel Reservoir. These conservation storage capacities are 150,000 acft, 200,000 acft, 250,000 acft, and 300,000 acft. Firm yield estimates for Nueces Off-Channel Reservoir for all

four conservation capacities are shown in Table 3.4.9-2. Current planning initiatives envision a conservation capacity of 250,000 for Nueces Off-Channel Reservoir, thereby yielding an additional water supply of 39,935 acft/yr above the Lake Corpus Christi / Choke Canyon Reservoir System yield of 231,925 acft/yr. Figure 3.4.9-4 shows the relationship between firm yield and conservation capacity for Nueces Off-Channel Reservoir / Lake Corpus Christi / Choke Canyon Reservoir System. For the purposes of this study, diversion pump station and pipeline capacities were assumed to be 1,000 cfs for all four conservation capacities.

Table 3.4.9-2.
Firm Yield vs. Conservation Storage for Nueces Off-Channel Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	2010 Firm Yield[1] (acft/yr)	2010 Yield Increase (acft/yr)
253.4	150,000	257,335	25,410
265.2	200,000	264,765	32,840
275.3*	250,000	271,860	39,935
284.4	300,000	272,013	40,088
*Proposed conservation storage. [1]Base System Yield without Nueces Off-Channel Reservoir is 231,925 acft/yr			
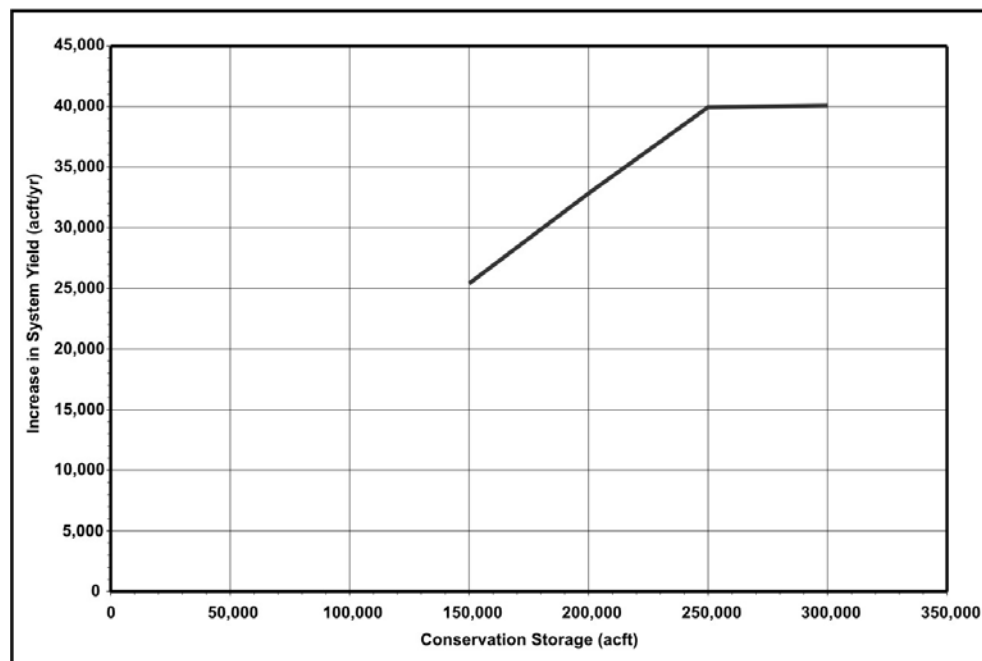
Figure 3.4.9-4. Firm Yield vs. Conservation Storage for Nueces Off-Channel Reservoir

Figure 3.4.9-5 illustrates storage fluctuations through time for Nueces Off-Channel Reservoir and Figure 3.4.9-6 shows the combined system storage in Lake Corpus Christi, Choke Canyon Reservoir, and Nueces Off-Channel Reservoir. The storage frequency curve in Figure 3.4.9-5 indicates that the reservoir would be full less than 10 percent of the time, more than half full about 45 percent of the time, and empty about 24 percent of the time. As shown in Figure 3.4.9-6, however, the system of reservoirs would be above 50 percent of storage capacity about 72 percent of the time.
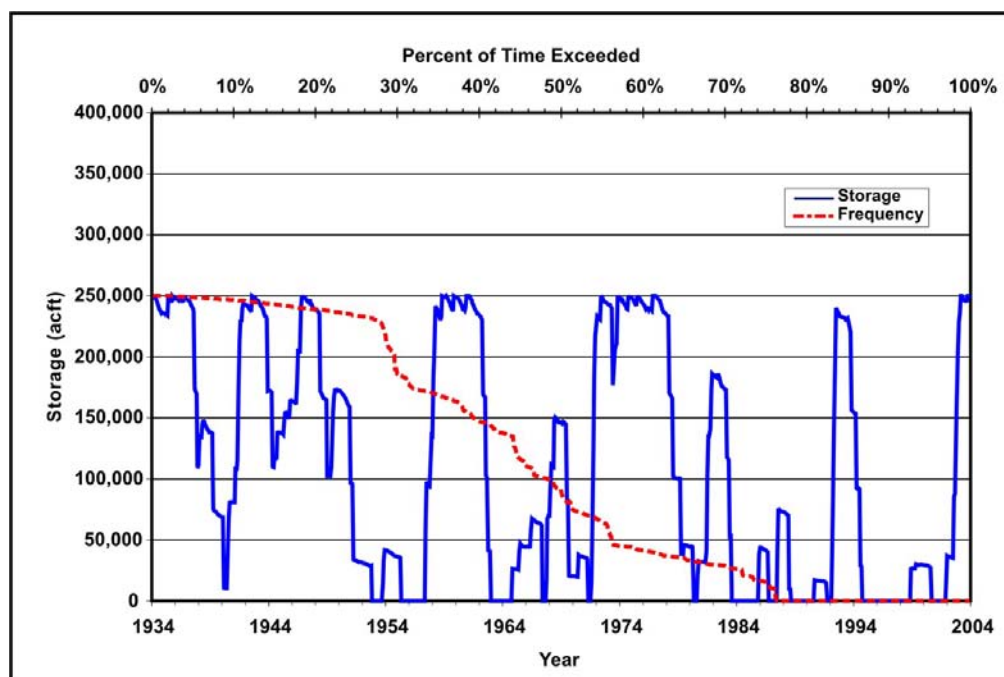
Figure 3.4.9-5. Simulated Storage in Nueces Off-Channel Reservoir
(Conservation Elevation = 275.3 ft-msl, Incremental Yield = 39,935 acft/yr)
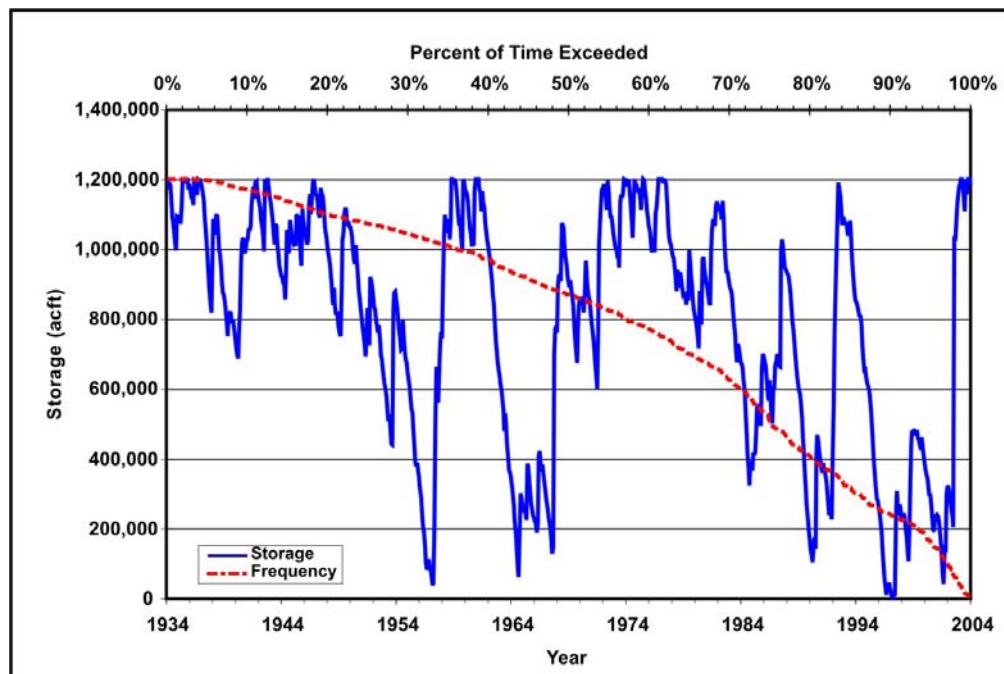
***Figure 3.4.9-6. Simulated System Storage for Lake Corpus Christi, Choke Canyon
Reservoir, and Nueces Off-Channel Reservoir
(System Diversion = 271,860 acft/yr)***

3.4.9.3   Reservoir Project Cost Estimates

The Nueces Off-Channel Reservoir is estimated to have a maximum earthen dam height
of 135 feet. The diversion works from Lake Corpus Christi to the Nueces Off-Channel Reservoir
includes a 646 MGD intake and pump station, a 2.8 mile, 120-inch pipeline, and a stilling basin.
Figure 3.4.9-7 shows the major conflicts within the conservation pool of Nueces Off-Channel
Reservoir.   Potential conflicts include oil and gas wells, water wells, product transmission
pipelines, and a power transmission line.   Resolution of facility conflicts represents
approximately 5 percent of the total construction cost.
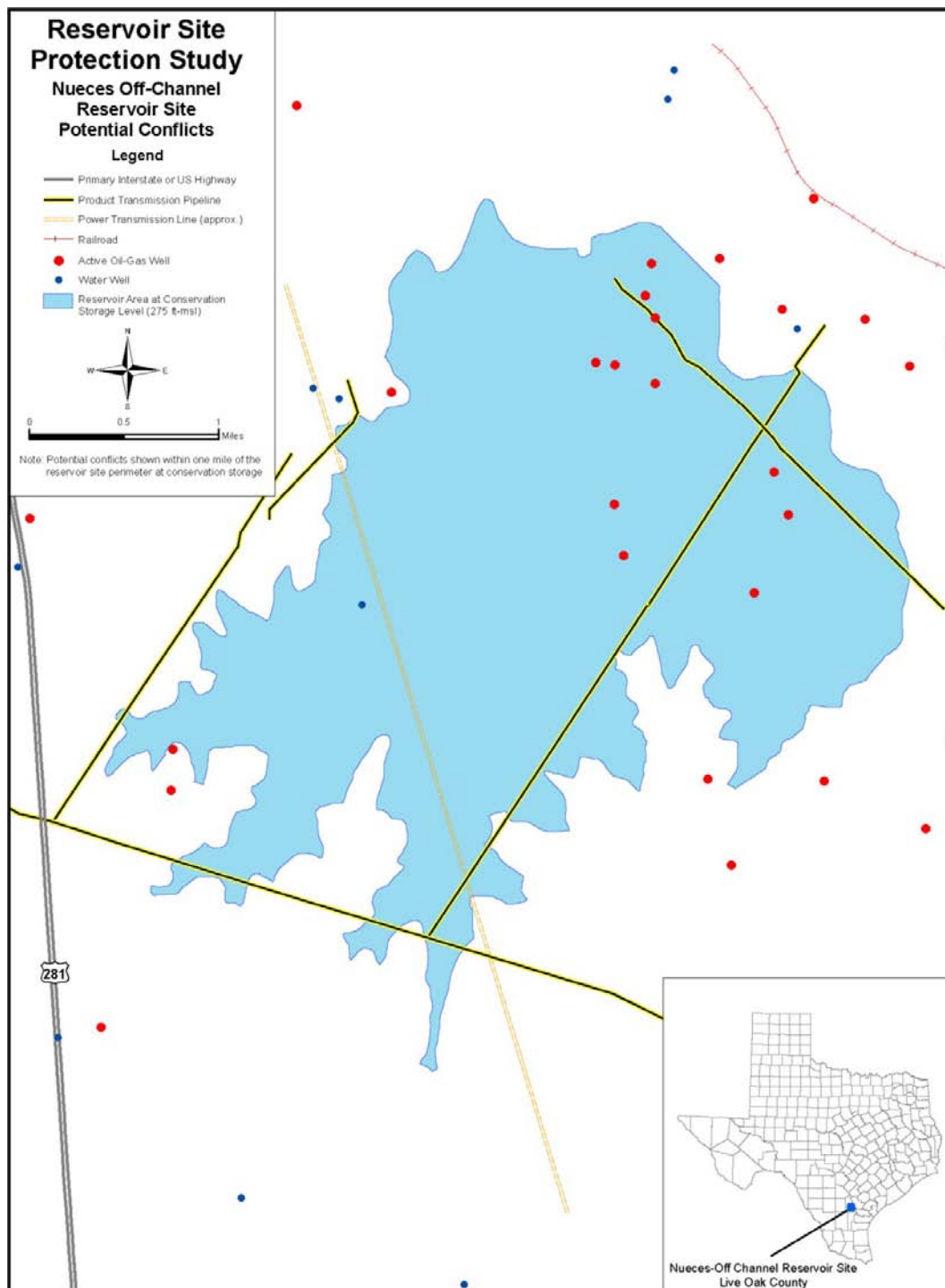
Figure 3.4.9-7. Potential Major Conflicts for Nueces Off-Channel Reservoir

A summary cost estimate for Nueces Off-Channel Reservoir at elevation 275 ft-msl (250,000 acft) is shown in Table 3.4.9-3. Quantities and relocation costs are detailed information from the 2006 Region N Water Plan. Dam and reservoir costs total about $97 million, while

relocations total another $9.8 million. Land, which includes mitigation lands, totals about $15.4 million. The diversion intake, pump station, and pipeline from Lake Corpus Christi to the Nueces Off-Channel Reservoir adds another $70 million. Annual costs for Nueces Off-Channel Reservoir are approximately $17 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $432/acft ($1.33 per 1,000 gallons).

Table 3.4.9-3.
Cost Estimate — Nueces Off-Channel Reservoir @ 275.3 ft-msl

	Quantity	*Unit*	*Unit Price*	*Cost*
Dam & Reservoir				
Dam Embankment	14,363,228	CY	$5.00	$71,816,140
Engineering Contingencies (35%)				$25,135,649
Subtotal Dam & Reservoir				**$96,951,789**
Pump & Pipeline				
Pump Station & Intake (25,820 HP; 646 MGD)	1	LS	$35,233,653	$35,233,653
Pipeline (120-inch)	14,770	LF	$870	$12,849,900
Stilling Basin (1000 cfs)	1	LS	$3,751,000	$3,751,000
Engineering Contingencies (35%)				$18,142,093
Subtotal Pump & Pipeline				**$69,976,646**
Conflicts				
H20 Wells	2	EA	$25,000	$50,000
Oil & Gas Wells	15	EA	$50,000	$750,000
Oil & Gas Pipeline	55,144	LF	$42	$2,316,055
Power Transmission Line	16,111	LF	$450	$7,249,989
Engineering Contingencies (35%)				$2,537,496
Subtotal Conflicts				**$9,787,485**
Land				
Land Acquisition	5,294	AC	$1,450	$7,676,300
Environmental Studies and Mitigation Lands	5,294	AC	$1,450	$7,676,300
Subtotal Land				**$15,352,600**
CONSTRUCTION TOTAL				**$192,068,520**
Interest During Construction (36 months)				**$23,048,222**
TOTAL COSTS				**$215,116,742**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$14,296,659
Operations & Maintenance				$2,501,127
Pumping Energy				$459,792
Total Annual Costs				**$17,257,577**
Firm Yield (acft/yr)				**39,935**
Unit Costs of Water ($/acft/yr)				**$432**
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.				

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3.4.9.4   Environmental Considerations

The Nueces Off-Channel Reservoir site is located adjacent to TCEQ-classified stream segment 2103. Although Texas Parks and Wildlife Department (TPWD) considers the upstream and downstream segments of the Nueces River ecologically significant (TPWD, 1999), it does not include Lake Corpus Christi, from which diversions to the Nueces Off-Channel Reservoir would be made, in this classification.

The Nueces Off-Channel Reservoir will inundate 5,294 acres of land at conservation storage capacity. Table 3.4.9-4 and Figure 3.4.9-8 summarize existing landcover for the Nueces Off-Channel Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (49 percent) and shrubland (43 percent).

Table 3.4.9-4.
Acreage and Percent Landcover for Nueces Off-Channel Reservoir

Landcover Classification	Acreage[1]	Percent
Grassland	2,637	49.4%
Shrubland	2,280	42.7%
Broad Leaf Evergreen Forest	394	7.4%
Urban / Developed Land	25	0.5%
Total	**5,336**	**100.0%**
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
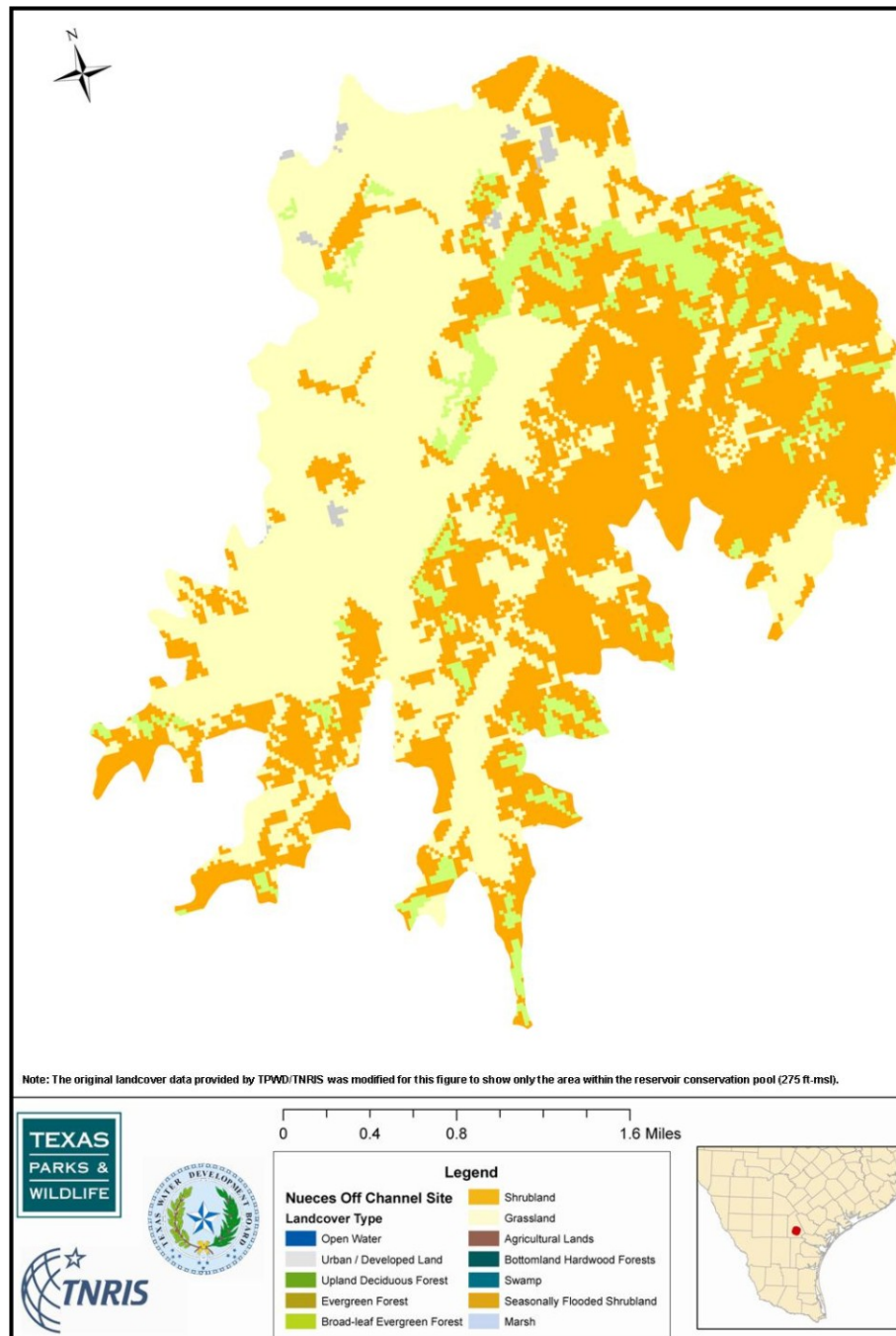
Figure 3.4.9-8. Existing Landcover for Nueces Off-Channel Reservoir

3.4.10 Palmetto Bend Reservoir — Stage II (Texana Stage II)

3.4.10.1 _Project Description_

The Texas Water Development Board (TWDB) and the Lavaca-Navidad River Authority (LNRA) hold Certificate of Adjudication No. 16-2095B, for the completion of Palmetto Bend Stage II Dam and Reservoir (Stage II of Lake Texana) on the Lavaca River. Stage I, now known as Lake Texana, was completed in 1981 and is located on the Navidad River. Stage I is operated by LNRA for water supply purposes and has a firm yield of 79,000 acft/yr.

Originally, the U.S. Bureau of Reclamation proposed that Stage II would be located on the Lavaca River and share a common pool with Stage I (Lake Texana). However, previous studies have shown that Stage II could be constructed more economically if operated separately from Lake Texana and located further upstream at an alternative site on the Lavaca River (HDR, May 1991). As proposed, at the original site, the Certificate of Adjudication states (TNRCC, 1994):

> "Upon completion of the Stage 2 dam and reservoir on the Lavaca River, owner Texas Water Development Board is authorized to use an additional amount of 18,122 acft/yr, for a total of 48,122 acft/yr, of which up to 7,150 acft/yr shall be for municipal purposes, up to 22,850 acft/yr shall be for industrial purposes, and at least 18,122 acft/yr shall be for the maintenance of the Lavaca-Matagorda Bay and Estuary System. The entire Stage 2 appropriation remains subject to release of water for the maintenance of the bay and estuary system until a release schedule is developed pursuant to the provisions of Section 4.B of this certificate of adjudication."

For the purposes of this study, Stage II is assumed to be constructed at the alternative site located approximately 1.4 miles upstream of the original site (Figure 3.4.10-1). Since this site results in a different yield than stated in the certificate, the conditions in the certificate will need to be revised to account for the change in yield of Stage II. The revisions to the certificate should also reflect the impacts that joint operations of Lake Texana and Palmetto Bend Stage II could have on the releases necessary to maintain the bay and estuary system downstream of the projects.
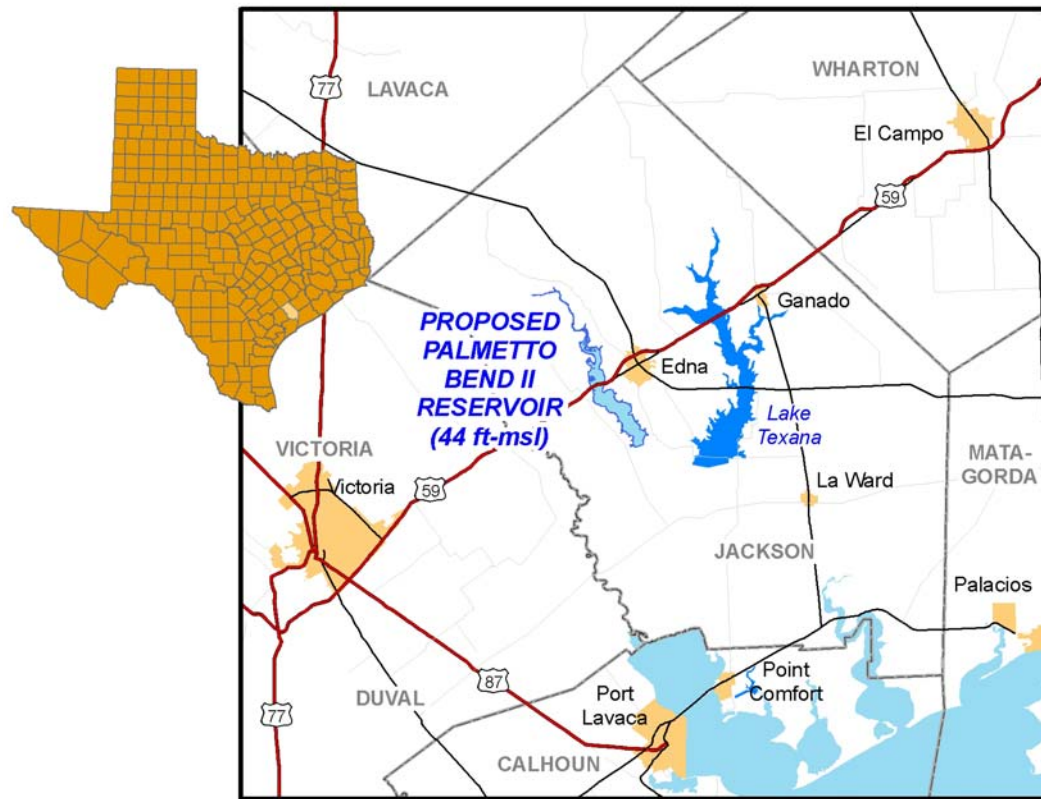
Figure 3.4.10-1. Location Map of Palmetto Bend Reservoir — Stage II

The LNRA has expressed a renewed interest in the potential development of Stage II. In the 2001 Coastal Bend Regional Water Plan (HDR, 2006), water supply from the development of Stage II was evaluated as part of an interregional water supply by both the Coastal Bend Regional Water Planning Group (Region N) and the South Central Texas Regional Water Planning Group (Region L). Previously, the South Central Texas Region Water Planning Group considered two Stage II water delivery options: to coastal irrigation areas near the Colorado River at Bay City and to the Guadalupe River near the Saltwater Barrier. However, the South Central Texas Regional Water Planning Group did not recommend these options in either the 2001 or 2006 regional water plans. Stage II is a recommended water management strategy in the 2006 Coastal Bend Regional Water Plan.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply prior to year 2060 total 79,857 acft/yr for counties within a 50-mile radius of the Palmetto Bend Reservoir – Stage II site. The 50-mile radius encompasses all or parts of Aransas, Calhoun, Colorado, Dewitt, Goliad, Jackson, Lavaca, Matagorda, Refugio,

Victoria, and Wharton Counties. The nearest major population and water demand centers to the Palmetto Bend Reservoir – Stage II site are Corpus Christi (93 miles) and Houston (100 miles).

3.4.10.2 *Reservoir Yield Analyses*

The elevation-area-capacity relationship for Palmetto Bend Reservoir – Stage II is presented in Figure 3.4.10-2 and Table 3.4.10-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.10-3. Surface areas and capacities associated with 44 ft-msl are computed by linear interpolation between values for 40 ft-msl and 45 ft-msl and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 44 ft-msl, Palmetto Bend Reservoir – Stage II would inundate 4,564 acres and have a capacity of 52,046 acft.

Table 3.4.10-1.
Elevation-Area-Capacity Relationship for
Palmetto Bend Reservoir – Stage II

Elevation (feet)	Area (acres)	Capacity (acft)
4	0	0
5	16	5
10	49	161
15	92	507
20	159	1,127
25	609	2,927
30	1,649	8,360
35	2,725	19,182
40	3,688	35,152
44	4,564	52,046
45	4,783	56,269
50	5,868	82,851
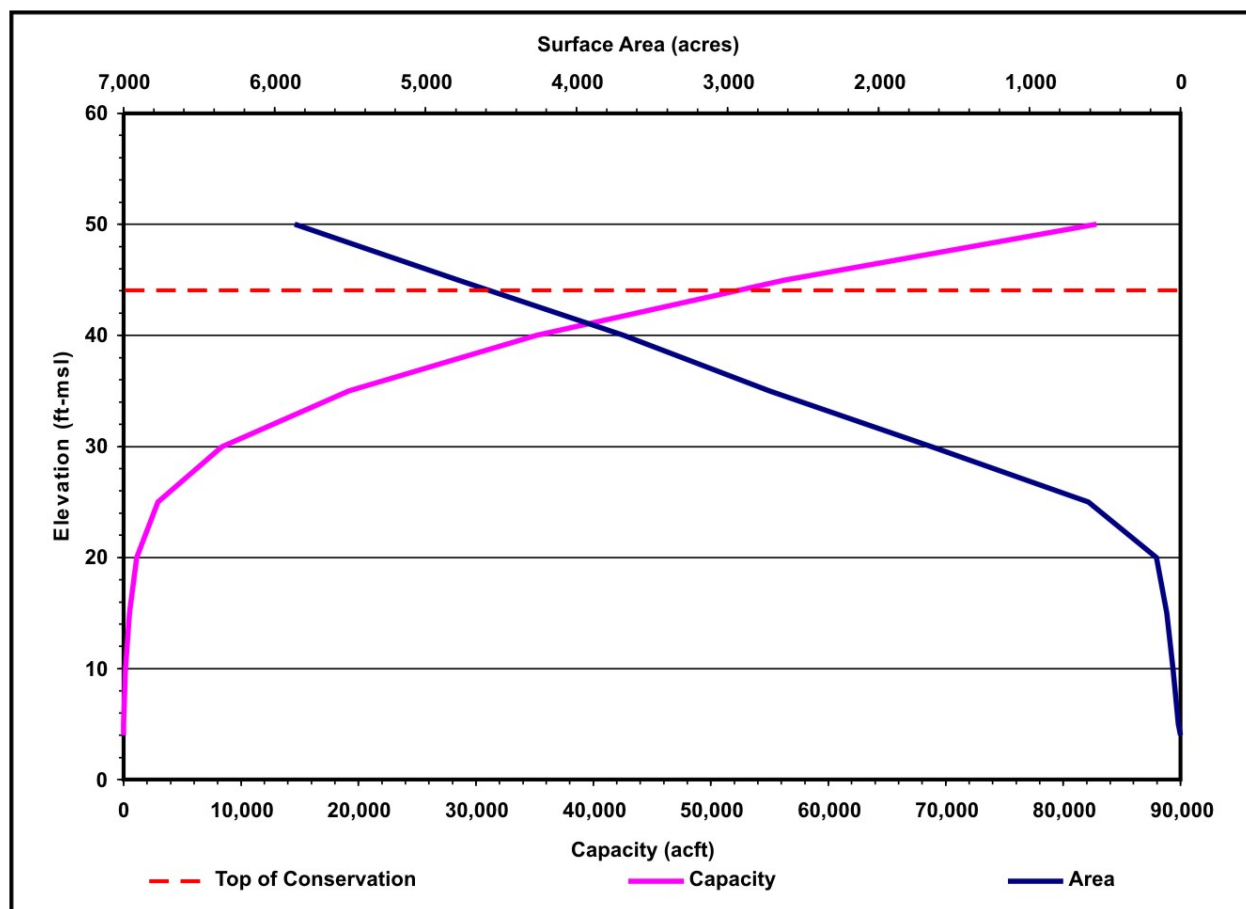
***Figure 3.4.10-2. Elevation-Area-Capacity Relationship for
Palmetto Bend Reservoir – Stage II***
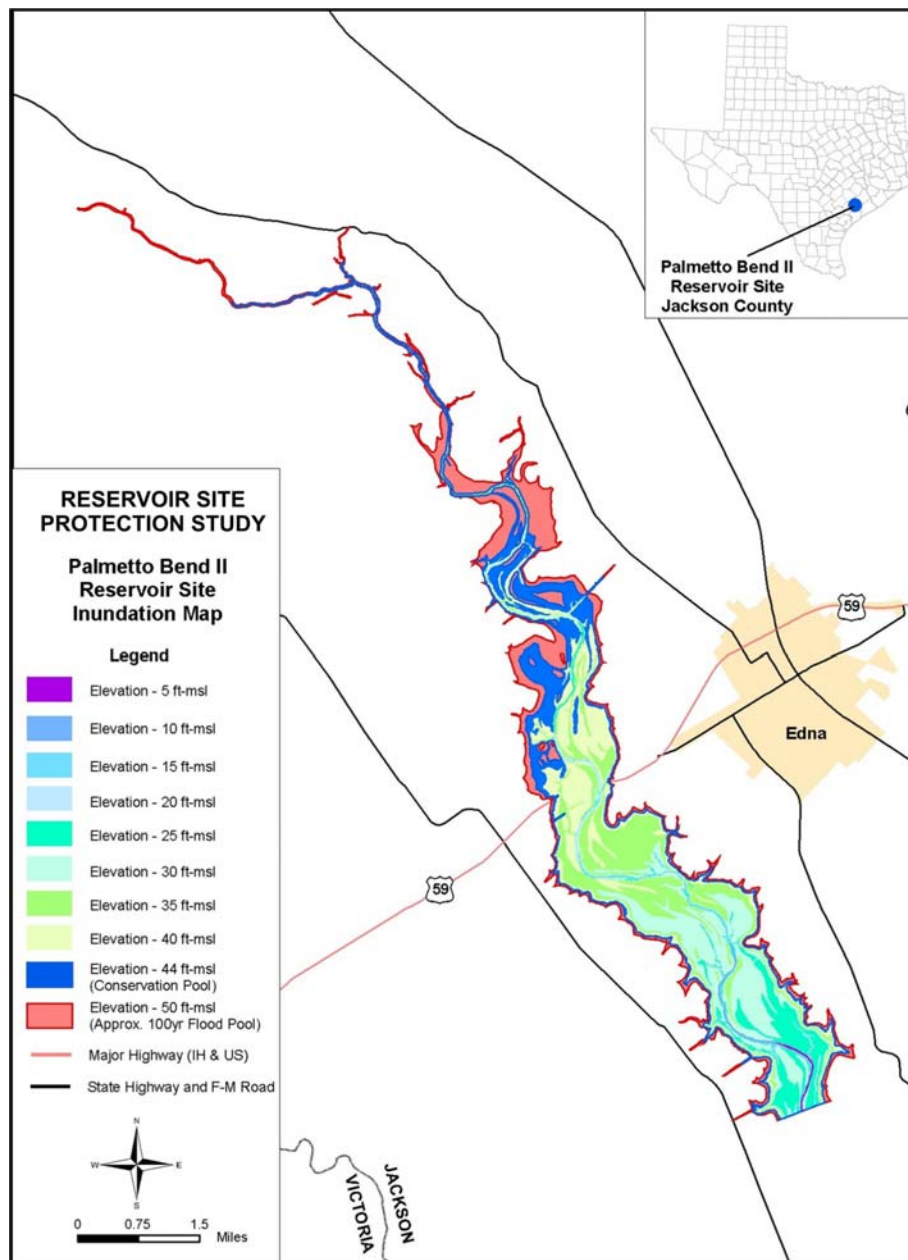
Figure 3.4.10-3. Inundation Map for Palmetto Bend Reservoir – Stage II

The Consensus Criteria for Environmental Flow Needs (CCEFN) (TWDB, August 1997), a three-staged criteria that uses percentage of reservoir capacity as triggers for determining the pass-through requirement, is used for modeling of Palmetto Bend Reservoir – Stage II. Pass-through flows are the monthly naturalized median flow when reservoir storage is greater than 80 percent of capacity, the monthly naturalized 25th percentile flow when the reservoir is between 50 and 80 percent of capacity, and the published 7Q2 when reservoir capacity is less than 50 percent of conservation capacity. The CCEFN values used include the median and

quartile flows in Table 3.4.10-2 and the 7Q2 value of 21.6 cfs published in the Texas Surface Water Quality Standards (Texas Administrative Code).

Table 3.4.10-2.
Consensus Criteria for Environmental Flow Needs for
Palmetto Bend Reservoir – Stage II

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Median (cfs)	63.0	92.8	76.9	78.9	92.2	85.6	47.5	37.3	41.2	39.2	48.3	55.1
Median (acft/mo)	3,874	5,154	4,728	4,695	5,669	5,094	2,921	2,294	2,452	2,410	2,874	3,388
Quartile (cfs)	26.1	39.0	37.6	36.8	35.4	36.7	22.7	21.6	21.6	21.6	21.6	24.3
Quartile (acft/mo)	1,605	2,166	2,312	2,190	2,177	2,186	1,396	1,328	1,285	1,328	1,285	1,494
7Q2 (cfs)	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6
7Q2 (acft/mo)	1,328	1,200	1,328	1,285	1,328	1,285	1,328	1,328	1,285	1,328	1,285	1,328

The firm yield of Palmetto Bend Reservoir – Stage II is estimated by using the TCEQ Lavaca River Basin Water Availability Model (Lavaca WAM) (USBR, 2001) data sets and the Water Rights Analysis Package (WRAP) (TCEQ, 2004). The Lavaca WAM simulates a repeat of the natural streamflows over the 57-year period of 1940 through 1996 accounting for the appropriated water rights of the Lavaca River Basin with respect to location, priority date, diversion amount, diversion pattern, storage, and special conditions including instream flow requirements.

Four potential conservation storage capacities are modeled for Palmetto Bend Reservoir – Stage II. These conservation storage capacities are associated with 50 ft-msl, 44 ft-msl, 40 ft-msl, and 35 ft-msl conservation pool elevations. Table 3.4.10-3 includes the conservation storage capacities associated with these four conservation elevations.

Palmetto Bend Reservoir – Stage II is simulated with the priority date as provided by TCEQ in Certificate of Adjudication No. 16-2095B. Firm yield estimates for Palmetto Bend Reservoir – Stage II for all four conservation elevations are shown in Table 3.4.5-3. Current planning envisions a conservation elevation of 44 ft-msl for Palmetto Bend Reservoir – Stage II, thereby yielding a water supply of 22,964 acft/yr. Figure 3.4.10-4 shows the relationship between firm yield and conservation capacity for Palmetto Bend Reservoir – Stage II.

Table 3.4.10-3.
Firm Yield vs. Conservation Storage for Palmetto Bend Reservoir – Stage II

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)
35.0	19,182	CCEFN	8,878
40.0	35,152	CCEFN	16,819
44.0*	52,046	CCEFN	22,964
		None	30,606
50.0	82,851	CCEFN	31,161
*Proposed conservation storage.			

Palmetto Bend Reservoir – Stage II was most recently evaluated by Regions L and N in the 2001 Regional Water Plans. The firm yield of Palmetto Bend Reservoir – Stage II was reported as 28,000 acft/yr at conservation elevation 44 ft-msl. The firm yield estimate in the current study differs from the 2001 Regional Water Plans because SIMDLY (a daily reservoir simulation model), rather than the WRAP model was used in regional planning. In addition, the refined elevation-area-capacity relationship in the current study has reduced the conservation capacity at elevation 44 ft-msl from 57,676 acft to 52,046 acft.
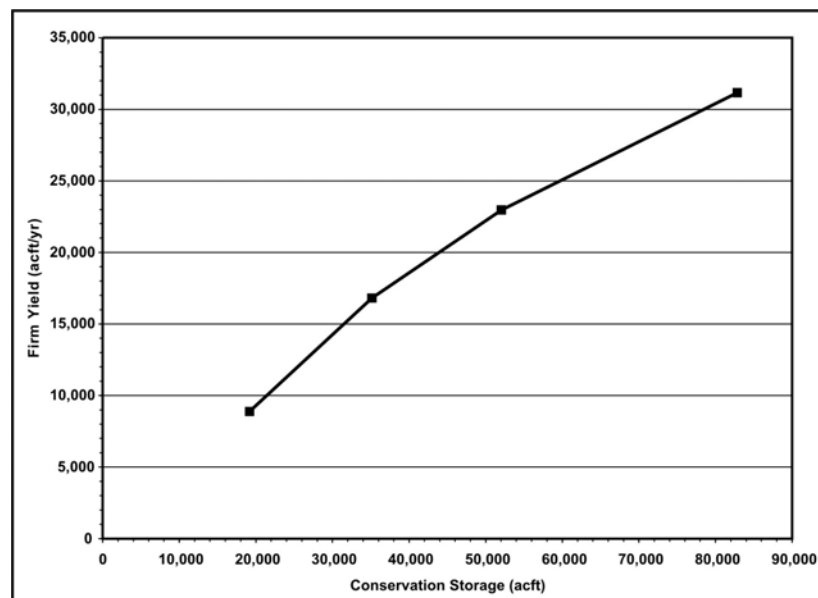
Figure 3.4.10-4. Firm Yield vs. Conservation Storage for
Palmetto Bend Reservoir – Stage II

Figure 3.4.10-5 illustrates storage fluctuations through time for Palmetto Bend Reservoir – Stage II subject to firm yield diversions and CCEFN. The reservoir storage frequency curve in Figure 3.4.10-5 indicates that the reservoir would be full about 38 percent of the time and more than half full about 90 percent of the time.
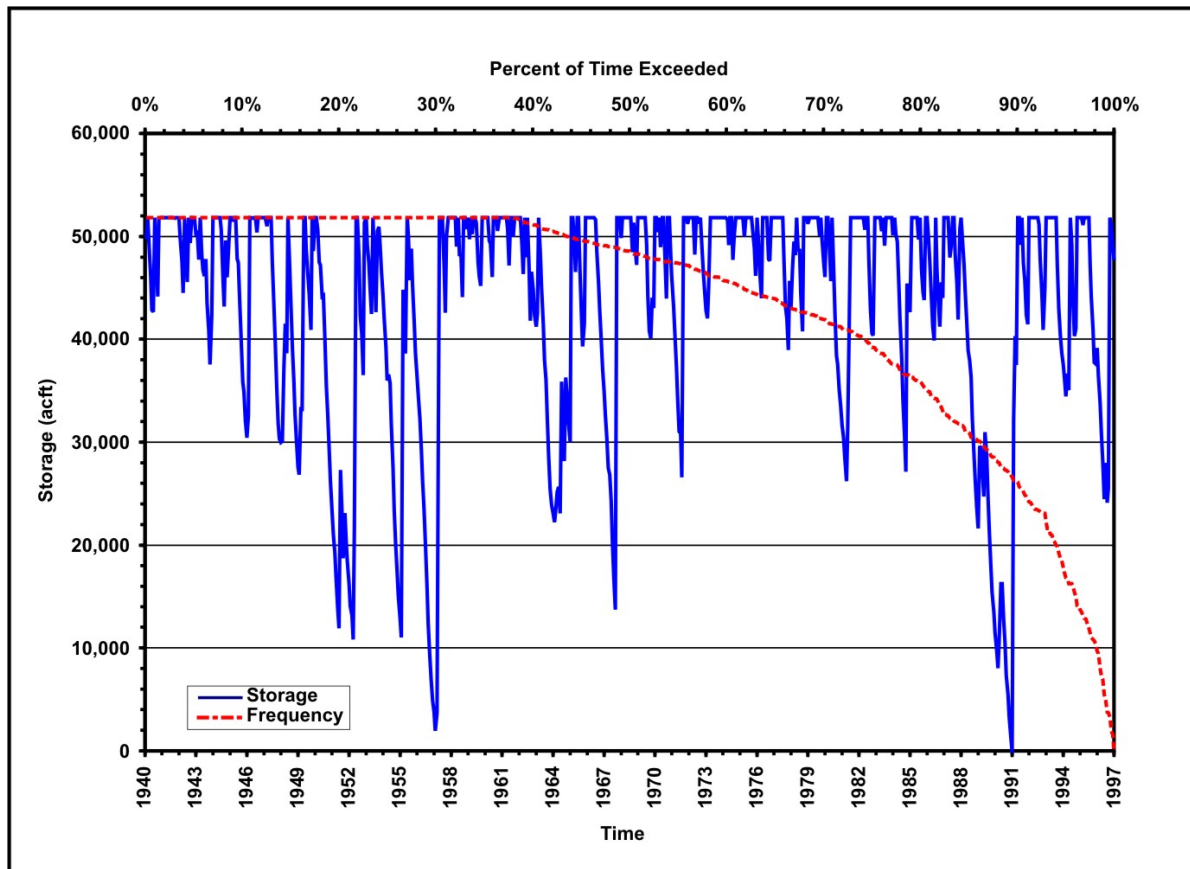
Figure 3.4.10-5. Simulated Storage in Palmetto Bend Reservoir – Stage II
(Conservation Elevation = 44 ft-msl, Diversion = 22,964 acft/yr)

3.4.10.3 *Reservoir Project Cost Estimates*

Costs for Palmetto Bend Reservoir – Stage II assume a zoned earthen embankment and uncontrolled spillway. The dam is estimated to be approximately 6,000 feet in length and have a maximum height of approximately 50 feet. Figure 3.4.10-6 shows the major conflicts within the conservation pool of Palmetto Bend Reservoir – Stage II. Potential conflicts include water wells, oil & gas wells, product transmission pipelines, power transmission lines, a railway, and U.S. Highway 59. Resolution of facility conflicts represents approximately 29 percent of the total construction cost.
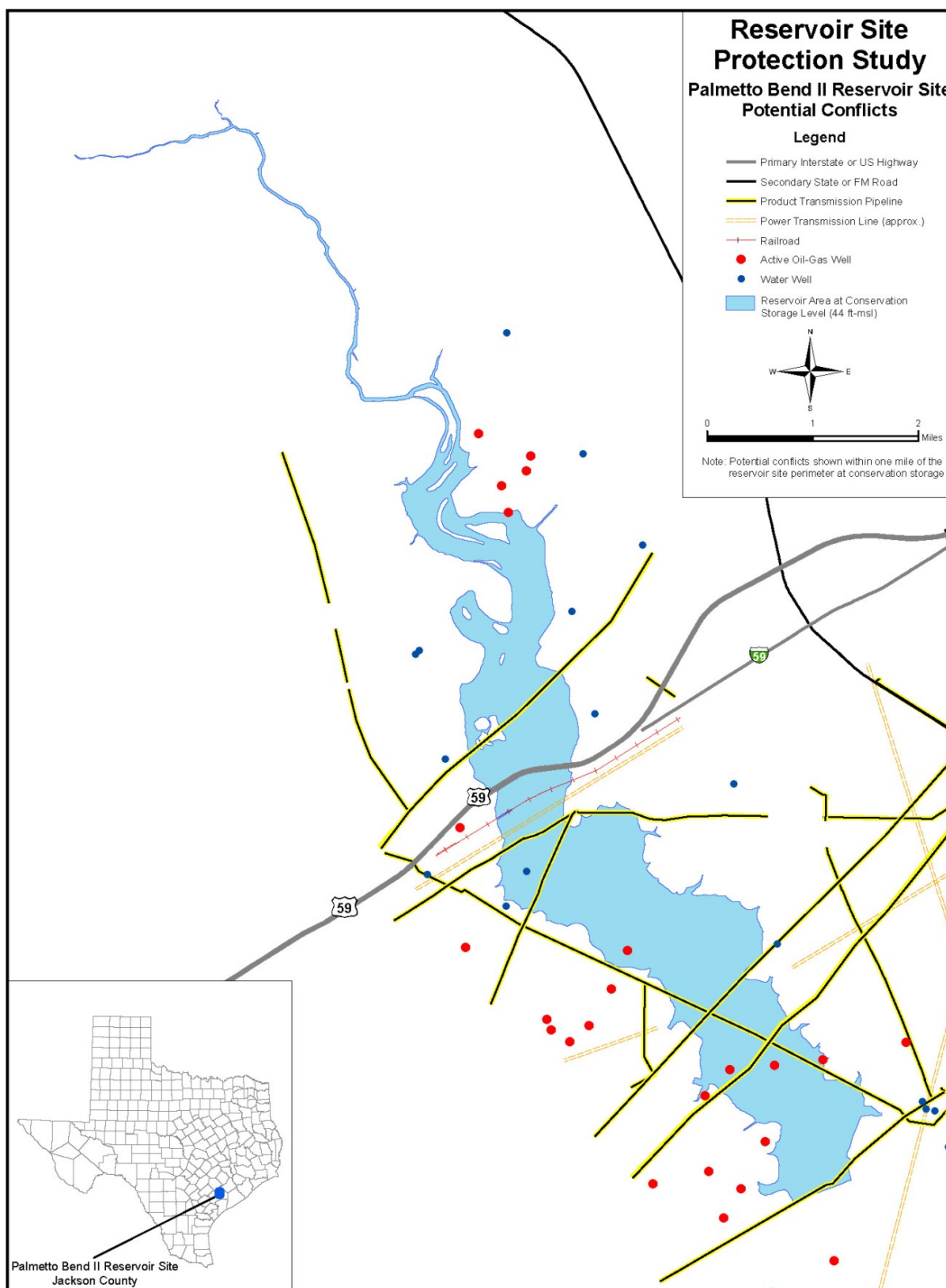
Figure 3.4.10-6. Potential Major Conflicts for Palmetto Bend Reservoir – Stage II

A summary cost estimate for Palmetto Bend Reservoir – Stage II at elevation 44 ft-msl is shown in Table 3.4.10-4. Dam and reservoir costs total about $83.8 million, while relocations total another $41.3 million. Land, which includes mitigation lands, totals about $17 million. Annual costs for Palmetto Bend Reservoir – Stage II are approximately $11.8 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $515/acftr ($1.58 per 1000 gallons).

Table 3.4.10-4.
Cost Estimate — Palmetto Bend Reservoir – Stage II @ Elevation 44 ft-msl
(page 1 of 2)

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Mobilization (5%)	1	LS		$2,797,713
Clearing and Grubbing		LS		$1,659,435
Care of Water During Construction (3%)	1	LS		$1,678,628
Dam		LS		$2,887,690
Spillway		LS		$41,022,059
Excess Excavation Disposal Berms & Drainage Channels		LS		$6,599,656
Upstream Slope Protection		LS		$1,436,364
Underdrain System		LS		$737,225
Channel Slope Protection		LS		$1,566,942
Dam Road		LS		$711,381
Revegetation		LS		$992,941
Engineering Contingencies (35%)				$21,731,512
Subtotal Dam & Reservoir				**$83,821,546**
Conflicts				
H20 Drill	2	EA	$25,000	$50,000
H20 Wells	5	EA	$25,000	$125,000
Oil & Gas Wells	4	EA	$25,000	$100,000
Oil & Gas Pipeline	48,619	LF	$98	$4,764,639
Power Transmission Line	25,580	LF	$450	$11,511,157
Rail	4,246	LF	$750	$3,184,675
Major Roads	12,094	LF	$900	$10,884,532
Engineering Contingencies (35%)				$10,717,001
Subtotal Conflicts				**$41,337,004**

Table 3.4.10-4.
Cost Estimate — Palmetto Bend Reservoir – Stage II @ Elevation 44 ft-msl
(page 2 of 2)

Land				
Land Acquisition	5,217	AC	$1,627	$8,488,059
Environmental Studies and Mitigation Lands	5,217	AC	$1,627	<u>$8,488,059</u>
Subtotal Land				**$16,967,118**
CONSTRUCTION TOTAL				**$142,134,667**
Interest During Construction (36 months)				**$17,056,160**
TOTAL COSTS				**$159,190,827**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$10,579,822
Operations & Maintenance				<u>$1,257,323</u>
Total Annual Costs				**$11,837,146**
Firm Yield (acft/yr)				**22,964**
Unit Costs of Water ($/acft/yr)				**$515**

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum;
SF = Square Foot; and SY = Square Yard.

3.4.10.4 *Environmental Considerations*

Palmetto Bend Reservoir – Stage II will inundate a portion of TCEQ-classified stream segment 1601 on the Lavaca River. Texas Parks and Wildlife Department (TPWD, 1999) listed the segment of the Lavaca River immediately downstream of the reservoir as ecologically significant. Palmetto Bend Reservoir – Stage II could have effects relevant to two TPWD criteria as follows:

- <u>Biological Function</u> — Extensive freshwater wetland habitat displays significant overall habitat value.
- <u>Threatened or Endangered Species/Unique Communities</u> — the diamondback terrapin is a species of concern.

Palmetto Bend Reservoir – Stage II will inundate 4,564 acres of land at conservation storage capacity. Table 3.4.10-5 and Figure 3.4.10-7 summarize existing landcover for the Palmetto Bend Reservoir – Stage II Reservoir site as determined by TPWD using methods

described in Appendix C. Existing landcover within this reservoir site is dominated by grassland
(42 percent) with broad-leaf evergreen forest (34 percent) and upland deciduous forest (11
percent) concentrated along the Lavaca River.

Table 3.4.10-5.
Acreage and Percent Landcover for Palmetto Bend Reservoir – Stage II

Landcover Classification	Acreage[1]	Percent
Grassland	2,020	42.2%
Broad Leaf Evergreen Forest	1,630	34.0%
Agricultural Land	234	4.9%
Upland Deciduous Forest	515	10.8%
Shrubland	365	7.6%
Open Water	22	0.5%
Total	**4,786**	**100.0%**

[1] *Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.*
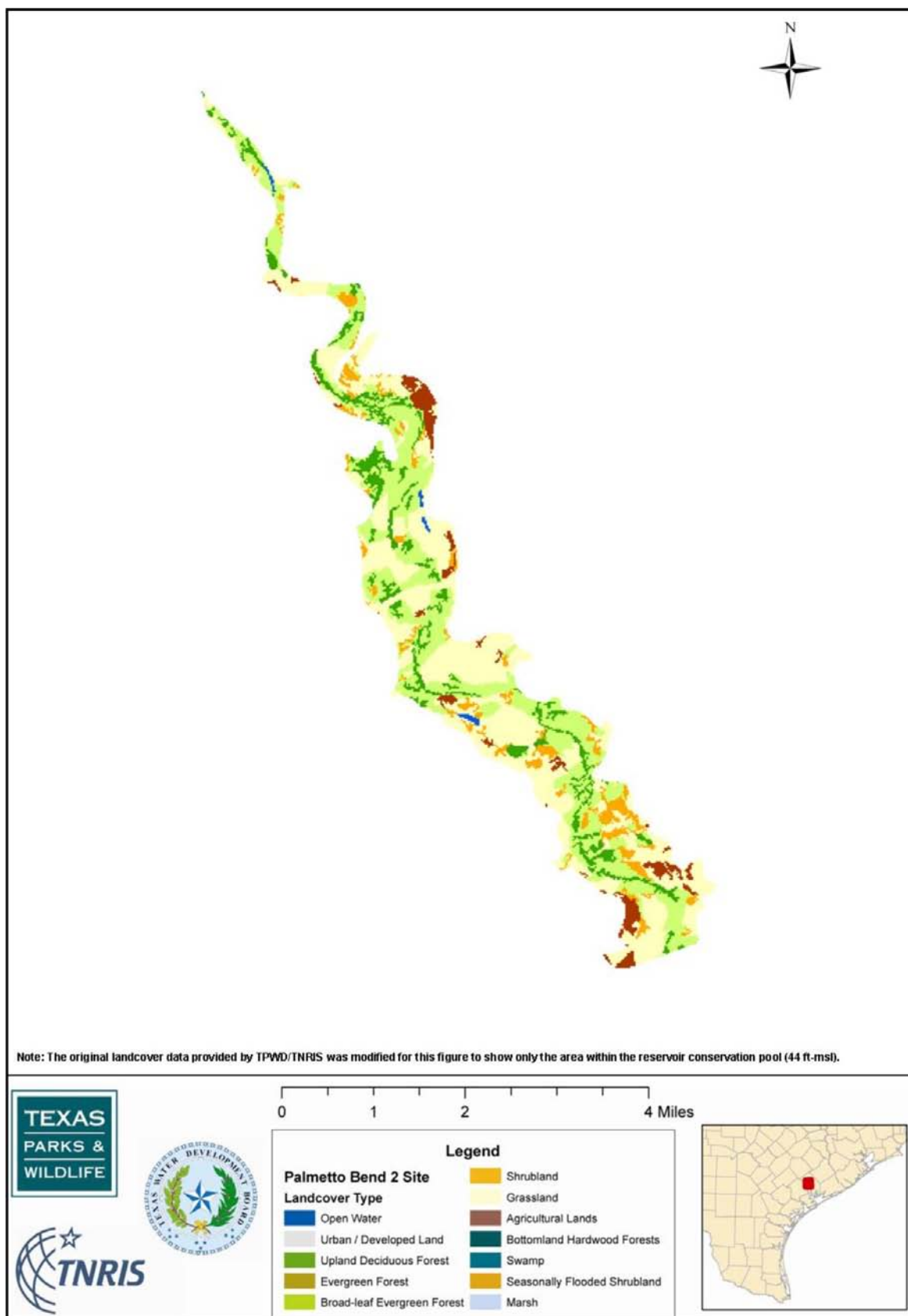
Figure 3.4.10 -7. Existing Landcover for Palmetto Bend Reservoir – Stage II

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3.4.11 George Parkhouse I Lake

3.4.11.1 *Description*

George Parkhouse I Lake would be located on the South Sulphur River in Delta and Hopkins Counties, about 18 miles northeast of the City of Sulphur Springs. Figure 3.4.11-1 shows the location of the reservoir. The proposed conservation pool is at elevation 401 ft-msl, with a conservation capacity of 651,712 acft. The inundated area at the top of conservation pool is 28,855 acres. The reservoir has a total drainage area of 654 square miles, of which 479 are above Lake Chapman.
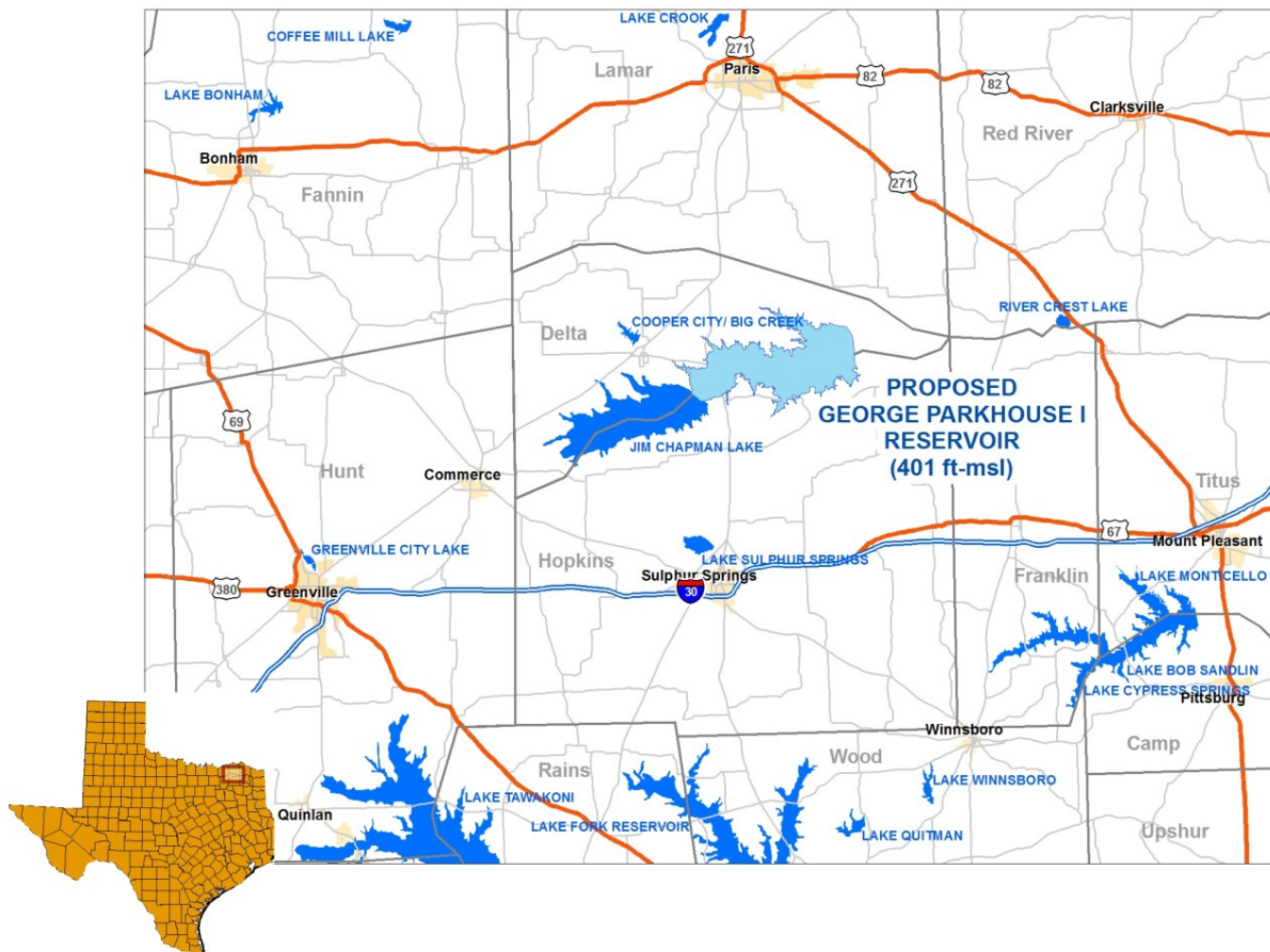
Figure 3.4.11-1. Location Map of George Parkhouse I Lake

This reservoir has been previously studied by Freese and Nichols (1990, 1996, and 2000) and it is an alternate water management strategy for North Texas Municipal Water District and the Upper Trinity River Water District in the 2006 *Region C Water Plan* (Freese and Nichols *et al.*, 2006a).

The George Parkhouse I Lake site is not a recommended unique reservoir site in the 2006 regional water plans, but it is one of several potential reservoir sites in the Sulphur River Basin. The projected needs for additional water supply within 50 miles of the proposed reservoir site are 561,591 acft/yr. Much of this need is associated with Region C, located west of the proposed reservoir site. The nearest major demand center is the Dallas-Fort Worth metroplex, which is located approximately 93 miles southwest of the reservoir site.

3.4.11.2 *Reservoir Yield Analysis*

The elevation-area-capacity relationship is included in Table 3.4.11-1 and shown in Figure 3.4.11-2. The data in Table 3.4.11-1 were developed by Freese and Nichols (2000) by measurement from U.S. Geological Survey topographic quadrangle maps with scale 1:24,000 and 10-foot contours. Figure 3.4.11-3 shows the inundation map at different elevations in a 10-foot interval. The elevation of the 100-year flood and the maximum probable flood depend on how the storm is routed through Lake Chapman. Lake Chapman flood control operations may change if George Parkhouse I Lake is built. The analysis required to determine the elevation of the 100-year flood and probable maximum flood requires detailed hydrologic modeling that are not part of the scope of this study. Therefore, the inundated areas during the representative flood events are not included for this reservoir.

Table 3.4.11-1.
Elevation-Area-Capacity Relationship for George Parkhouse I Lake

Elevation (feet)	Area (acres)	Capacity (acft)
335.0	0	0
340.0	28	74
345.0	242	745
350.0	456	2,489
355.0	2,513	9,884
360.0	4,571	27,584
365.0	6,567	55,423
370.0	8,563	93,245
375.0	11,158	142,543
380.0	13,752	204,814
385.0	17,270	282,363
390.0	20,787	377,499
395.0	24,563	490,868
400.0	28,338	623,116
401.0	28,855	651,712
405.0	30,922	771,264
410.0	33,506	932,332
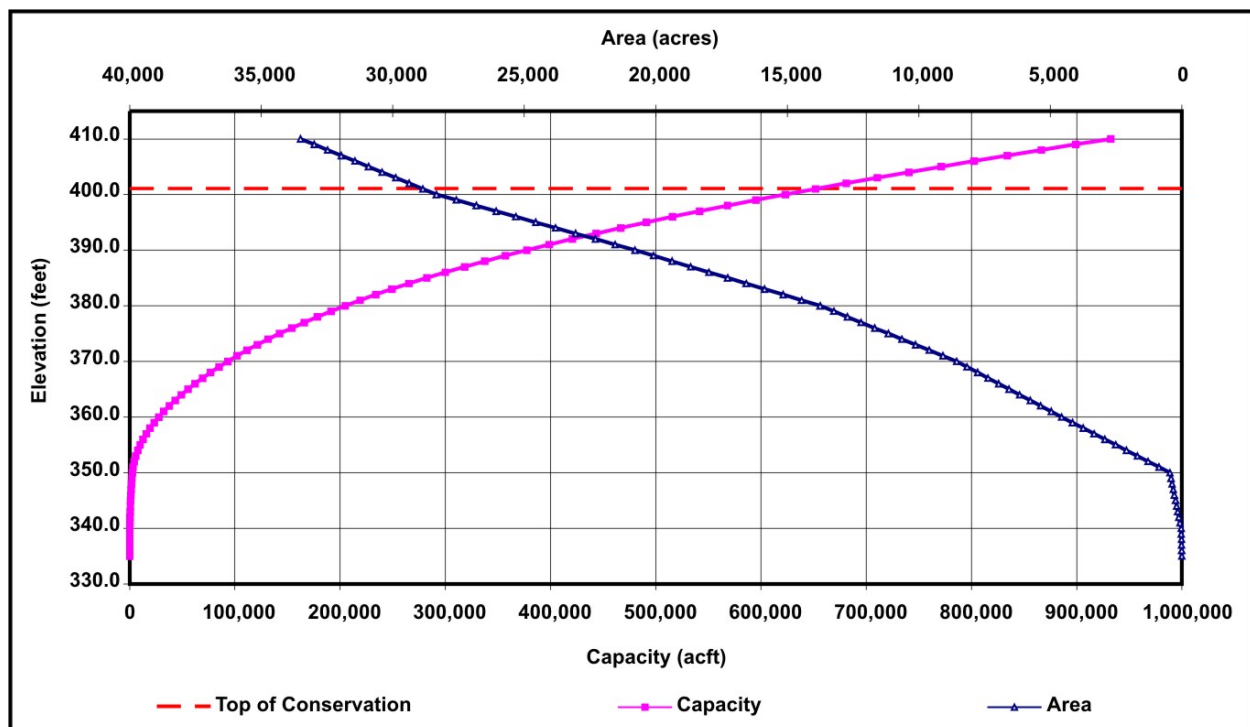
Figure 3.4.11-2. Elevation-Area-Capacity Relationship for George Parkhouse I Lake

The reservoir will be subject to bypass of inflow for environmental needs. Table 3.4.11-2 includes the environmental flows needs calculated using the Consensus Criteria for Environmental Flow Needs (TWDB, 1997). The analyses assume that the reservoir will have to pass the lesser of the inflow and the values of Table 3.4.11-2.

Table 3.4.11-2.
Consensus Criteria for Environmental Flow Needs for George Parkhouse I Lake

	Median		25th Percentile		7Q2	
	acft/mo	*cfs*	*acft/mo*	*cfs*	*acft/mo*	*cfs*
Jan	1,919	31.2	318	5.2	0	0.0
Feb	3,596	64.2	794	14.2	0	0.0
Mar	3,748	60.9	800	13.0	0	0.0
Apr	2,697	45.3	638	10.7	0	0.0
May	4,687	76.2	741	12.0	0	0.0
Jun	1,854	31.1	294	4.9	0	0.0
Jul	233	3.8	22	0.4	0	0.0
Aug	47	0.8	0	0.0	0	0.0
Sep	72	1.2	0	0.0	0	0.0
Oct	180	2.9	9	0.2	0	0.0
Nov	696	11.7	88	1.5	0	0.0
Dec	1,916	31.1	177	2.9	0	0.0
Total	21,644		3,879		0	
Average	1,804	30.0	323	5.4	0	0.0

Figure 3.4.11-3. Inundation Map for George Parkhouse I Lake

The firm yield of Parkhouse I Lake was calculated with the full authorization scenario (Run 3) of the Water Availability Model of the Sulphur River Basin (dated July 15, 2004) obtained from TCEQ (Brandes, 1999 and TCEQ, 2006). A control point was added on the South Sulphur River at the dam location.

The naturalized flows at the reservoir sites were calculated using the drainage area ratio method with the existing series naturalized flows at gaged locations and drainage areas obtained from the USGS, as was done for Marvin Nichols (See Section 3.4.8).

Net evaporation rates were calculated from TWDB quadrangle data of precipitation and gross lake evaporation. Evaporation at the reservoir site was based on data from Quadrangle 412. Net evaporation rates entered in the Sulphur WAM were adjusted to remove the portion of the precipitation on the reservoir surface area that has been accounted for in the natural inflow.

Yields were calculated for elevations 410, 401, 396, and 390 feet, subject to bypass for environmental flow needs and assuming stand-alone reservoir operations with no minimum

reserve content. Results of firm yield analyses at these elevations are included in Table 3.4.11-3 and Figure 3.4.11-4. A conservation pool elevation of 401 ft-msl was selected for this study to minimize the potential conflicts with Jim Chapman Lake and impacts to the communities of Charleston and Vasco. At higher conservation pool elevation (410 feet), additional protection of the dam and possible modifications to the spillway operation at Lake Chapman would be needed. Also the spillway size for the Parkhouse I Lake would need to be increased to keep the probable maximum flood from impacting neighboring communities. At the conservation pool level of 401 feet, the firm yield is 122,000 acft/yr. Environmental flow requirements reduce the yield of the reservoir by 2,400 acft/yr.

The yield of Parkhouse I Lake will decrease if one or more of the proposed reservoirs in the Sulphur Basin (Ralph Hall, Parkhouse II, and/or Marvin Nichols) are built and Parkhouse I Lake has a junior priority to any of these reservoirs. The scenario that produces the lowest yield assumes that Parkhouse I Lake is built after all of the other proposed reservoirs in the Sulphur Basin. Under this scenario, the yield of Parkhouse I Lake would be 48,400 acft/yr, or 73,600 acft/yr less than assuming the reservoir is senior to any other proposed reservoir. Appendix A is a memorandum describing the sensitivity of firm yield to the development of other reservoirs.

Table 3.4.11-3.
Firm Yield vs. Conservation Storage for George Parkhouse I Lake

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)	Critical Period
390.0	377,409	CCEFN	86,600	6/51 - 1/57
396.0	515,807	CCEFN	104,700	9/50 -2/57
401.0*	651,712	CCEFN	122,000	9/50 - 2/57
		None	124,400	
410.0	932,332	CCEFN	157,300	6/50-3/66
*Proposed conservation storage.				
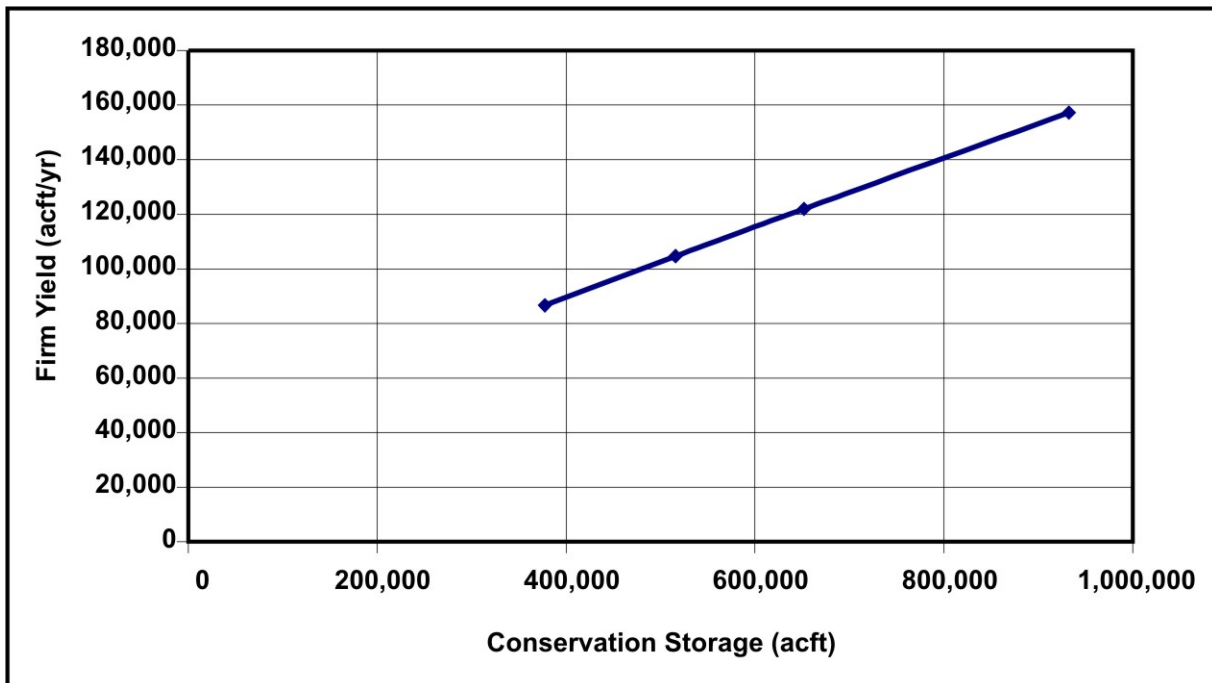
Figure 3.4.11-4. Firm Yield vs. Conservation Storage for George Parkhouse I Lake

Previous evaluations of the yield of the George Parkhouse I reservoir site have been conducted by Freese and Nichols in 1990, 1996, 2000, and 2006. The 2000 study shows that the firm yield (without restrictions due to environmental flows) is 164,500 acft/yr. The 2006 Region C Water Plan (Freese and Nichols *et al*., 2006) shows that yield of Parkhouse I is 135,600 acft/yr. Both of these studies assume a conservation pool elevation of 410 ft-msl for yield. Other differences in the yields are due to assumptions for drainage areas. The Sulphur WAM uses maps developed by CRWR to calculate drainage areas. CRWR drainage areas were used for consistency with the other areas of the Sulphur WAM, and were used in the yield determination for Region C Water Plan. The 2000 study and this study used drainage areas calculated with USGS data, which results in greater inflow to the reservoir.

Figure 3.4.11-5 presents a simulated storage trace and a frequency curve for storage content assuming annual diversions of 122,000 acft. At the conservation pool of 401 feet, and with full diversion, the reservoir would be full about 11 percent of the time and would be below 50 percent of the conservation storage about 13 percent of the months.
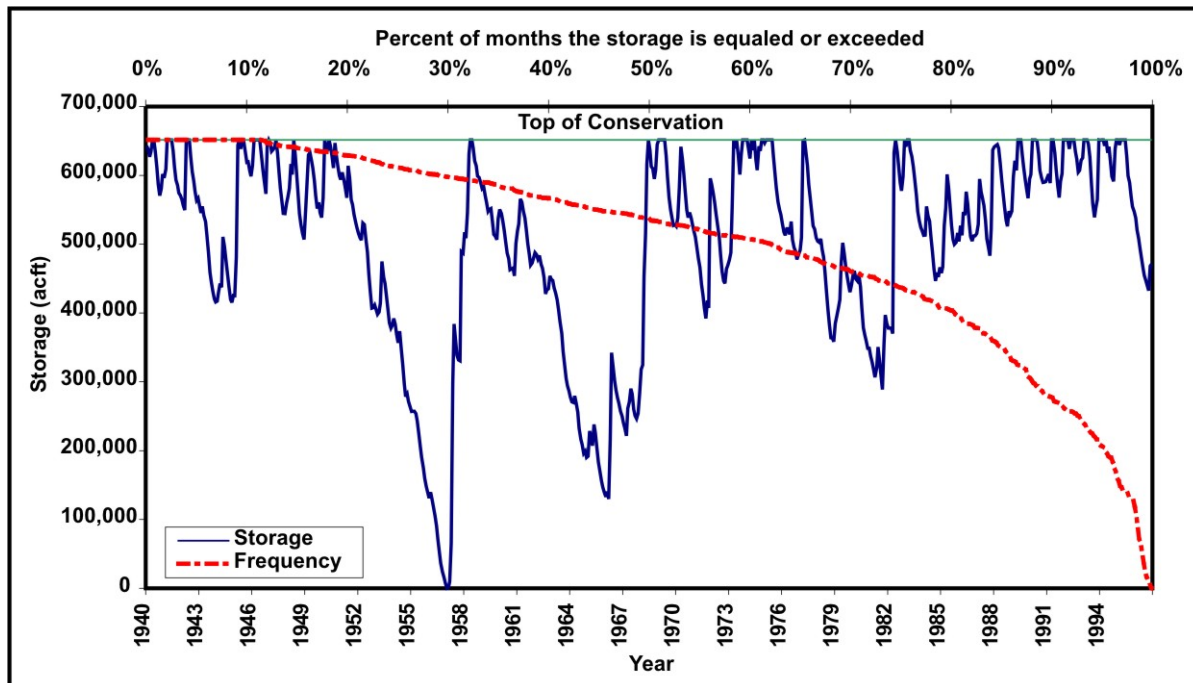
***Figure 3.4.11-5. Simulated Storage in George Parkhouse I Lake
(Conservation Elevation = 401 ft-msl, Diversion = 122,000 acft/yr)***

3.4.11.3 Reservoir Cost

The quantities used for the costs for the George Parkhouse I Dam are based on data developed from previous studies (Freese and Nichols, 1990 and 2006a). The dam and spillway costs assume a zoned earthen embankment with a gated spillway structure. The length of the dam is estimated at 22,000 feet with a maximum elevation at 420 ft-msl. The service spillway includes a gated ogee-type weir constructed of concrete, eight tainter gates, a stilling basin and discharge channel. An 800-foot wide emergency spillway is also included in the preliminary design assumptions.

The structural conflicts identified at the site include electrical lines, several roads (including State Highways 154 and 19), and product transmission pipelines. A list of the potential conflicts is provided in Table 3.4.11-4. Quantities for these conflict resolutions are based on data obtained from the Railroad Commission and TNRIS. Figure 3.4.11-6 shows the conflicts as mapped by TNRIS. In addition to these conflicts, there are several environmental conflicts. The reservoir pool includes a 200-acre tract that is in the wetland reserve program and 1,200 acres of the Jim Chapman Lake Wildlife Management Area.

Table 3.4.11-4.
List of Potential Conflicts for George Parkhouse I Lake

Gas Pipelines	Power Transmission Lines
Roads	Parks

Figure 3.4.11-6. Potential Major Conflicts for George Parkhouse I Lake

Table 3.4.11-5 shows the estimated capital costs for the George Parkhouse I Lake Project, including construction costs, engineering, permitting and mitigation. Costs for the dam and reservoir are based on the unit cost assumptions used in this study. The total estimated cost of the project is $291 million (2005 prices). Assuming a yield of 122,000 acft/yr, raw water from the project will cost approximately $174 per acre-foot ($0.53 per 1,000 gallons) during the debt service period.

3.4.11.4 *Environmental Considerations*

The George Parkhouse I Lake is not located on an identified ecologically significant stream segment. The Region D Water Planning Group did not identify the Sulphur River as ecologically unique in the 2006 water plan. The reservoir site is located some distance upstream of a Priority 1 bottomland hardwood preservation site identified as Sulphur River Bottoms West (USFWS, 1985).

George Parkhouse I Lake would inundate approximately 29,000 acres at conservation storage capacity. Table 3.4.11-6 and Figure 3.4.11-7 summarize existing landcover for the George Parkhouse I Lake site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by contiguous bottomland hardwood forest (37 percent) with sizeable areas of grassland (16 percent), marsh (16 percent), and agricultural land (16 percent).

Table 3.4.11.5.
Cost Estimate — George Parkhouse I Lake @ Elevation 401 ft-msl
(page 1 of 2)

	Quantity	*Unit*	*Unit Price*	*Cost*
Dam & Reservoir				
Excavation				
Approach Channel	140,200	CY	$2.50	$351,000
Discharge Channel	123,000	CY	$2.50	$308,000
Spillway	289,300	CY	$2.50	$723,000
Emergency Spillway	434,300	CY	$2.50	$1,086,000
Fill				
Random Compacted Fill	7,169,400	CY	$2.50	$17,924,000
Impervious Fill	1,567,800	CY	$3.00	$4,703,000
Filter	668,200	CY	$35	$23,387,000
Bridge	190	LF	$1,300	$247,000
Roadway	63,067	SY	$20	$1,261,000
Slurry Trench	800,000	SF	$15	$12,000,000
Soil Cement	394,130	CY	$65	$25,618,000
Elevator	1	LS	$100,000	$100,000
Barrier Warning System	456	LF	$100	$46,000
Gates				
Gate & Anchor	2,240	SF	$275	$616,000
Stop Gate & Lift	160	LF	$2,000	$320,000
Hoist	8	EA	$250,000	$2,000,000
Electrical	1	LS	$550,000	$550,000
Power Drop	1	LS	$250,000	$250,000
Spillway Low-Flow System	1	LS	$400,000	$400,000
Stop Gate Monorail System	390	LF	$1,000	$390,000
Embankment Internal Drainage	39,300	LF	$60	$2,358,000
Guardrail	780	LF	$30	$23,000
Grassing	28	AC	$4,500	$126,000
Concrete (mass)	52,000	CY	$150	$7,800,000
Concrete (walls)	5,600	CY	$475	$2,660,000
Mobilization (5% of subtotal)				$5,262,000
Care of water (3% of subtotal)				$3,157,000
Clearing and Grubbing	200	AC	$4,000	$800,000
Land Clearing	950	AC	$1,000	$950,000
Engineering and Contingencies (35%)				<u>$40,396,000</u>
Subtotal for Dam & Reservoir				**$155,812,000**
Conflicts				
Highways				
State Highways (S.H. 154 and S.H. 19)	35,100	LF	$900	$31,590,000
F.M.	18,500	LF	$150	$2,775,000
Gas pipelines				
30-inch	95,000	LF	$98	$9,310,000
10.75-in	81,300	LF	$30	$2,439,000
Power Transmission lines	5,330	LF	$450	$2,399,000
Engineering and Contingencies (35%)				<u>$16,980,000</u>
Subtotal of Conflicts				**$65,493,000**

Table 3.4.11.5.
Cost Estimate — George Parkhouse I Lake @ Elevation 401 ft-msl
(page 2 of 2)

Dam & Reservoir	Quantity	Unit	Unit Price	Cost
Land Acquisition	31,741	AC	$1,201	$38,121,000
Environmental Studies and Mitigation Lands	31,741	AC	$1,201	$38,121,000
Total Reservoir Construction Cost				**$259,426,000**
Interest During Construction (36 months)				**$31,564,000**
TOTAL COST				**$290,990,000**
ANNUAL COSTS				
Debt Service (6% for 40 years)				$19,340,000
Operation & Maintenance				$1,894,000
Total Annual Costs				**$21,234,000**
UNIT COSTS				
Per Acre-Foot				$174
Per 1,000 Gallons				$0.53
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.				

Table 3.4.11-6.
Acreage and Percent Landcover for George Parkhouse I Lake

Landcover Classification	Acreage[1]	Percent
Bottomland Hardwood Forest	10,379	36.8%
Marsh	4,566	16.2%
Seasonally Flooded Shrubland	584	2.1%
Swamp	83	0.3%
Upland Deciduous Forest	2,428	8.6%
Grassland	4,611	16.4%
Shrubland	211	0.7%
Agricultural Land	4,470	15.9%
Urban / Developed Land	5	0.0%
Open Water	848	3.0%
Total	28,185	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
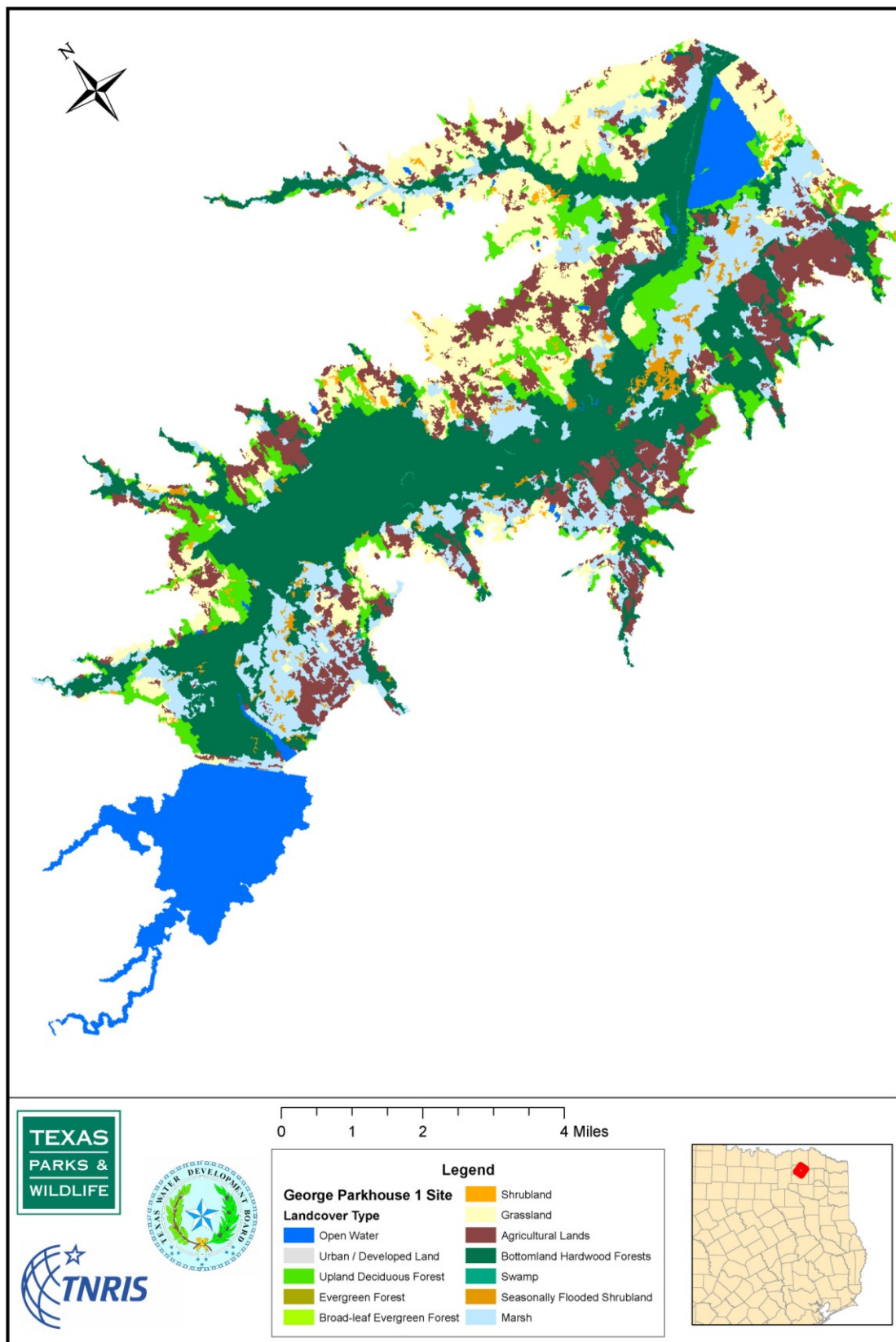
Figure 3.4.11-7. Existing Landcover for George Parkhouse I Lake

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3.4.12   George Parkhouse II Lake

3.4.12.1   _Description_

George Parkhouse II Lake (North) would be located on the North Sulphur River in Lamar and Delta Counties, about 15 miles southeast of the City of Paris. Figure 3.4.12-1 shows the location of the reservoir. The proposed conservation pool is at elevation 410 feet, with a conservation capacity of 330,871 acft. The inundated area at the top of conservation pool is 14,387 acres. The reservoir has a total drainage area of 421 square miles.
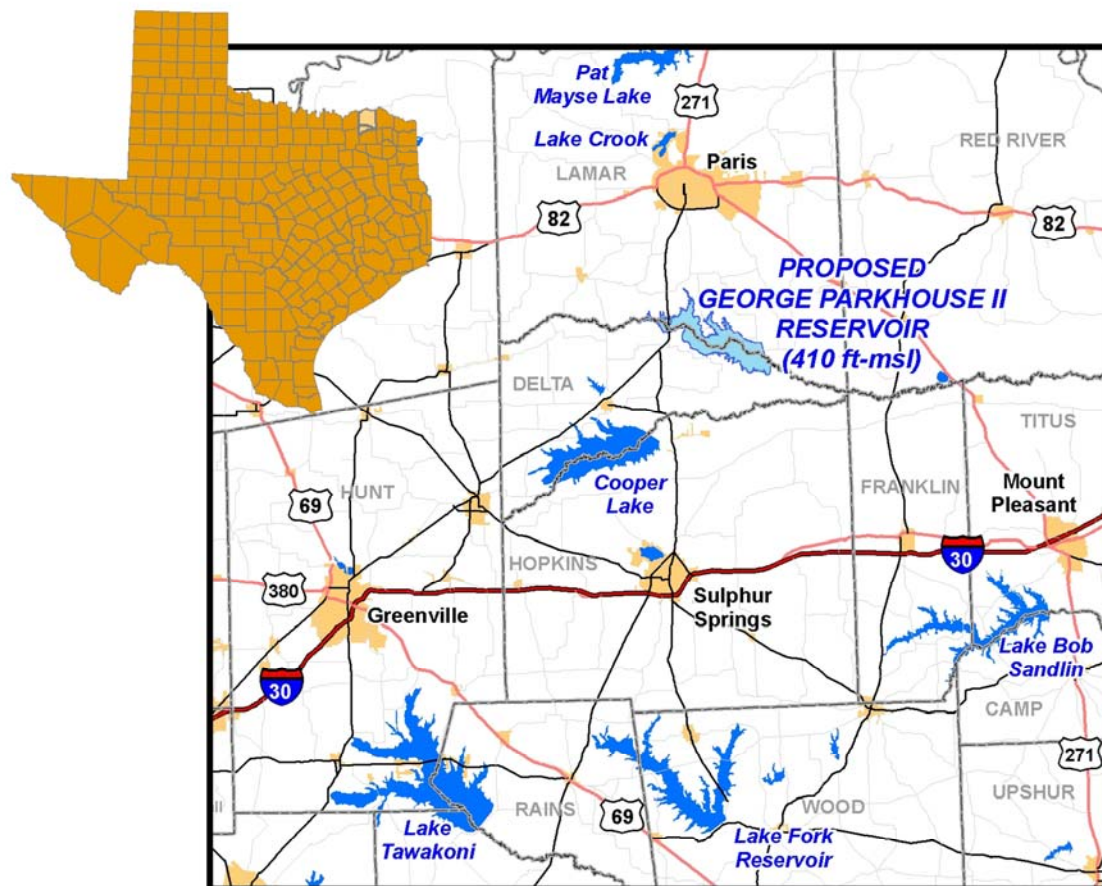
Figure 3.4.12-1 Location Map of George Parkhouse II Lake

This reservoir has been previously studied by Freese and Nichols (1990, 1996, 2000 and 2006). The Region C Water Plan (Freese and Nichols _et al._, 2006) lists George Parkhouse II Lake as an alternate water management strategy for Dallas, the North Texas Municipal Water District, Tarrant Regional Water District, and the Upper Trinity Municipal Water District.

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The George Parkhouse II Lake site is not a recommended unique reservoir site in the 2006 regional water plans, but it is one of several potential reservoir sites in the Sulphur River Basin. The projected needs within 50 miles of the proposed reservoir site are 473,850 acft/yr. Much of this need is associated with Region C, located west of the proposed reservoir site. The nearest major demand center is the Dallas-Fort Worth metroplex, which is located approximately 94 miles southwest of the reservoir site.

3.4.12.2   Reservoir Yield Analysis

The elevation-area-capacity relationship is included in Table 3.4.12-1 and shown in Figure 3.4.12-2. The data in Table 3.4.12-1 were developed by Freese and Nichols (2000) by measurement from U.S. Geological Survey topographic quadrangle maps with scale 1:24,000 and 10-foot contour interval. Figure 3.4.12-3 shows the inundation map at different elevations in a 10-foot interval, including the elevation with the probable maximum flood at 418 ft-msl.

Table 3.4.12-2 includes the environmental flows needs calculated using the Consensus Criteria for Environmental Flow Needs (TWDB, 1997). For the yield analyses, it was assumed that the reservoir will have to pass the lesser of the inflow and the values in Table 3.4.12-2.

The firm yield of Parkhouse II Lake was calculated with the full authorization scenario (Run 3) of the Water Availability Model of the Sulphur River Basin (dated July 15, 2004) obtained from TCEQ (Brandes, 1999 and TCEQ, 2006). A control point was added on the Sulphur River at the dam location.

The naturalized flows at the reservoir sites were calculated using the drainage area ratio method with the existing series naturalized flows at gaged location and drainage areas obtained from the USGS, similarly to Parkhouse I and Marvin Nichols (see Section 3.4.8). For Parkhouse II Lake, the naturalized flows were calculated using the incremental flow between the South Sulphur River near Cooper (Control Point A10), the North Sulphur River near Cooper (Control Point B10), and the South Sulphur River near Talco (Control Point C10).

Net evaporation rates were calculated from TWDB quadrangle data of precipitation and gross lake evaporation. Evaporation at the reservoir site was based on data from the Quadrangle 412. Net evaporation rates entered in the Sulphur WAM were adjusted to remove the portion of the precipitation on the reservoir surface area that has been accounted for in the natural inflow.

Table 3.4.12-1.
Elevation-Area-Capacity Relationship for George Parkhouse II Lake

Elevation (feet)	Area (acres)	Capacity (acft)
340.0	0	0
345.0	49	121
350.0	99	490
355.0	162	1,142
360.0	226	2,113
365.0	1,334	5,997
370.0	2,442	15,432
375.0	3,532	30,364
380.0	4,621	50,744
385.0	6,097	77,536
390.0	7,573	111,707
395.0	9,255	153,773
400.0	10,937	204,252
405.0	12,662	263,249
410.0	14,387	330,871
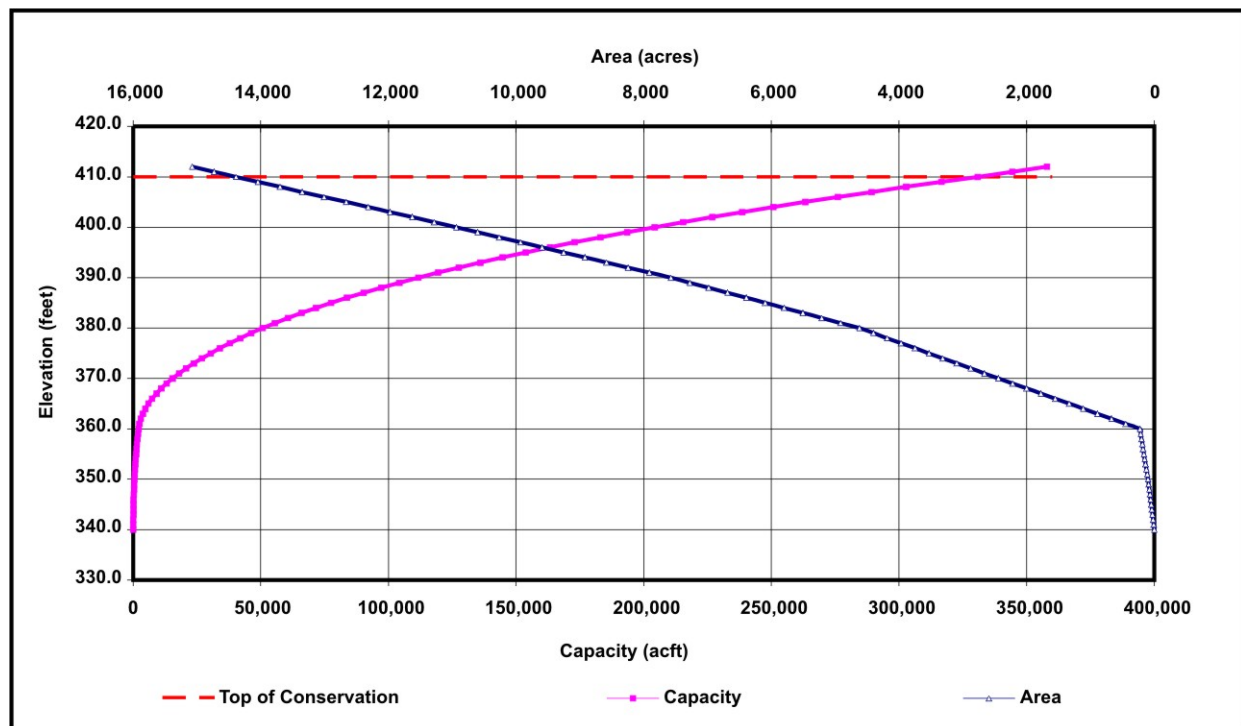
Figure 3.4.12-2. Elevation-Area-Capacity Relationship for George Parkhouse II Lake

Table 3.4.12-2.
Consensus Criteria for Environmental Flow Needs for George Parkhouse II Lake

	Median		25th Percentile		7Q2	
	acft	*cfs*	*acft*	*cfs*	*acft*	*cfs*
Jan	2,396	39.0	532	8.6	0	0.0
Feb	3,266	58.3	1,096	19.6	0	0.0
Mar	3,333	54.2	1,045	17.0	0	0.0
Apr	3,129	52.6	1,049	17.6	0	0.0
May	3,289	53.5	874	14.2	0	0.0
Jun	1,175	19.7	205	3.4	0	0.0
Jul	183	3.0	12	0.2	0	0.0
Aug	50	0.8	0	0.0	0	0.0
Sep	66	1.1	0	0.0	0	0.0
Oct	174	2.8	3	0.1	0	0.0
Nov	920	15.4	73	1.2	0	0.0
Dec	2,068	33.6	243	4.0	0	0.0
Total	20,046		5,132		0	
Average	1,671	27.8	428	7.2	0	0.0

Figure 3.4.12-3. Inundation Map for George Parkhouse II Lake

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Yields were calculated for elevations 410, 402, 396, and 390 feet, subject to bypass for environmental flow needs and assuming stand-alone reservoir operations with no minimum reserve content. Results of firm yield at these elevations are included in Table 3.4.12-3 and Figure 3.4.12-4. At the conservation pool level of 410 feet, the firm yield is 144,300 acft/yr. Environmental flow requirements reduce the firm yield of the reservoir by 2,500 acft.

Table 3.4.12-3.
Firm Yield vs. Conservation Storage for George Parkhouse II Lake

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)	Critical Period
390.0	111,707	CCEFN	71,900	8/77-12/78
396.0	163,196	CCEFN	98,600	5/77-12/78
402.0	226,816	CCEFN	120,100	5/54-1/57
410.0*	330,871	CCEFN	144,300	6/51-1/57
		None	146,800	
*Proposed Conservation Storage				
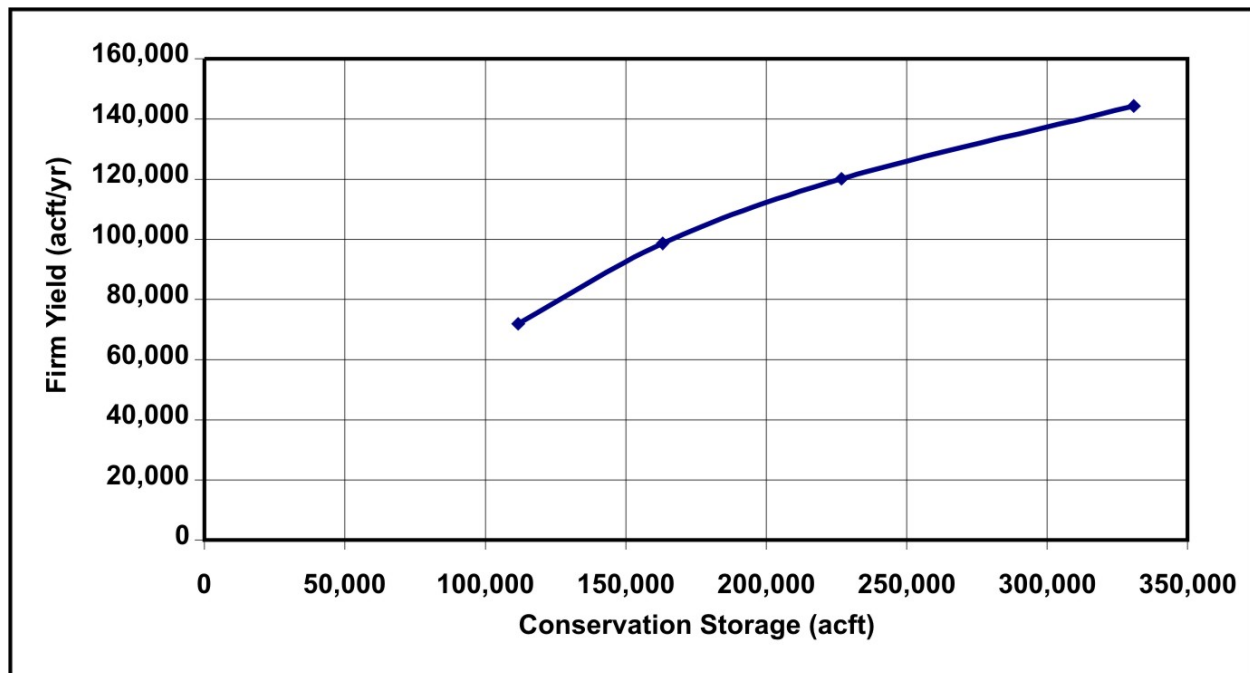
Figure 3.4.12-4. Firm Yield vs. Conservation Storage for George Parkhouse II Lake

The firm yield of Parkhouse II Lake will decrease if one or more of the proposed reservoirs in the Sulphur Basin (Ralph Hall, Parkhouse I, and/or Marvin Nichols) are built and Parkhouse II Lake has a junior priority to any of these reservoirs. As of November 2006, Ralph

Hall Lake is in the permitting process and likely would be senior to Parkhouse II. Yield analysis determined that Ralph Hall Lake would reduce the firm yield of Parkhouse II by 26,900 acft/yr, which is 18 percent of the stand-alone yield. If Parkhouse II is junior to all of the other proposed reservoirs in the Sulphur Basin, its yield would be 32,100 acft/yr, which is 112,200 acft/yr less than the stand-alone yield (or a reduction of 78 percent). Appendix A is a memorandum describing the sensitivity of firm yield to the development of other reservoirs.

Freese and Nichols (1990, 1996, 2000, and 2006) has performed previous evaluations of this reservoir. The 2000 study shows that the firm yield (without restrictions due to environmental flows) is 152,500 acft/yr. The 2006 Region C Water Plan (Freese and Nichols et al., 2006) shows that yield of Parkhouse II is 148,700 acft/yr, which is 4,400 (or 3 percent) more than the yield of this study. Differences between the Region C estimate and this study are due to assumptions for drainage areas for estimating flow. The Region C yield used the Sulphur WAM methodology for calculating drainage areas while this study used calculations from USGS data. The 2000 study shows a higher yield because it does not consider environmental flows.

The simulated storage trace and frequency curve for storage content for George Parkhouse II Lake with an annual diversion of 144,300 acft are shown in Figure 3.4.12-5. At the conservation pool of 410 feet, assuming full diversion, the reservoir would be full about 23 percent of the time and would be below 50 percent of the conservation storage about 8 percent of the months.
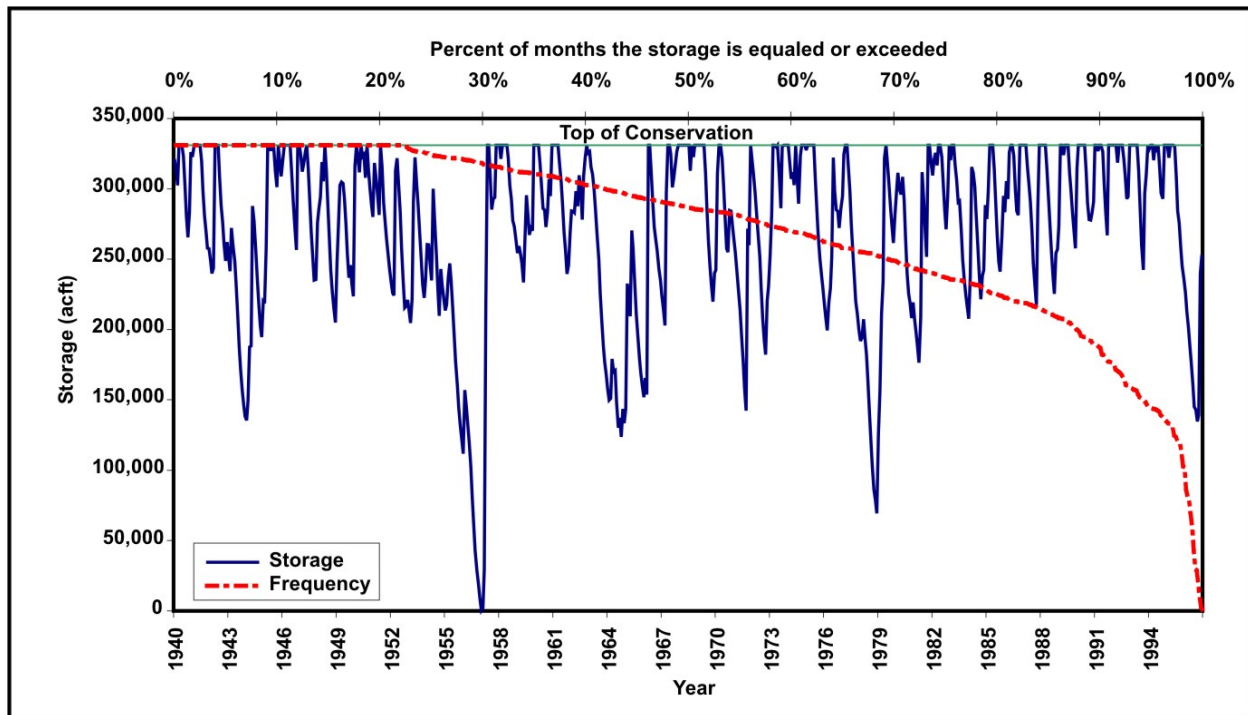
**Figure 3.4.12-5. Simulated Storage in George Parkhouse II Lake
(Conservation Elevation = 410 ft-msl, Diversion = 144,300 acft/yr)**

3.4.12.3 *Reservoir Cost*

The quantities used for the costs for the George Parkhouse II Dam are based on data developed from previous studies (Freese and Nichols, 2000). The dam and spillway costs assume a zoned earthen embankment with a gated spillway structure. The length of the dam is estimated at 24,760 feet with a maximum elevation of 420 ft-msl. The service spillway includes a gated ogee-type weir constructed of concrete, ten tainter gates, a stilling basin and discharge channel.

The conflicts identified at the site include electrical lines, roads (including State Highway 19), oil and gas wells, one water well, and two 30-inch parallel gas lines. A list of the potential conflicts is provided in Table 3.4.12-4. Quantities for these conflict resolutions are based on data obtained from the Railroad Commission and TNRIS. Figure 3.4.12-6 shows the conflicts as mapped by TNRIS.

**Table 3.4.12-4.
List of Potential Conflicts for George Parkhouse II Lake**

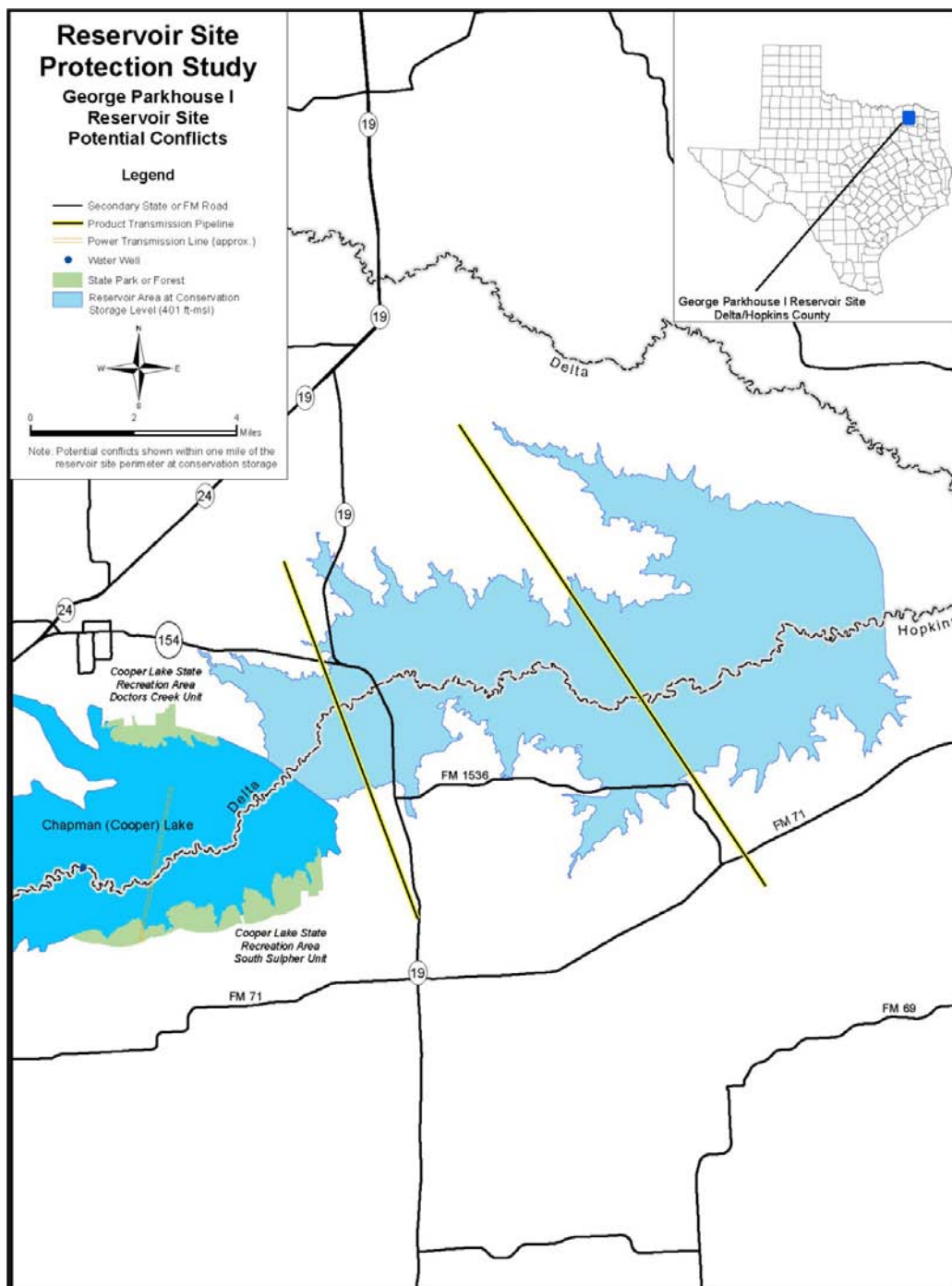| Gas Pipelines	Power Transmission Lines
Roads	Wells
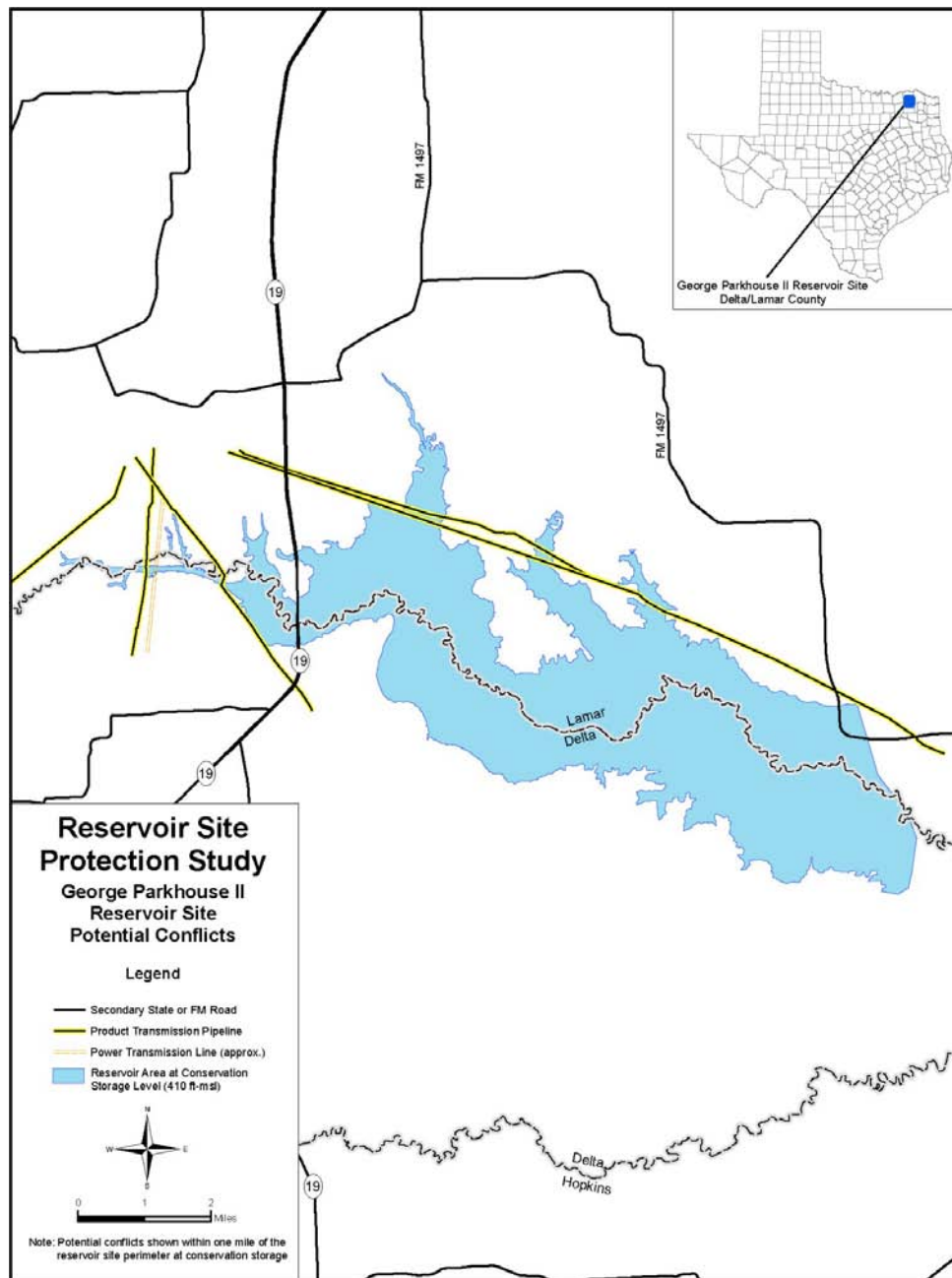
Figure 3.4.12-6. Potential Major Conflicts for George Parkhouse II Lake

Table 3.4.12-5 shows the estimated capital costs for the George Parkhouse II Lake Project, including construction costs, engineering, permitting, and mitigation. Unit costs for the dam and reservoir are based on the unit cost assumptions used in this study. The total estimated cost of the project is $210 million (2005 prices). Assuming a yield of 144,300 acft/yr, raw water from the project will cost approximately $107 per acft ($0.33 per 1,000 gallons) during the debt service period.

3.4.12.4   *Environmental Considerations*

The George Parkhouse II Lake is not located on an identified ecologically significant stream segment. The Region D Water Planning Group did not identify the Sulphur River as ecologically unique in the 2006 water plan. The reservoir site is located some distance upstream of a Priority 1 bottomland hardwood preservation site identified as Sulphur River Bottoms West (USFWS, 1985).

George Parkhouse II Lake will inundate approximately 14,400 acres of land at conservation storage capacity. Table 3.4.12-6 and Figure 3.4.12-7 summarize existing landcover for the George Parkhouse II Lake site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (49 percent) with sizeable areas of upland deciduous forest (26 percent) and agricultural land (16 percent). Only about 1.4 percent of this site is classified as bottomland hardwood forest.

Table 3.4.12-5.
Cost Estimate - George Parkhouse II Reservoir @ Elevation 410 ft-msl
(page 1 of 2)

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Excavation	802,200	CY	$2.50	$2,005,500
Fill				
Random Compacted Fill	3,173,100	CY	$2.50	$7,932,800
Impervious Fill	786,000	CY	$3.00	$2,358,000
Structural Fill	8,600	CY	$12.00	$103,200
Filter Drain	296,300	CY	$35	$10,370,500
Bridge	490	LF	$1,300	$637,000
Roadway	60,520	SY	$20	$1,210,400
Slurry Trench	1,078,000	SF	$15	$16,170,000
Soil Cement	208,100	CY	$65	$13,526,500
Barrier Warning System	490	LF	$100	$49,000
Gates				
Gate & Anchor	10,000	SF	$275	$2,750,000
Stop Gate & Lift	490	LF	$2,000	$980,000
Hoist	10	EA	$250,000	$2,500,000
Electrical	1	LS	$550,000	$550,000
Power Drop	1	LS	$250,000	$250,000
Spillway Low-Flow System	1	LS	$400,000	$400,000
Stop Gate Monorail System	490	LF	$1,000	$490,000
Guardrail	780	LF	$30	$23,400
Grassing	100	AC	$4,500	$450,000
Concrete (mass)	79,700	CY	$150	$11,955,000
Concrete (reinforced)	24,100	CY	$475	$11,447,500
Subtotal				***$86,158,800***
Mobilization (5% of subtotal)				$4,307,900
Care of water (3% of subtotal)				$2,584,800
Clearing and Grubbing	150	AC	$4,000	$600,000
Land Clearing	3,600	AC	$1,000	$3,600,000
Engineering and Contingencies (35%)				$34,038,000
Subtotal for Dam & Reservoir				**$131,289,500**
Conflicts				
Highways				
State Highways (S.H.19)	8,400	LF	$900	$7,560,000
F.M.	11,100	LF	$150	$1,665,000
Gas pipelines				
30-inch (2 pipelines)	33,800	LF	$98	$3,312,000
Oil & Gas wells	9	EA	$25,000	$225,000
Water Wells	1	EA	$49,000	$49,000
Power Transmission lines	610	LF	$450	$275,000
Engineering and Contingencies (35%)				$4,580,000
Subtotal of Conflicts				**$17,666,000**
	Quantity	**Unit**	**Unit Price**	**Cost**
Land Acquisition	15,826	AC	$1,201	$19,007,000
Environmental Studies and Mitigation Lands	15,826	AC	$1,201	$19,007,000
Total Reservoir Construction Cost				**$186,969,500**
Interest During Construction (36 months)				**$22,749,000**
TOTAL COST				**$209,718,500**

Table 3.4.12-5.
Cost Estimate - George Parkhouse II Reservoir @ Elevation 410 ft-msl
(page 2 of 2)

ANNUAL COSTS	
Debt Service (6% for 40 years)	$13,938,000
Operation & Maintenance	$1,551,000
Total Annual Costs	**$15,489,000**
UNIT COSTS	
Per Acre-Foot	$107
Per 1,000 Gallons	$0.33

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

Table 3.4.12-6.
Acreage and Percent Landcover for George Parkhouse II Reservoir

Landcover Classification	*Acreage[1]*	*Percent*
Bottomland Hardwood Forest	208	1.4%
Seasonally Flooded Shrubland	170	1.1%
Swamp	31	0.2%
Evergreen Forest	9	0.0%
Upland Deciduous Forest	4,003	26.0%
Grassland	7,605	49.5%
Shrubland	672	4.4%
Agricultural Land	2,424	15.8%
Urban / Developed Land	45	0.3%
Open Water	200	1.3%
Total	15,367	100.0%

[1] *Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.*
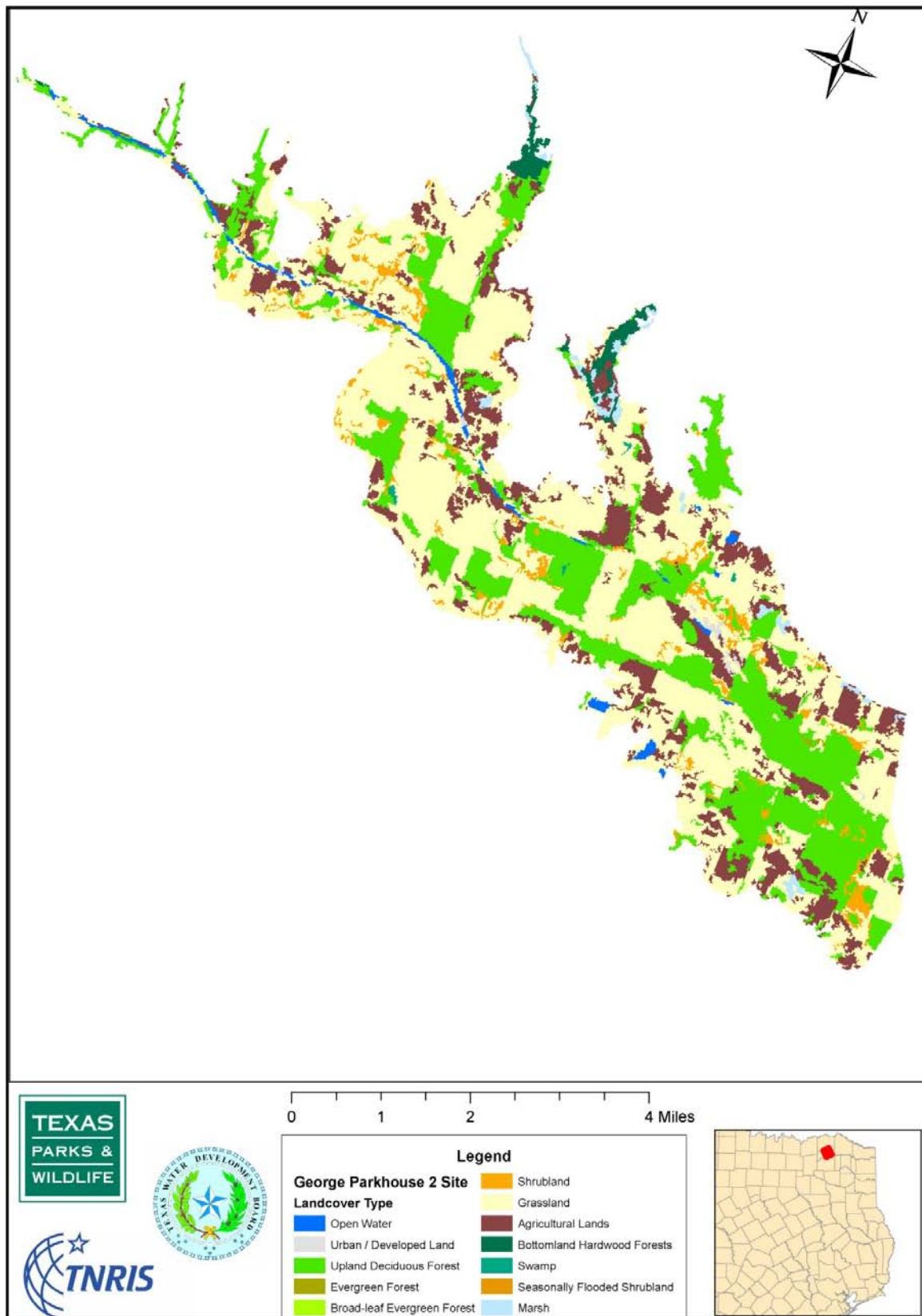
Figure 3.4.12-7. Existing Landcover for George Parkhouse II Lake

3.4.13   Lake Ralph Hall

3.4.13.1   Description

Lake Ralph Hall is proposed by the Upper Trinity Regional Water District (UTRWD) on the North Sulphur River in the Sulphur River Basin in Fannin County, as illustrated in Figure 3.4.13-1. The reservoir is recommended as a water management strategy in the 2006 Region C Water Plan and the 2007 State Water Plan (Texas Water Development Board, 2006). The primary purpose of the project is to provide a municipal water supply source to meet future water demands within that portion of Fannin County that lies within the Sulphur Basin and future demands within the service area of the UTRWD in the Trinity River Basin. A water rights permit application for the project is pending review and approval at the Texas Commission on Environmental Quality (TCEQ).   An application for a Section 404 permit has also been submitted to the U. S. Army Corps of Engineers.
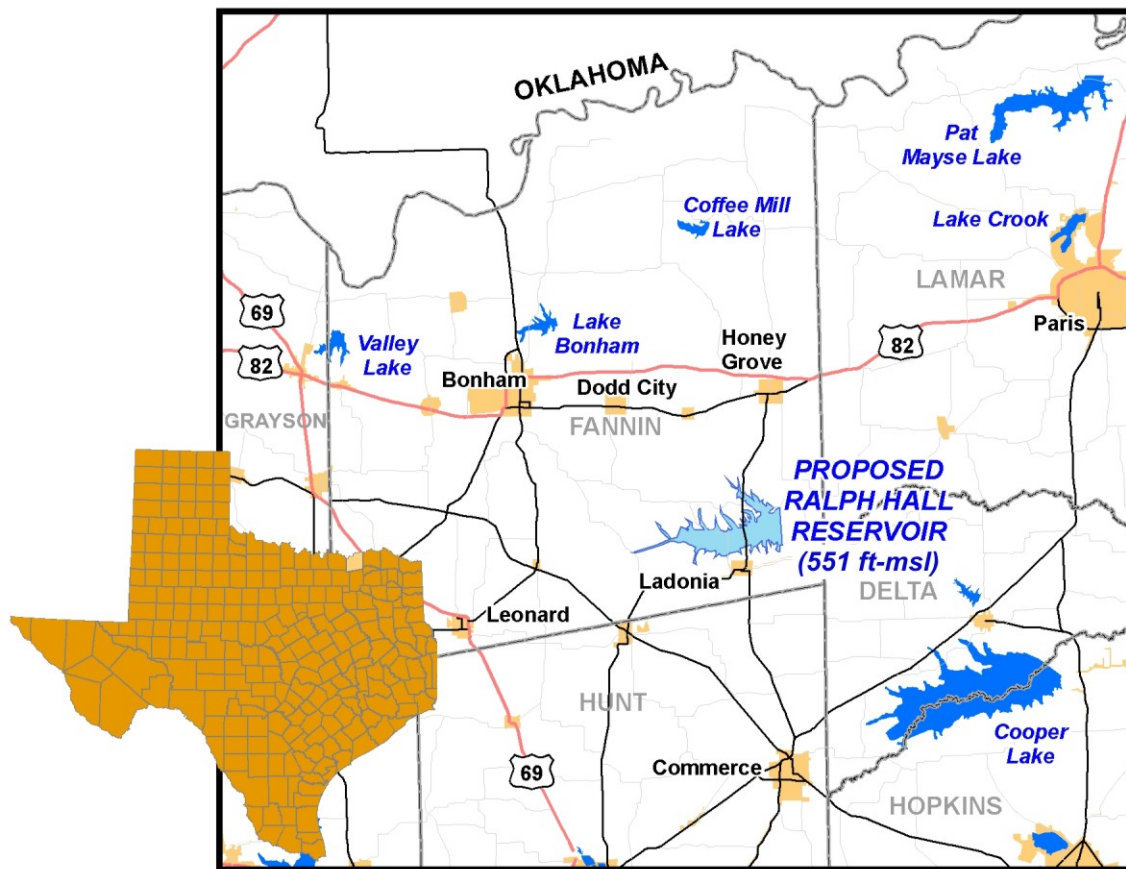
Figure 3.4.13-1. Location Map of Lake Ralph Hall

The maximum storage capacity of the project is proposed to be 160,235 acft at an elevation of 551 ft-msl. The firm yield is estimated to be approximately 32,940 acft/yr; however, annual withdrawals from the reservoir may be as much as 45,000 acft/yr as the project is operated in a systems mode with other UTRWD sources of water in order to maximize UTRWD's overall available water supply. The projected water needs within 50 miles of the proposed reservoir site by 2060 are approximately 419,000 acft/yr. The nearest major demand center is the Dallas/Fort Worth metroplex, which is located approximately 70 miles west of the project site.

The upstream drainage area of the project is approximately 101 square miles. The reach of the North Sulphur River, where Lake Ralph Hall is to be located, is unique because of the deep, incised, and eroded river channel that lies within a fairly broad, flat floodplain. While the depth and width of the river channel vary in the vicinity of the proposed project, at the proposed dam site, it is a steep-walled, deep gorge approximately 40 feet deep and 300 feet wide, with the capacity to fully contain and convey the 100-year flood. The existing river channel has been formed over the years by extensive erosion of a relatively small man-made drainage ditch that was constructed in the late 1920's and early 1930's along the valley of the North Sulphur River to protect and drain agricultural fields. With the impoundment of Lake Ralph Hall, the ongoing erosional processes in the river channel within the reservoir and for some distance downstream will be curtailed.

The proposed structure will consist of an earth-filled embankment across the valley of the North Sulphur River with a crest elevation of 562 ft-msl. An ungated concrete principal spillway will be constructed within the channel of the river near the center of the embankment, and a concrete-capped emergency spillway will be located within the embankment on the northern floodplain of the river.

3.4.13.2   *Reservoir Yield Analysis*

The water supply capabilities of the proposed reservoir site were previously investigated by R. J. Brandes Company as part of the original planning for the project, and results from that study formed the basis for the water rights permit application that has been submitted to the TCEQ. Additional yield analyses have not been undertaken since the physical features of the dam and reservoir for Lake Ralph Hall already have been established and included in the pending application.

The elevation-area-capacity relationship and the corresponding conservation storage capacity for the proposed reservoir, as determined from a two-foot contour map of the reservoir site prepared specifically for the project, are presented in Table 3.4.13-1 and depicted graphically in Figure 3.4.13-2. Figure 3.4.13-3 shows the reservoir inundation area at different water surface elevations.

Table 3.4.13-1.
Elevation-Area-Capacity Relationship for Lake Ralph Hall

Elevation (ft-msl)	Area (acres)	Capacity (acft)
460.0	0	0
470.0	18	57
480.0	50	397
500.0	208	2,357
510.0	941	7,521
520.0	2,003	21,849
530.0	3,307	47,989
540.0	5,189	90,104
550.0	7,345	152,630
551.0	7,605	160,235
560.0	9,914	238,693
564.0	10,985	280,506
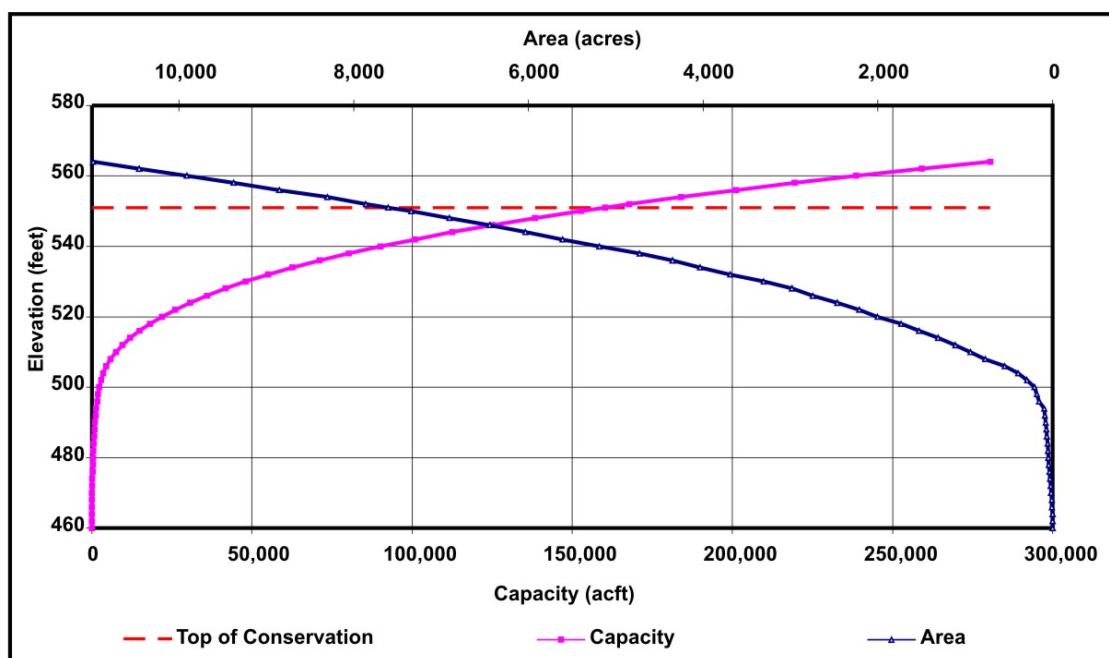
Figure 3.4.13-2. Elevation-Area-Capacity Relationship for Lake Ralph Hall
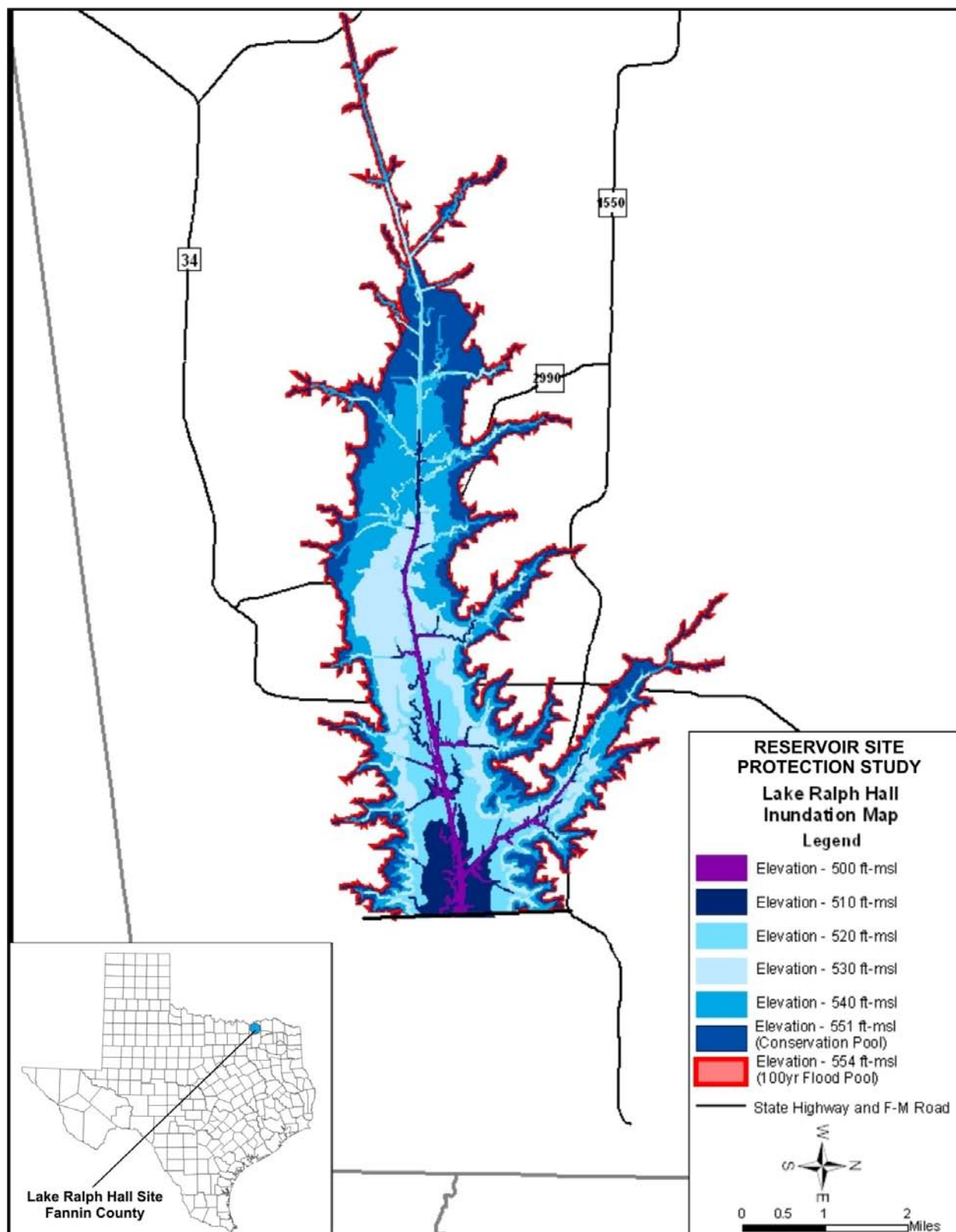
Figure 3.4.13-3. Inundation Map for Lake Ralph Hall

For purposes of the pending water rights permit application for Lake Ralph Hall, the Lyons Method was used for estimating environmental flow requirements as a placeholder until field studies could be undertaken to provide a more scientific basis for establishing appropriate river flows for protecting downstream biological resources. This method basically assumes that 40 percent of the median daily flow for each of the months of October through February and 60 percent of the median daily flow for each of the months of March through September are adequate to protect existing riverine aquatic resources. For the North Sulphur River at the project site, this calculated environmental flow was adjusted to a minimum of the seven-day average low flow with a two-year recurrence interval, or 0.1 cfs for this reach of the North Sulphur River. The resulting environmental flow values that were used in the original yield analyses are presented in Table 3.4.13-2.

Table 3.4.13-2.
Lyons Criteria for Environmental Flow Needs for Lake Ralph Hall

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Median	acft/mo	584	818	812	607	541	238	37	6	12	37	202	449
	cfs	9.5	14.6	13.2	10.2	8.8	4.0	0.6	0.1	0.2	0.6	3.4	7.3
Lyons	acft/mo	211	325	486	365	324	144	22	6	7	14	81	180
	cfs	3.4	5.8	7.9	6.1	5.3	2.4	0.4	0.1	0.1	0.2	1.4	2.9
7Q2	acft/mo	6	6	6	6	6	6	6	6	6	6	6	6
	cfs	0.1											
Note: The 7Q2 value is used when it exceeds the value of the median and/or quartile.													

Simulations using the TCEQ Sulphur Basin Water Availability Model, appropriately modified to incorporate Lake Ralph Hall and its associated environmental flow requirements as described above, were made during the initial planning investigations for the project to evaluate its potential yield. These firm yield analyses were performed assuming stand-alone reservoir operations with no minimum reserve content. Results from these simulations, considered in conjunction with various topographic, environmental and physiographic factors regarding the reservoir site, culminated in the decision to establish the conservation pool level for the reservoir at elevation 551 ft-msl, which provided the adopted total conservation storage capacity of 160,235 acft. The firm yield at this reservoir capacity was determined to be 32,940 acft/yr. As noted previously, Lake Ralph Hall is to be operated as part of the overall water supply system for the UTRWD; therefore, the pending water rights permit application stipulates that up to 45,000

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acft/yr may be withdrawn from the reservoir. Figure 3.4.13-4 presents a graph of the simulated storage trace for Lake Ralph Hall operated under firm yield conditions and the corresponding storage frequency curve. Subject to firm yield diversions, the reservoir is expected to be full about 10 percent of the time and more than half full about 85 percent of the time.
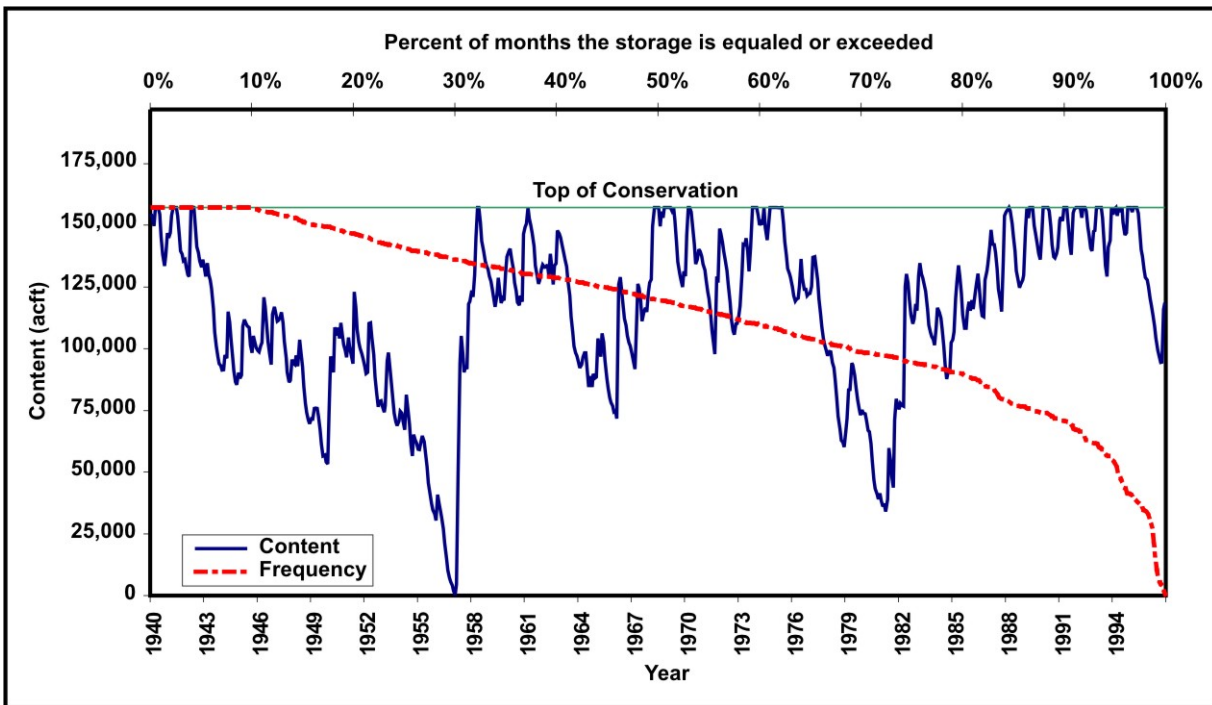
Figure 3.4.13-4. Simulated Storage in Lake Ralph Hall
(Conservation Elevation = 551 ft-msl, Diversion = 32,940 acft/yr)

3.4.13.3   Reservoir Costs

The projected costs for the Lake Ralph Hall dam assume a zoned earthen embankment with an impervious core which will have a maximum height of 100 feet. The upstream face of the embankment will be constructed with a 3:1 slope (horizontal-to-vertical) and will be protected from wave erosion with a rock riprap blanket. The downstream face will be constructed with a 4:1 slope to improve stability and to facilitate maintenance and mowing activities. The overall top width of the embankment will be 20 feet at elevation 562 ft-msl. Internal drains will be provided to remove any seepage that may accumulate within the downstream slope of the embankment. As planned, a 5-cycle labyrinth weir will act as the principal spillway with a total spillway width of 300 feet. An emergency spillway is planned for the left abutment with a total ogee crest length of 1,550 feet. The embankment will be approximately 12,900 feet in length, including the spillways.

The conflicts identified at the site include roadways, bridges, utilities, and miscellaneous relocations. A list of the potential conflicts is provided in Table 3.4.13-3. The conflict costs represent less than 18 percent of the total construction cost of the reservoir project. Figure 3.4.13-5 shows the conflicts as mapped by TNRIS.

Table 3.4.13-3.
List of Potential Conflicts for Lake Ralph Hall

Description	Unit	Quantity
Roadways	Mile	2.1
Bridges	Mile	1.7
Utilities	Mile	10.1
Miscellaneous Relocations		
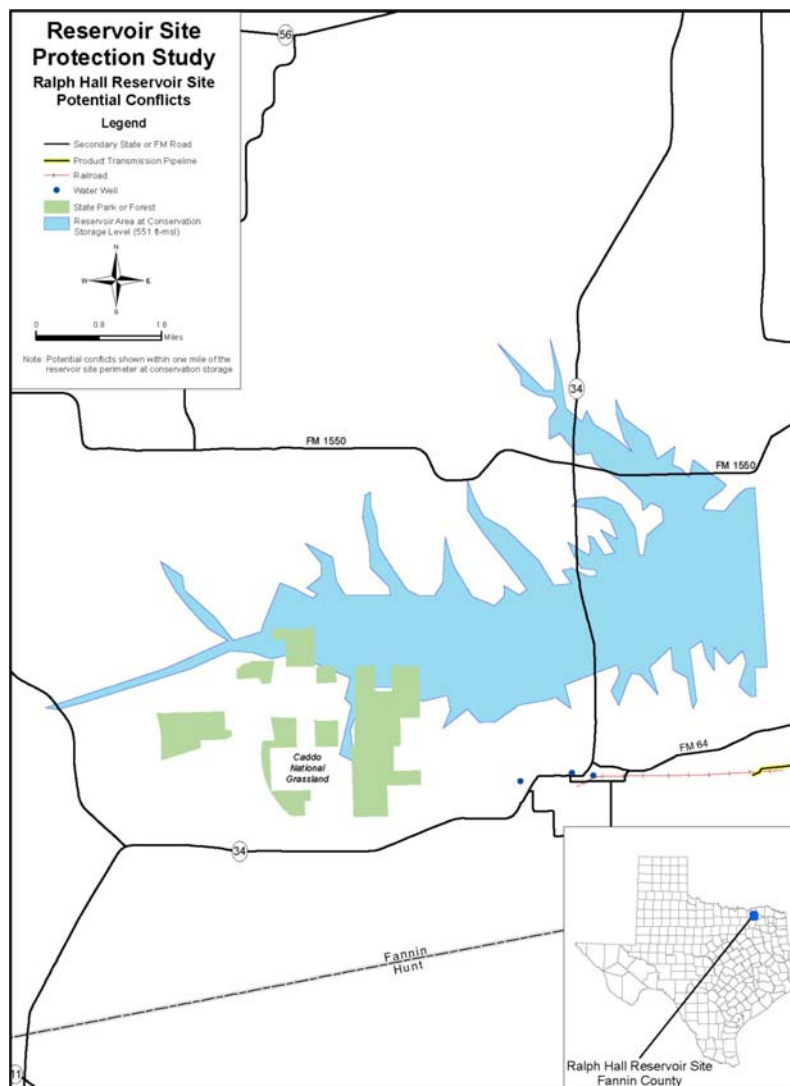
Figure 3.4.13-5. Potential Major Conflicts for Lake Ralph Hall

Table 3.4.13-4 summarizes the estimated capital costs for the Lake Ralph Hall dam and reservoir project, including construction costs, engineering, permitting and mitigation. Unit costs for the dam and reservoir are based on the cost assumptions used in this study. The total estimated cost of the project is $198.5 million (2005 prices). Assuming an annual yield of 32,940 acft/yr, raw water from the project will cost approximately $430 per acft ($1.32 per 1,000 gallons) during the debt service period.

3.4.13.4   *Environmental Considerations*

Environmental impacts of constructing and operating the Lake Ralph Hall project are considered to be minimal primarily because of the characteristics of the reservoir site. As noted above, the segment of the river channel that is to be inundated by the reservoir already has undergone significant change due to extensive erosion, such that the channel is a steep-walled, deep gorge approximately 40 feet deep and 300 feet wide, with the capacity to fully contain and convey the 100-year flood. Overbank areas outside of the channel consist primarily of pasture land, with some farming.

Studies conducted to date indicate that the presence of the reservoir will tend to curtail the channel erosion process and provide a more stable condition. For mitigation purposes, the UTRWD proposes to restore an abandoned segment of the original river channel within the overbank area near the dam site in order to create new aquatic and wildlife habitat.

Lake Ralph Hall will inundate approximately 7,605 acres of land at conservation storage capacity. Table 3.4.13-5 and Figure 3.4.13-6 summarize existing landcover for the Lake Ralph Hall site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (48 percent) with sizeable, but fragmented, areas of upland deciduous forest (23 percent) and agricultural land (18 percent). TPWD did not classify any of the reservoir site as bottomland hardwood forest.

Table 3.4.13-4.
Cost Estimate – Lake Ralph Hall @ Elevation 551 ft-msl
(page 1 of 2)

	Size	*Quantity*	*Unit*	*Unit Price*	*Cost*
Mobilization and Demobilization (5%)		1	LS	$4,306,387	**$4,306,387**
Dam & Reservoir					
Stormwater Prevention		1	LS	$897,711	$897,711
Clearing & Grubbing		450	AC	$2,500	$1,125,000
Embankment Random Fill		3,285,720	CY	$2	$6,571,440
Embankment Core		842,830	CY	$3	$2,528,490
Principal Spillway Reinf. Conc.		38,034	CY	$320	$12,170,880
Emergency Spillway Mass/Reinf. Conc.		39,060	CY	$290	$11,327,400
Emergency Spillway Excavation.		6,630,000	CY	$2	$13,260,000
Rock Riprap		196,455	SY	$80	$15,716,400
Care of Water		1	LS	$201,000	<u>$201,000</u>
Subtotal for Dam and Reservoir					**$63,798,321**
Engineering and Contingencies (35% Dam & Reservoir)					**$22,329,412**
Total - Dam & Reservoir Construction					**$90,434,120**
Conflicts					
Roadways		11,140	LF	$200	$2,228,000
Bridges		9,000	LF	$2,070	$18,630,000
Utility Relocations		53,500	LF	$75	$4,012,500
Miscellaneous Relocations		1	LS	$2,000,000	<u>$2,000,000</u>
Subtotal Conflicts					**$26,870,500**
Engineering & Contingencies (35% Conflicts)					**$9,404,675**
Subtotal (Dam & Reservoir, Conflicts)					**$126,709,295**
Land Acquisition		**11,300**	**AC**	**$2,675**	**$30,227,500**
Mitigation		**11,300**	**AC**	**$2,675**	**$30,227,500**
CONSTRUCTION TOTAL					**$187,164,295**
Interest During Construction (24 months)					**$11,314,064**
TOTAL COST					**$198,478,359**

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Table 3.4.13-4.
Cost Estimate – Lake Ralph Hall @ Elevation 551 ft-msl
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	Size	*Quantity*	*Unit*	*Unit Price*	*Cost*
ANNUAL COSTS					
Debt Service (6% for 40 years)					$13,191,000
Operation & Maintenance					$956,975
Total Annual Costs					**$14,147,975**
FIRM YIELD (acft/yr)					**32,940**
UNIT COSTS					
Per Acre-Foot					$430
Per 1,000 Gallons					$1.32
Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.					

Table 3.4.13-5.
Acreage and Percent Landcover for Lake Ralph Hall

Landcover Classification	*Acreage[1]*	*Percent*
Swamp	3	0.0%
Upland Deciduous Forest	1,873	23.4%
Grassland	3,874	48.5%
Shrubland	771	9.6%
Agricultural Land	1,436	18.0%
Urban / Developed Land	19	0.2%
Open Water	21	0.3%
Total	7,997	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
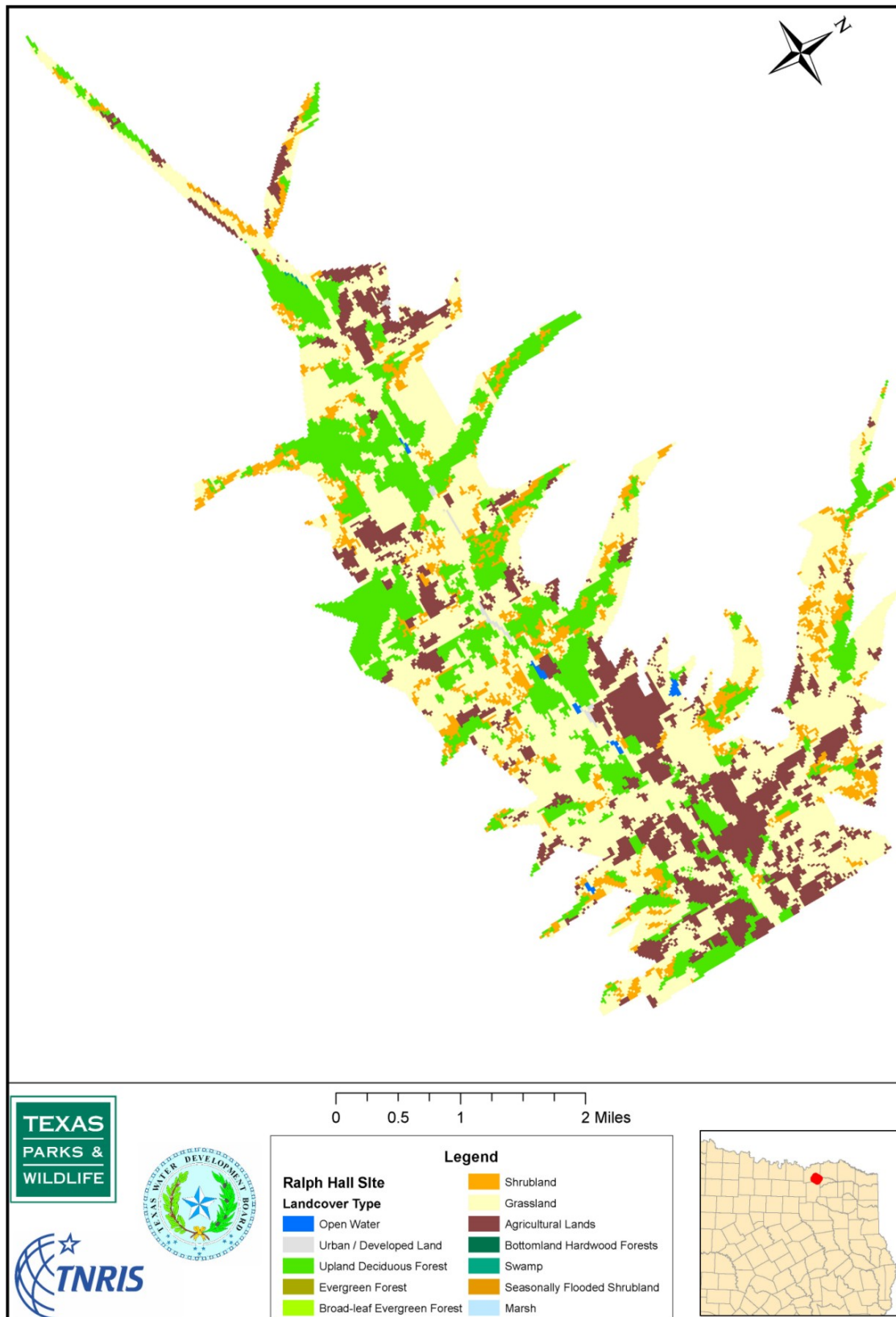
Figure 3.4.13-6. Existing Landcover for Lake Ralph Hall

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3.4.14   Ringgold Reservoir

3.4.14.1   Description

Ringgold Reservoir would be located on the Little Wichita River east of Henrietta, just upstream of the confluence with the Red River in Clay County. Figure 3.4.14-1 shows the location of the reservoir. The proposed conservation pool is at elevation 844 feet, with a conservation capacity of 271,600 acft. The inundated area at the top of conservation pool is 14,980 acres. The reservoir has a total contributing drainage area of 1,475 square miles, of which 822 are controlled by Lake Arrowhead.
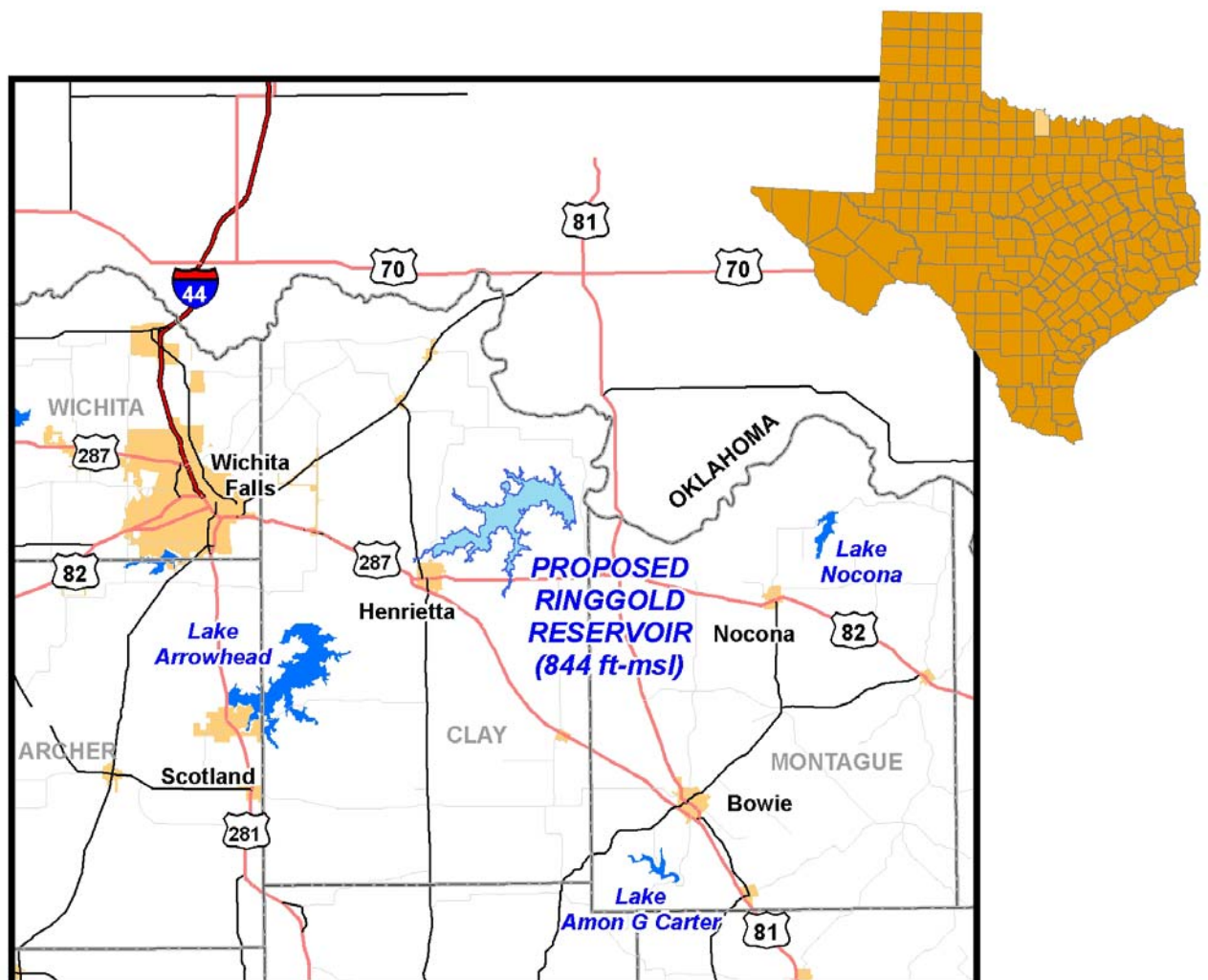
Figure 3.4.14-1 Location Map of Ringgold Reservoir

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This reservoir has been previously studied by Freese and Nichols (1958 and 1981). Ringgold Reservoir was a recommended water management strategy for the City of Wichita Falls in the 2001 Region B Water Plan, and it is an alternate water management strategy in the 2006 Region B Water Plan (Biggs & Mathews *et al.*, 2001 and 2006).

The Region B Water Planning Group recognizes that the Ringgold Reservoir site may be one of the last viable reservoir sites in the area, but the region chose not to recommend designation as a Unique Reservoir Site until additional information is made available to the planning group. The reservoir has historically been included as part of the long-term water supply plans for the City of Wichita Falls, which provides most of the municipal and manufacturing supplies in Region B. The projected needs for additional water supply within 50 miles of the proposed reservoir site are 313,933 acft/yr. Much of this need is associated with Region C, located east and south of the proposed reservoir site. The nearest major demand center is the Dallas-Fort Worth metroplex, which is located approximately 96 miles southeast of the reservoir site.

3.4.14.2   *Reservoir Yield Analysis*

The elevation-area-capacity relationship is included in Table 3.4.14-1 and Figure 3.4.14-2. The data in Table 3.4.14-1 were developed by Freese and Nichols (1981) by measurement from U.S. Geological Survey topographic quadrangle maps. Figure 3.4.14-3 shows the inundation map at different elevations in a 10-foot interval. Figure 3.4.14-3 also shows the inundation of the reservoir at elevation 847 ft-msl, which is the estimated maximum elevation before the emergency spillway starts operating in a flood event. The elevation of the emergency spillway was also determined in the 1981 Study.

Table 3.4.14-1.
Elevation-Area-Capacity Relationship for Ringgold Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
783.0	5	4
785.0	14	22
790.0	64	198
795.0	170	754
800.0	330	1,954
805.0	820	4,499
810.0	1,920	11,259
815.0	3,270	24,194
820.0	4,850	44,344
825.0	6,610	72,904
830.0	8,480	110,629
835.0	10,510	158,014
840.0	12,800	216,189
844.0	14,980	271,600
845.0	15,620	286,900
847.0	16,990	319,500
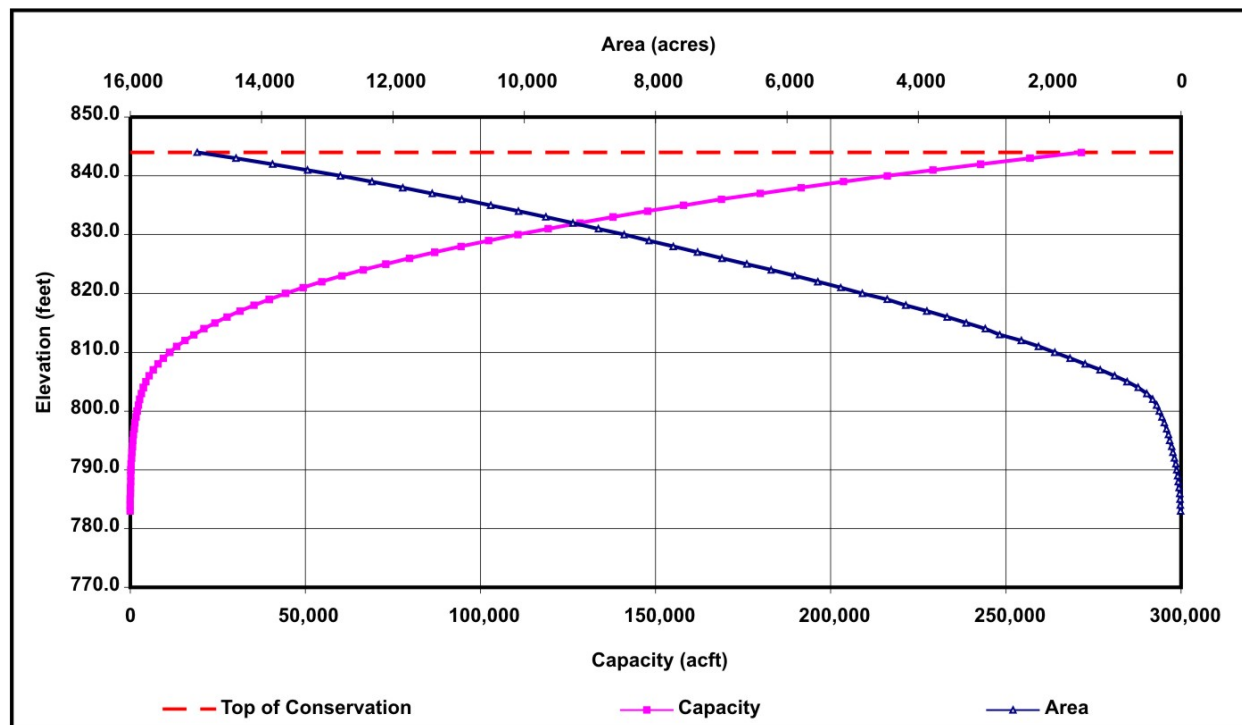
Figure 3.4.14-2. Elevation-Area-Capacity Relationship for Ringgold Reservoir

The reservoir will be subject to regulatory bypass to meet environmental needs. For this study, the Consensus Criteria for Environmental Flow Needs (TWDB, 1997) were adopted and are shown in Table 3.4.14-2. The reservoir will have to pass the lesser of the inflow and the values of Table 3.4.14-2.

The firm yield of Ringgold Reservoir was calculated with the full authorization scenario (Run 3) of the Water Availability Model of Red River Basin (dated April 1, 2006) obtained from TCEQ (Espey Consultants *et al.*, 2002 and TCEQ, 2006). A control point (U10021) was added on the Little Wichita River below the existing control point U10020. Natural flows at the dam site were calculated using the drainage area ratio method with the naturalized flows at the Little Wichita above Henrietta (S10000) and the East Fork Little Wichita River near Henrietta (T10000). These gages are located in the same watershed of the reservoir and are appropriate for estimating flows at the reservoir site. The control point of Ringgold was entered as primary control point with calculated inflow.
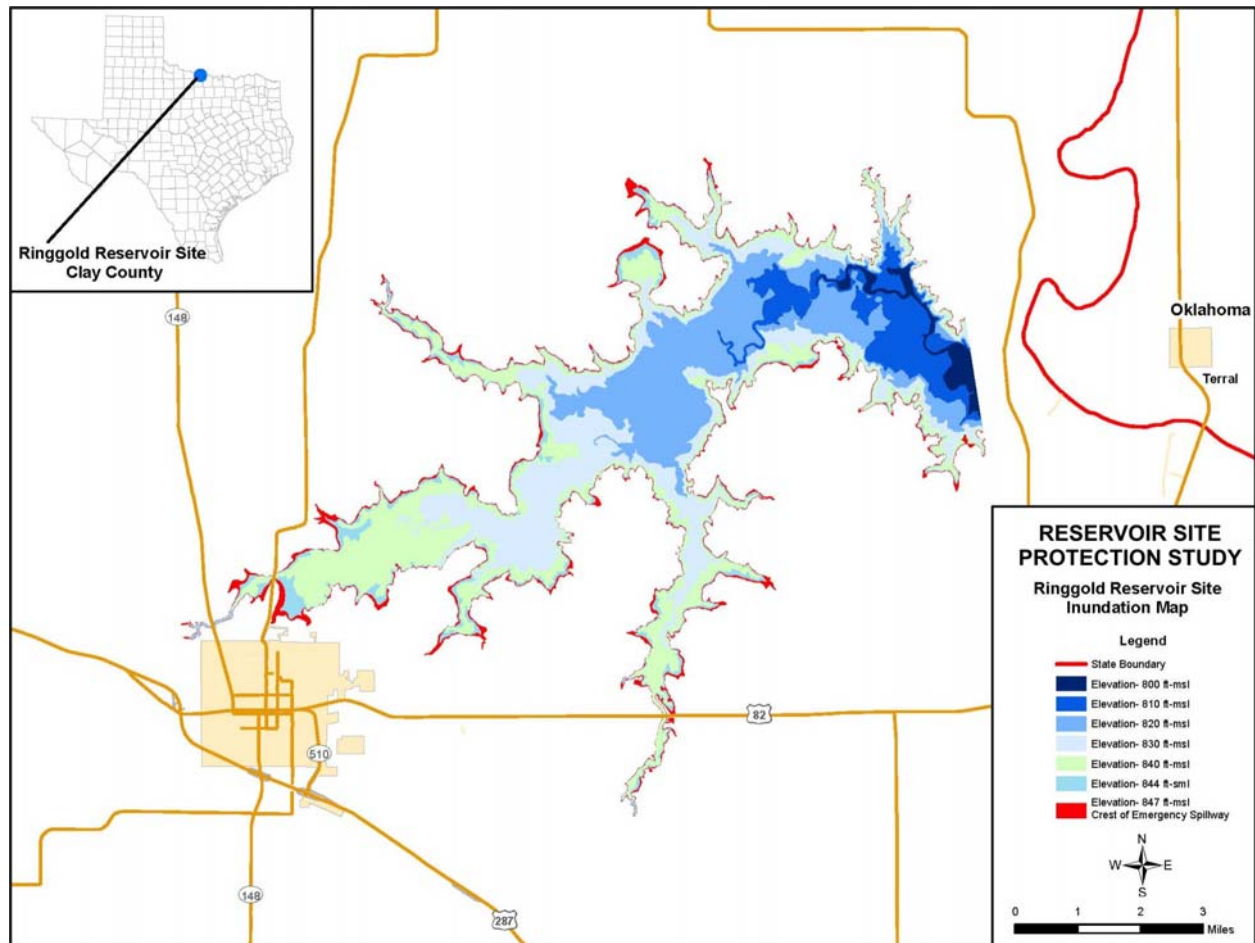
Figure 3.4.14-3. Inundation Map for Ringgold Reservoir

Table 3.4.14-2.
Consensus Criteria for Environmental Flow Needs for Ringgold Reservoir

	Median		25th Percentile		7Q2	
	acft/mo	cfs	acft/mo	cfs	acft/mo	cfs
Jan	640	10.4	0	0.0	0	0.0
Feb	930	16.6	22	0.4	0	0.0
Mar	1,341	21.8	92	1.5	0	0.0
Apr	1,393	23.4	208	3.5	0	0.0
May	2,534	41.2	332	5.4	0	0.0
Jun	2,643	44.4	388	6.5	0	0.0
Jul	437	7.1	0	0.0	0	0.0
Aug	394	6.4	0	0.0	0	0.0
Sep	202	3.4	0	0.0	0	0.0
Oct	49	0.8	0	0.0	0	0.0
Nov	30	0.5	0	0.0	0	0.0
Dec	92	1.5	0	0.0	0	0.0
Total	10,684		1,043		0	
Average	890	14.8	87	1.4	0	0.0

The Red River WAM calculates natural flows at other control points in the Little Wichita watershed using not only the gages in the Little Wichita River, but also the gages at Wichita River at Charlie, the Red River near Burkburnett, and the Red River near Terral, Oklahoma. However, use of the WAM hydrology of the main stem tends to overestimate flows in this part of the basin. Therefore, yield analyses for this study considered local gages in the Little Wichita subbasin. The reservoir location was entered as a primary control point (with known naturalized flows) in the WAM model. The flow distribution parameters of other secondary control points in the Little Wichita basin below the Henrietta gage were changed to use known flows in the same watershed (including the calculated flow at Ringgold as the downstream source) to avoid discontinuity in flow between consecutive control points.

Net evaporation rates were calculated from TWDB quadrangle data of precipitation and gross lake evaporation. Evaporation at the reservoir site was based on data from Quadrangles 409 and 410. Net evaporation rates entered in the WAM model were adjusted to remove the portion of the precipitation in the reservoir surface area that has been accounted for in the natural inflow.

Yields were calculated for elevations 844, 840, 835, and 830 ft-msl, subject to environmental flow needs and assuming stand-alone reservoir operations with no minimum reserve content. Results of firm yield analyses at these elevations are included in Table 3.4.14-3 and Figure 3.4.14-4. At the conservation pool level of 844 feet, the firm yield is 32,800 acft/yr. Assuming no environmental flow releases, the yield of the reservoir increases by 400 acft/yr at the recommended conservation pool elevation.

Table 3.4.14-3.
Firm Yield vs. Conservation Storage for Ringgold Reservoir

Conservation Pool Elevation (ft-msl)	Conservation Storage (acft)	Environmental Bypass Criteria	Yield (acft/yr)	Critical Period
830.0	110,629	CCEFN	23,700	8/75-2/81
835.0	158,014	CCEFN	29,300	7/75-2/81
840.0	216,189	CCEFN	31,900	5/58-2/81
844.0 *	271,600	CCEFN	32,800	11/57-2/81
		None	33,200	11/57-2/81
*Proposed Conservation Storage				
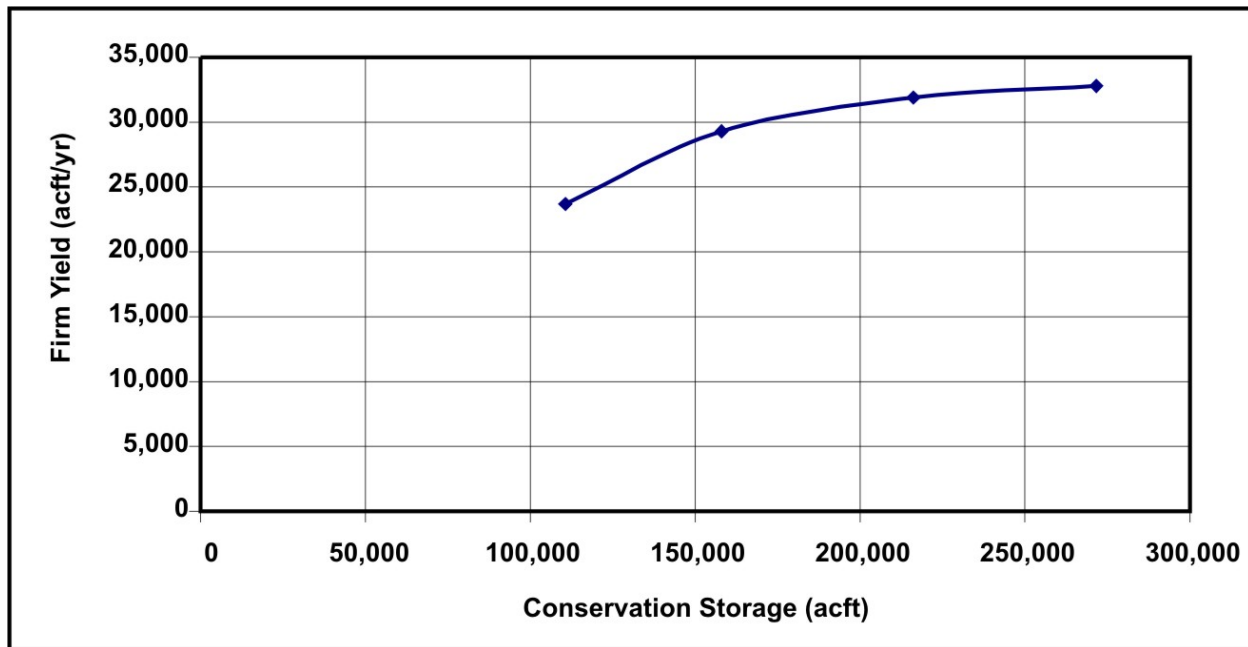
Figure 3.4.14-4. Firm Yield vs. Conservation Storage for Ringgold Reservoir

As part of a previous study, Freese and Nichols (1981) evaluated the gain of yield when operating Ringgold as a system with Lakes Kickapoo and Arrowhead. The 1981 study determined a net gain of 27,640 acft/yr, which is lower than the firm yield determined in this study. The yield from the 1981 study is lower because it assumes that Ringgold Reservoir has a minimum reservoir reserve at elevation 805 ft-msl, leaving about 4,500 acft in storage. The study also assumes a runoff depletion due to soil and water conservation practices on farm lands and the construction of numerous small ponds on small tributaries that will tend to diminish the amount of runoff available to large reservoirs. The 1981 study determined that runoff depletions would reduce the firm yield of Ringgold Reservoir by 1,800 acft/yr. The WAM hydrology does not account for changes in land use or future small impoundments.

Figure 3.4.14-5 presents a simulated storage trace and a frequency curve for storage content derived using the Red River WAM as modified for this study. At the conservation pool of 844 ft-msl and assuming full diversion, the reservoir would be full about 5 percent of the time and would be below 50 percent of the conservation storage about 33 percent of the months.
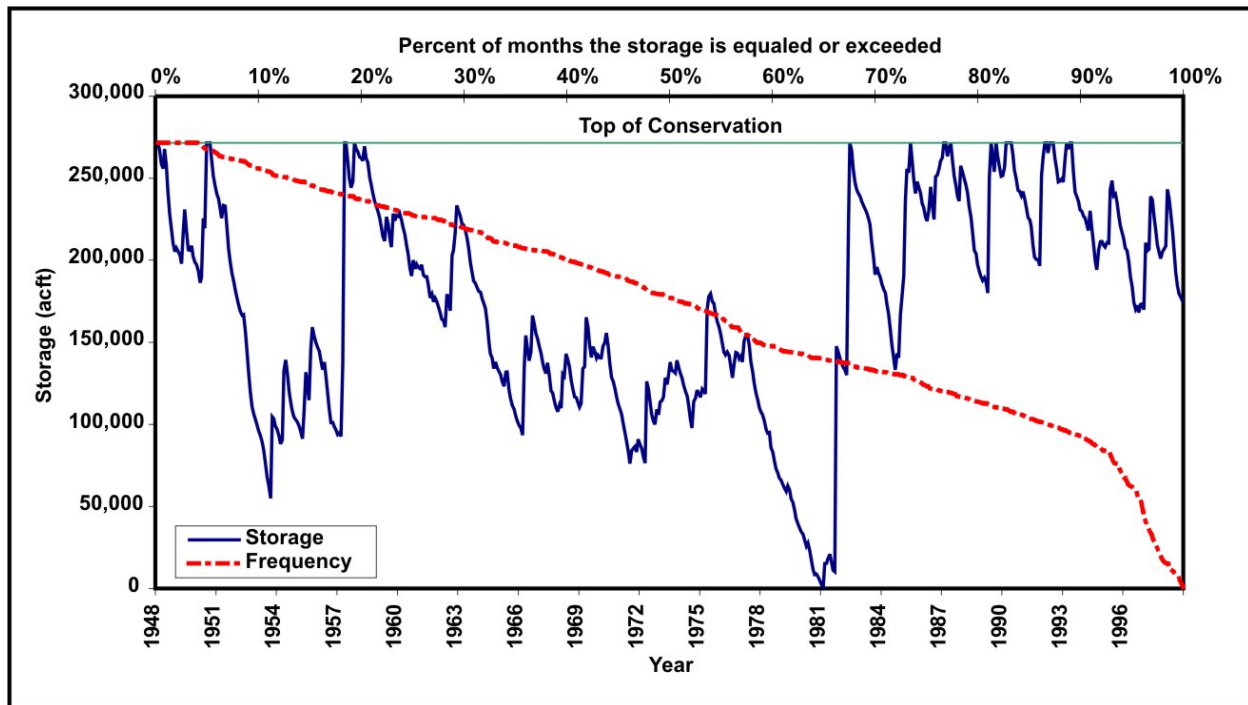
Figure 3.4.14-5. Simulated Storage in Ringgold Reservoir
(Conservation Elevation = 844 ft-msl, Diversion = 32,800 acft/yr)

3.4.14.3   Reservoir Cost

The costs for the Ringgold Reservoir Dam assume a zoned earthen embankment and a gated spillway. The length of the dam is estimated at 9,350 feet with the top of the embankment at elevation 871 ft-msl. The service spillway is designed as a control structure with five tainter gates, each 40 feet wide by 25 feet high. The reservoir also includes an emergency spillway, approximately 900 wide, at elevation 847 ft-msl.

The conflicts identified at the site include electrical lines, minor roads, oil and gas lines and one oil and gas well. A list of the potential conflicts is provided in Table 3.4.14-4. Costs for these conflict resolutions were developed from data provided by TNRIS. The conflict costs represent 6 percent of the total construction cost of the reservoir project. Figure 3.4.14-6 shows the conflicts as mapped by TNRIS.

Table 3.4.14-4.
List of Potential Conflicts for Ringgold Reservoir

Oil and Gas Pipelines	Power Transmission Lines
Roads	Oil and Gas Well
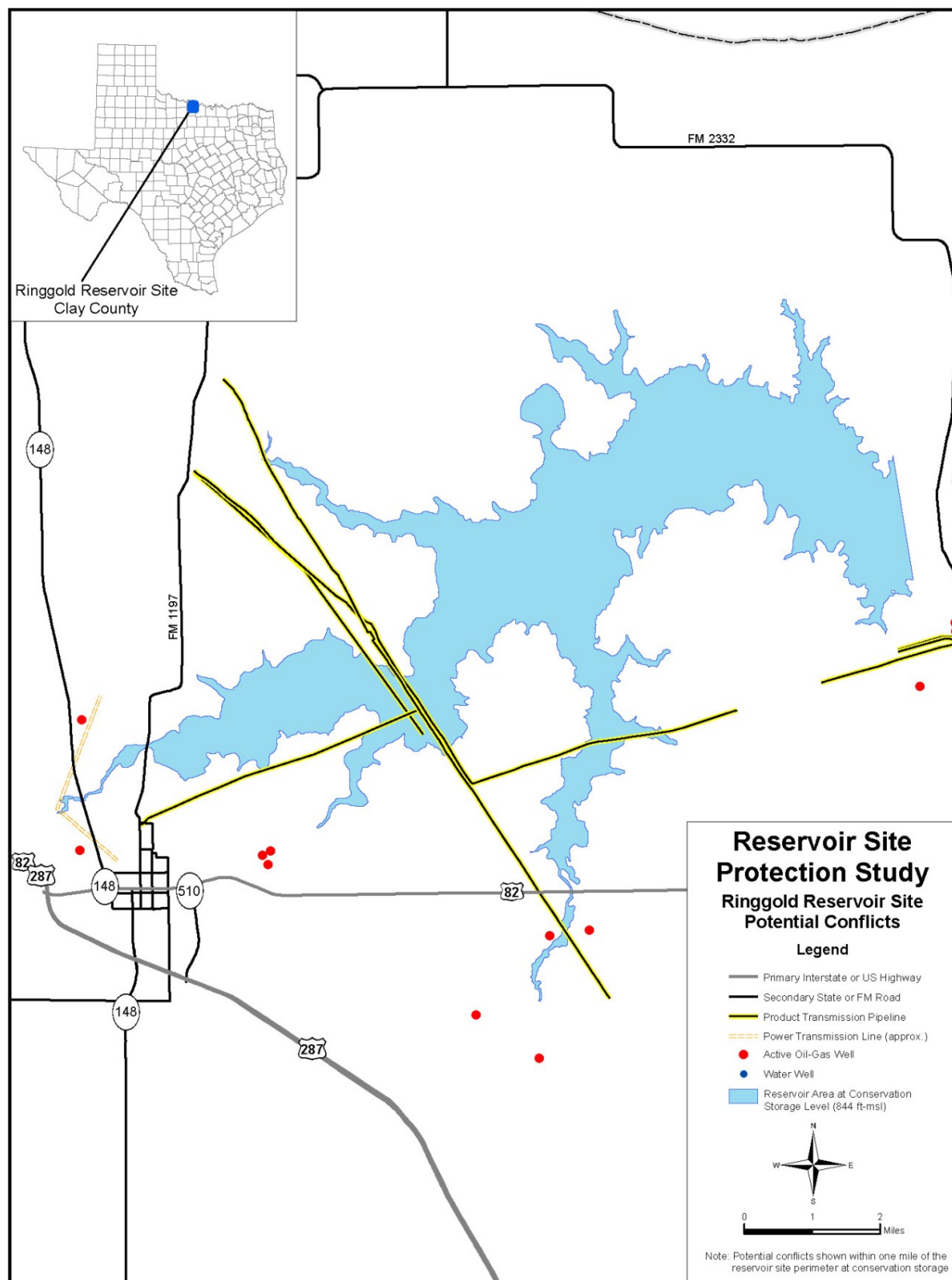
Figure 3.4.14-6. Potential Major Conflicts for Ringgold Reservoir

Table 3.4.14-5 shows the estimated capital costs for the Ringgold Reservoir Project, including construction costs, engineering, permitting and mitigation. Costs for the dam and reservoir are based on the unit cost assumptions used in this study. Quantities are taken from the 1981 Freese and Nichols study. The total estimated cost of the project is $119 million (2005 prices). Assuming a yield of 32,800 acft/yr, raw water from the project will cost approximately $273 per acft ($0.84 per 1,000 gallons) during the debt service period.

3.4.14.4   *Environmental Considerations*

Ringgold Reservoir is not located on or immediately upstream of an identified ecologically significant stream segment. There are no known significant environmental concerns with this reservoir site. Ringgold Reservoir will inundate approximately 15,000 acres of land at conservation storage capacity. Table 3.4.14-6 and Figure 3.4.14-7 summarize existing landcover for the Ringgold Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by grassland (52 percent) with sizeable, contiguous areas of upland deciduous forest (28 percent) along the Little Wichita River and its tributaries. Agricultural lands are concentrated near the dam site and the upper end of the reservoir and comprise about 13 percent of the inundated area.

Table 3.4.14-5.
Acreage and Percent Landcover for Ringgold Reservoir

| Landcover Classification	Acreage[1]	Percent
Upland Deciduous Forest	4,316	28.1%
Grassland	8,020	52.2%
Shrubland	1,942	12.6%
Agricultural Land	756	4.9%
Open Water	335	2.2%
Total	15,369	100.0%
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		

Table 3.4.13-5.
Cost Estimate – Ringgold Reservoir @ Elevation 844 ft-msl

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Unclassified Excavation	2,591,000	CY	$2.50	$6,478,000
Structural Excavation	700,000	CY	$2.50	$1,750,000
Fill				
Random Compacted Fill	2,229,000	CY	$2.50	$5,573,000
Impervious Fill	743,000	CY	$3.00	$2,229,000
Filter	337,000	CY	$35	$11,795,000
Bridge	240	LF	$1,300	$312,000
Roadway	23,333	SY	$20	$467,000
Slurry Trench	118,000	SF	$15	$1,770,000
Soil Cement	121,000	CY	$65	$7,865,000
Gates				
Gate & Anchor	5,000	SF	$275	$1,375,000
Stop Gate & Lift	200	LF	$2,000	$400,000
Hoist	5	Ea	$250,000	$1,250,000
Electrical	1	LS	$550,000	$550,000
Power Drop	1	LS	$250,000	$250,000
Spillway Low-Flow System	1	LS	$400,000	$400,000
Embankment Internal Drainage	15,400	LF	$60	$924,000
Guardrail	480	LF	$30	$14,000
Grassing	50	AC	$4,500	$225,000
Concrete (mass)	54,747	CY	$150	$8,212,000
Reinforced Concrete (formed)	14,160	CY	$475	$6,726,000
Mobilization (5% of subtotal)				$2,928,000
Care of water (1% of subtotal)				$586,000
Clearing and Grubbing	150	AC	$4,000	$600,000
Land Clearing	425	AC	$1,000	$425,000
Engineering and Contingencies (35%)				<u>$22,086,000</u>
Subtotal for Dam & Reservoir				**$85,190,000**
Conflicts				
Highways	6650	LF	$150	$998,000
Pipelines				
4.5-in crude oil	58,900	LF	$17	$1,001,000
16-inch gas	55,800	LF	$42	$2,344,000
8.63-inch crude oil	23,800	LF	$25	$595,000
Oil & gas well (plug & abandon)	1	EA	$25,000	$25,000
Power Lines	240	LF	$450	$108,000
Engineering and Contingencies (35%)				<u>$1,388,000</u>
Subtotal of Conflicts				**$6,459,000**
Land Acquisition	17,000	AC	$850	$14,450,000
Environmental Studies and Mitigation Lands	17,000	AC	$850	$14,450,000
Total Reservoir Construction Cost				**$106,099,000**
Interest During Construction (36 months)				**$12,909,000**
TOTAL COST				**$119,008,000**
ANNUAL COSTS				
Debt Service (6% for 40 years)				$7,909,000
Operation & Maintenance				<u>$1,054,000</u>
Total Annual Costs				**$8,963,000**
UNIT COSTS				
Per Acre-Foot				$273
Per 1,000 Gallons				$0.84

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.
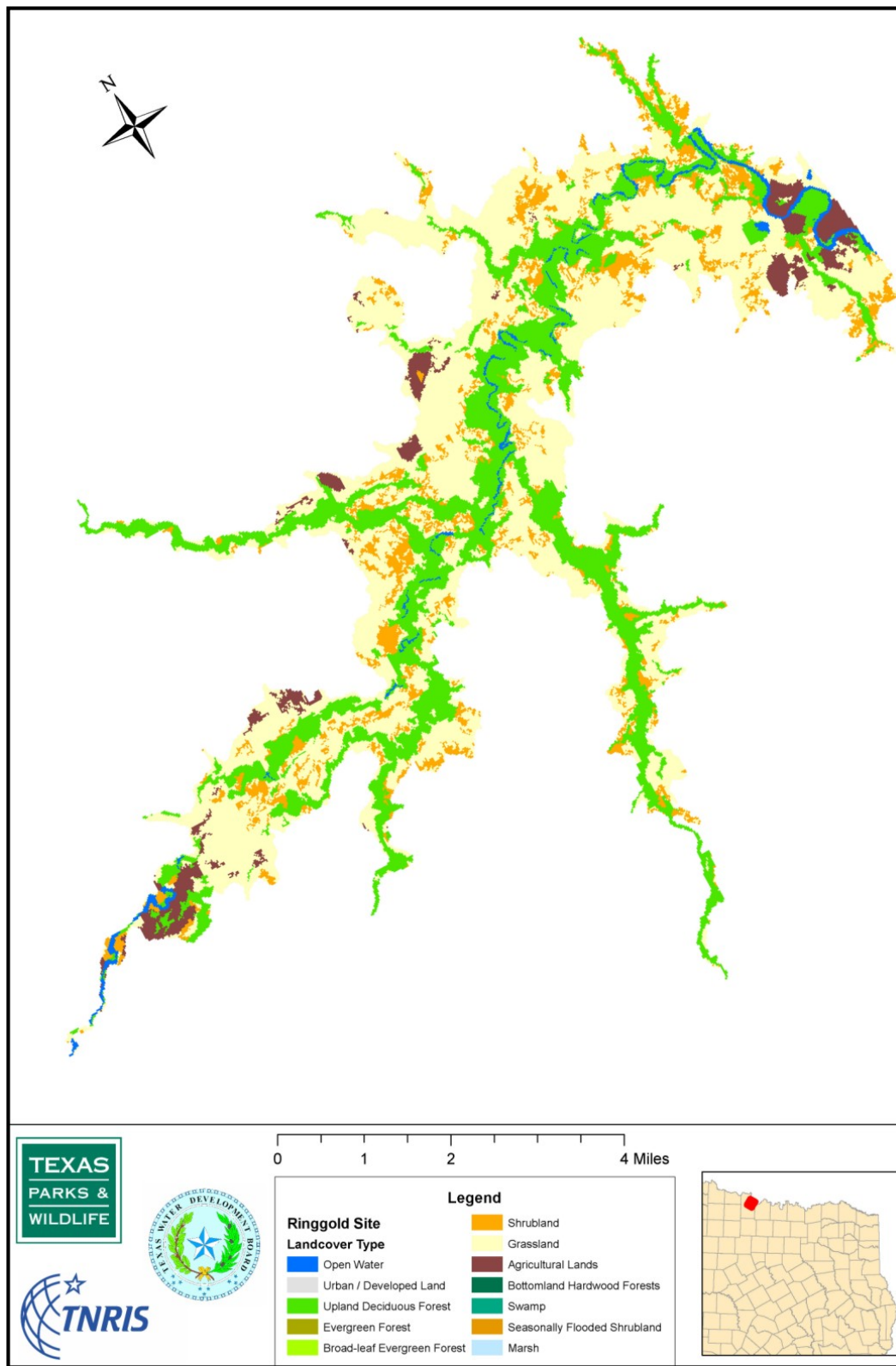
Figure 3.4.14-7. Existing Landcover for Ringgold Reservoir

3.4.15   Tehuacana Reservoir

3.4.15.1   *Description*

Tehuacana Reservoir is a proposed water supply project on Tehuacana Creek within the Trinity River Basin. Tehuacana Creek is a tributary of the Trinity River and lies immediately south and adjacent to Richland Creek on which the existing Richland-Chambers Reservoir is located. Tehuacana Reservoir, which would likely be sponsored by the Tarrant Regional Water District (TRWD), would connect to the TRWD's Richland-Chambers Reservoir by a 9,000-foot channel and be operated as an integrated extension of Richland-Chambers Reservoir. Figure 3.4.15-1 presents a map showing the location of Tehuacana and Richland-Chambers Reservoirs in Freestone and Navarro Counties. The project would inundate approximately 15,000 acres adjacent to Richland-Chambers Reservoir.
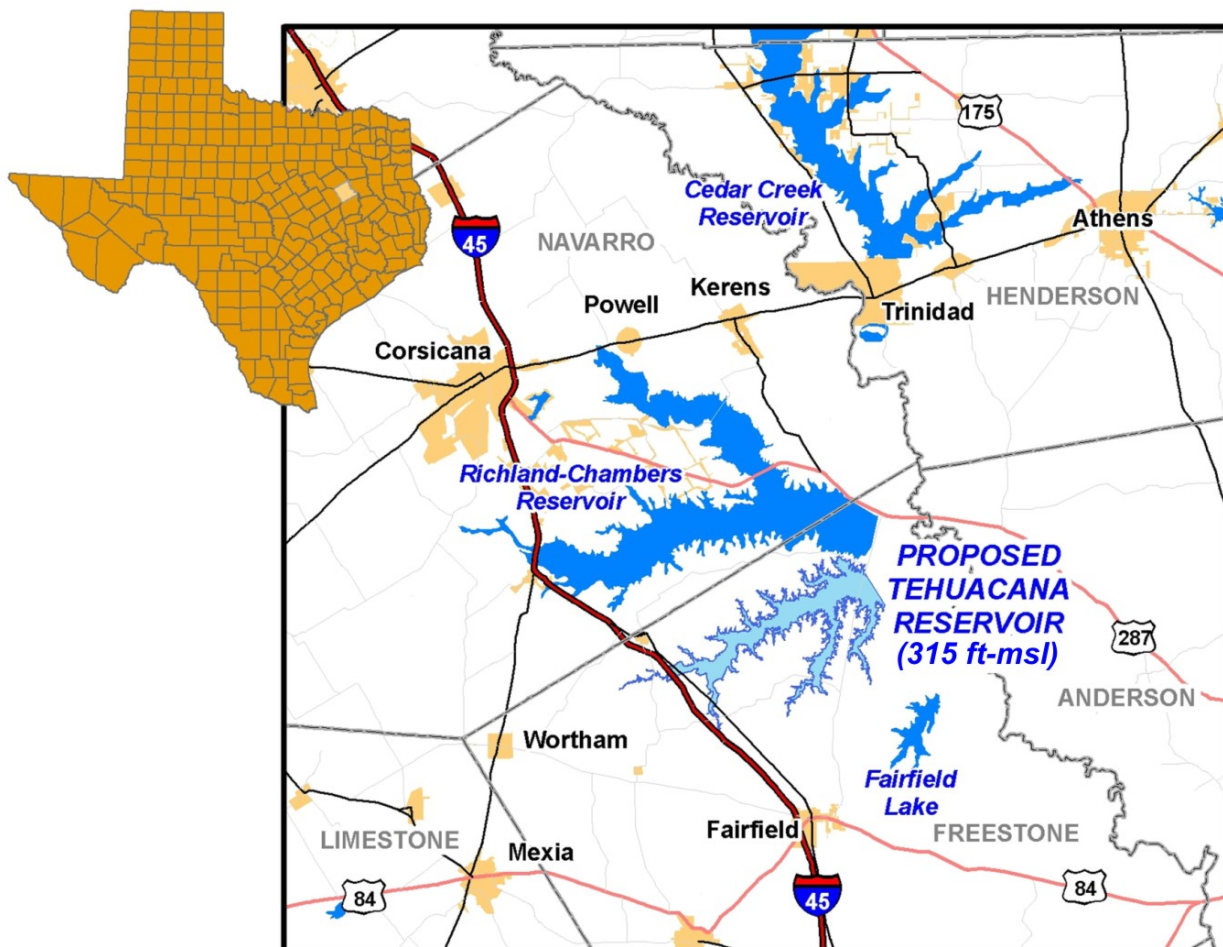
Figure 3.4.15-1. Location Map of Tehuacana Reservoir

Tehuacana Reservoir has been a part of the TRWD's long-term planning since the project was first proposed in the late 1950s. It is included as an alternative strategy for the TRWD in the 2001 and 2006 Region C Water Plans (Freese and Nichols *et al.*, 2001 and 2006a) and is not a recommended water management strategy for any Region C water supplier. The projected needs within 50 miles of the proposed reservoir site by 2060 are 890,895 acft/yr. The nearest major demand center is the greater Dallas-Fort Worth area, which is located approximately 80 miles northwest of the reservoir site.

The existing spillway for Richland-Chambers Reservoir was designed to provide enough discharge capacity to accommodate the increased flood flows from Tehuacana Reservoir for the probable maximum flood event. Therefore, the dam for Tehuacana Reservoir can be constructed without a spillway and actually can function as merely an extension of Richland-Chambers Reservoir. Development of this site will require a new water right, construction of the dam and reservoir, and up-sizing of the TRWD's pipelines to deliver water to Tarrant County.

3.4.15.2   *Reservoir Yield Analysis*

Tehuacana Reservoir was studied by Freese and Nichols in 2005 as part of the Region C water supply planning process (Freese and Nichols *et al.*, 2006a). These analyses treated Tehuacana Reservoir as an extension of the existing Richland-Chambers Reservoir.

The firm yield of Tehuacana Reservoir was calculated in this present study using a version of the water availability model (WAM) of the Trinity River Basin (dated July 23, 2005), with Run 3 assumptions, as provided by Freese and Nichols. The monthly WAM simulations were performed using the Water Rights Analysis Package (WRAP, executable dated 5/24/2004). This version of the WAM, as modified by Freese and Nichols, includes the proposed Tehuacana Reservoir combined with Richland-Chambers Reservoir. Since the two reservoirs are to be connected by a channel, they are represented as a single reservoir in the WAM. The additional storage capacity of Tehuacana Reservoir is added to the existing storage capacity of Richland-Chambers, with a junior priority date for refilling. The conservation pool elevation of the combined reservoirs is assumed to be the same as that of Richland-Chambers (i.e., 315 ft-msl).

The elevation-area-capacity relationship for Tehuacana Reservoir, as developed by Freese & Nichols, is presented in Table 3.4.15-1 and Figure 3.4.15-2. The combined elevation-area-capacity relationship for the Richland-Chambers and Tehuacana Reservoir system is

presented in Table 3.4.15-2 and Figure 3.4.15-3. Figure 3.4.15-4 shows the reservoir inundation

at 10-foot contours.

Table 3.4.15-1.
Elevation-Area-Capacity Relationship for Tehuacana Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
250.0	20	10
255.0	286	775
260.0	552	2,870
265.0	1,168	7,170
270.0	1,784	14,550
275.0	2,586	25,474
280.0	3,387	40,406
285.0	4,701	60,625
290.0	6,014	87,411
295.0	7,551	121,323
300.0	9,087	162,917
305.0	10,694	212,368
310.0	12,300	269,852
315.0	14,938	337,947

Table 3.4.15-2.
Elevation-Area-Capacity Relationship for Tehuacana and
Richland Chambers Reservoirs Combined

Elevation (feet)	Area (acres)	Capacity (acft)
250.0	20	10
255.0	674	1,294
260.0	2,522	9,290
265.0	5,677	29,674
270.0	9,035	65,213
275.0	12,861	121,065
280.0	16,825	194,794
285.0	21,947	290,422
290.0	27,162	413,626
295.0	32,253	561,859
300.0	37,445	736,215
305.0	43,885	938,794
310.0	50,517	1,176,219
315.0	58,559	1,447,257
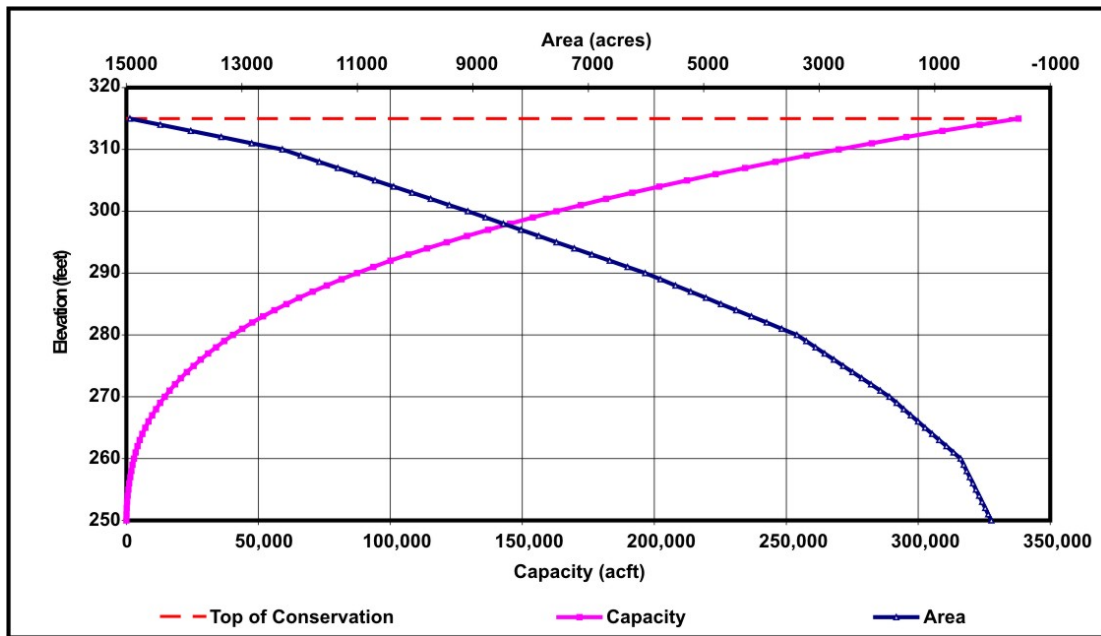
Figure 3.4.15-2. Elevation-Area-Capacity Relationship for Tehuacana Reservoir
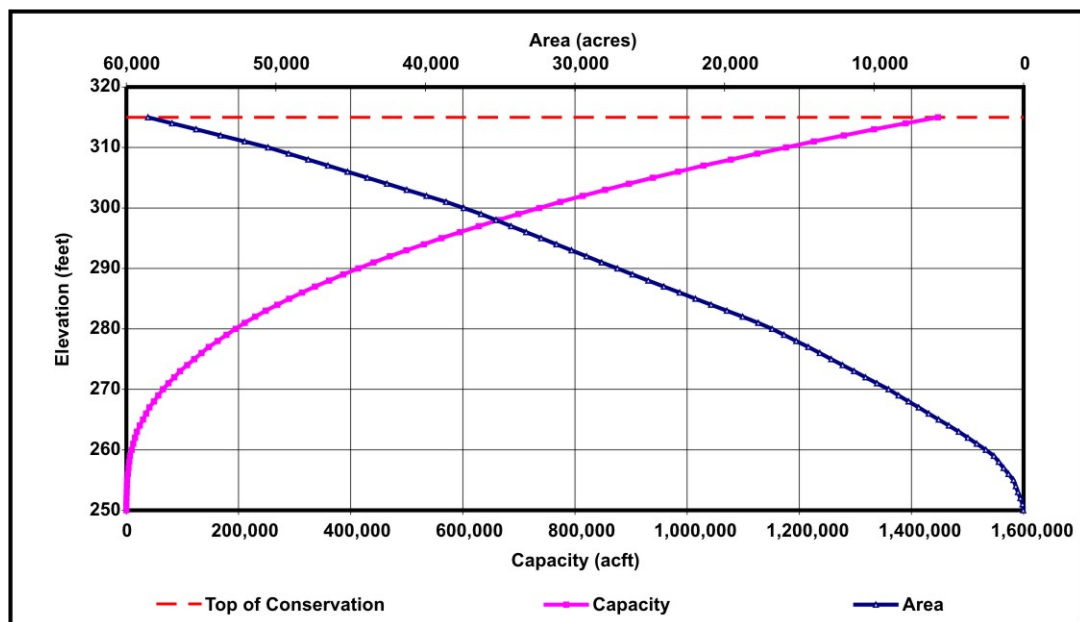
Figure 3.4.15-3. Elevation-Area-Capacity Relationship for Tehuacana and Richland Chambers Reservoirs Combined

For purposes of this yield study, it is assumed that inflows to Tehuacana Reservoir would have to be passed downstream to provide environmental flows for Tehuacana Creek. These minimum environmental flow requirements are based on Consensus Criteria for Environmental Flow Needs (CCEFN) (TWDB, 1997), and they are summarized in Table 3.4.15-3. The reservoir has to pass the lesser of the inflow and the values in Table 3.4.15-3 depending on storage in the reservoir, i.e., the median or the 25-percentile flow when the storage is greater than 80 or 50 percent full, respectively, and the 7Q2 flow when the storage is less than 50 percent full.

Table 3.4.15-3.
Consensus Criteria for Environmental Flow Needs for Tehuacana and
Richland Chambers Reservoirs Combined

		Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*
Median	acft/mo	694	1,054	1,215	934	1,218	505	68	6	6	12	138	465
	cfs	11.3	18.8	19.8	15.7	19.8	8.5	1.1	0.1	0.1	0.2	2.3	7.6
25th	acft/mo	74	267	329	243	251	69	6	6	6	6	6	22
	cfs	1.2	4.8	5.3	4.1	4.1	1.2	0.1	0.1	0.1	0.1	0.1	0.4
7Q2	acft/mo	6	6	6	6	6	6	6	6	6	6	6	6
	cfs	0.1											
Note: The 7Q2 value is used when it exceeds the value of the median and/or quartile.													
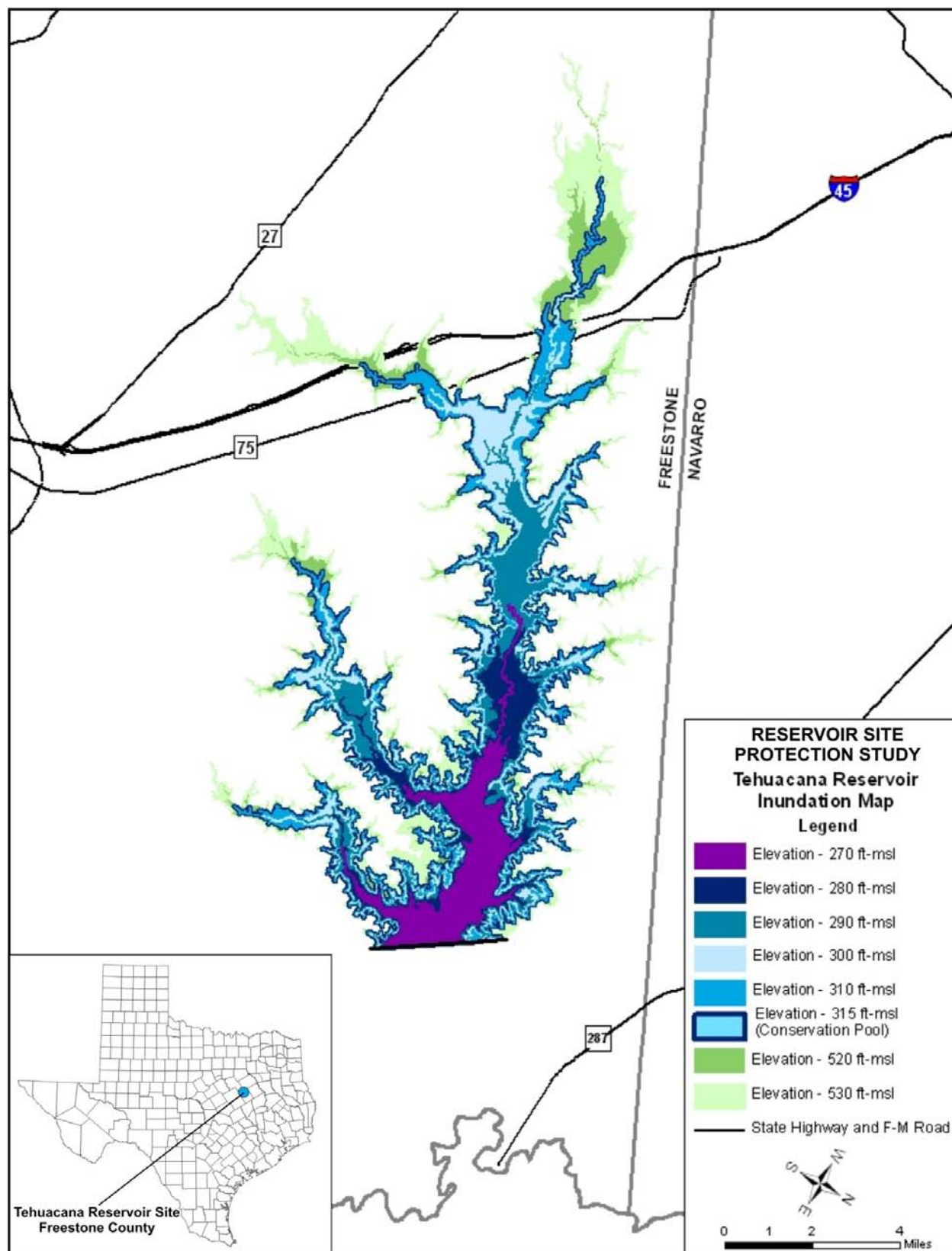
Figure 3.4.15-4. Inundation Map for Tehuacana Reservoir

As stated in Certificate of Adjudication No. 4248, Lake Livingston, even though it is senior in priority, will be subordinated to Tehuacana Reservoir when and if Tehuacana Reservoir is issued a water right by the TCEQ. The Lake Livingston subordination to Tehuacana Reservoir is recognized and modeled in this yield study.

WAM simulations were made for firm annual yield determinations with the top of the conservation pool of the combined Richland-Chambers and Tehuacana reservoir assumed to be at elevations 312, 313, 314, and 315 ft-msl. For these simulations, the minimum reservoir content was set at 116,975 acft to be consistent with the simulated minimum storage in Richland-Chambers Reservoir (stand-alone) with its demand equal to its own authorized diversion amount (i.e., 210,000 acft/yr). (This is consistent with the TRWD's operation of its reservoirs on a safe yield basis.) The incremental increase in firm yield above the authorized diversion amount for Richland-Chambers Reservoir was considered to be the firm yield attributable to the addition of Tehuacana Reservoir. Results from these simulations are summarized in Table 3.4.15-4 and Figure 3.4.15-5. As shown, at the conservation pool level of 315 feet, or 1,447,257 acft of total combined storage capacity, the incremental firm yield of Tehuacana Reservoir is 41,900 acft/yr. CCEFN requirements reduce the yield of the reservoir by about 2,200 acft/yr.

Table 3.4.15-4
Firm Yield vs. Conservation Storage for Tehuacana and
Richland Chambers Reservoirs Combined

Pool Elevation (ft-msl)	Storage (acft)	Environmental Bypass Criteria	Firm Yield[1] (acft/yr)	Critical Period
312.0	1,279,413	CCEFN	26,300	5/48-6/57
313.0	1,333,378	CCEFN	32,100	5/48-6/57
314.0	1,389,508	CCEFN	34,400	5/48-6/57
315.0*	1,447,257	CCEFN	41,900	5/48-6/57
		None	44,100	5/48-6/57
[1]Incremental firm yield attributable to Tehuacana Reservoir.				
*Proposed conservation storage.				

Figure 3.4.15-6 presents a simulated storage trace for the combined Tehuacana-Richland-Chambers Reservoir with a conservation storage capacity of 1,447,257 acft (elevation 315 ft-msl) and an incremental firm yield diversion of 41,900 acft/yr attributable to Tehuacana Reservoir. The corresponding storage frequency curve is also shown in Figure 3.4.15-5. Based on the 1940-1996 monthly WAM simulations, at the conservation pool level of 315 ft-msl, the

combined reservoir would be full about 26 percent of the time and would be below 50 percent

full about 6 percent of the time.
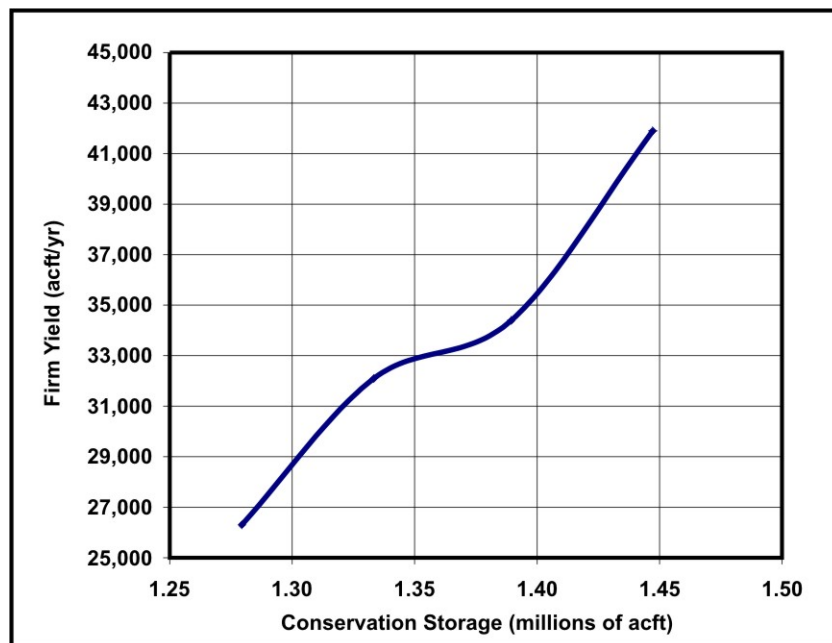
Figure 3.4.15-5. System Yield vs. Conservation Storage for Tehuacana and Richland Chambers Reservoirs Combined
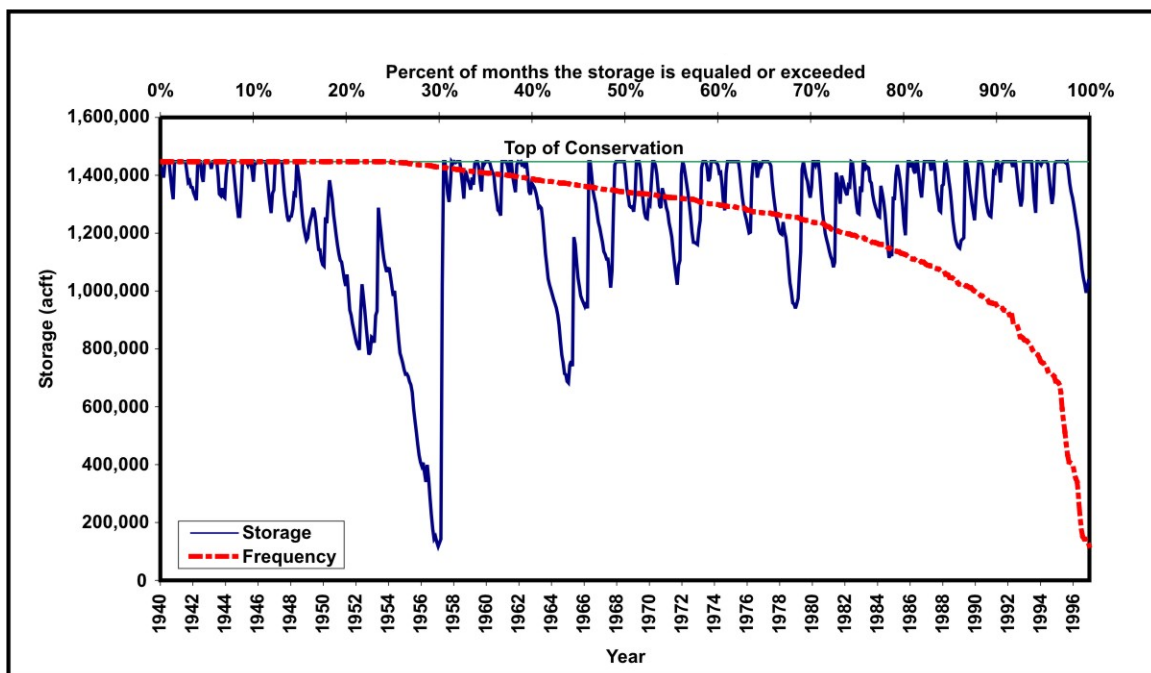
Figure 3.4.15-6. Simulated Storage in Tehuacana and Richland-Chambers Reservoirs (Conservation Elevation = 315 ft-msl, Incremental Yield = 41,900 acft/yr)

3.4.15.3 Reservoir Costs

The estimated costs for the Tehuacana Reservoir dam assume a zoned earthen embankment with a maximum height of 81 feet. As planned, the lake will be hydraulically connected to nearby Richland-Chambers Reservoir with a 9,000-foot channel. The length of the additional embankment is estimated to be 13,700 feet. It is assumed that no modifications to Richland-Chambers dam are required.

The potential conflicts identified at the site include pipelines, power lines, roads, railroads and oil fields. A list of the potential conflicts is provided in Table 3.4.15-5. The conflict costs represent less than 10 percent of the total construction cost of the reservoir project. Figure 3.4.1-7 shows the conflicts as mapped by TNRIS.

Table 3.4.15-5.
List of Potential Conflicts for Tehuacana Reservoir

Roads	Powerlines
Railroads	Oil Wells
Transmission Pipelines	

Table 3.4.15-6 presents the estimated capital costs for the Tehuacana Reservoir dam, including construction costs, engineering, permitting and mitigation. Unit costs for the dam and reservoir are based on the cost assumptions used in this study. The total estimated cost of the project is approximately $192 million (2005 prices). Assuming an annual yield of 41,900 acft/yr, raw water from the project will cost approximately $320 per acft ($0.98 per 1,000 gallons) during the debt service period.
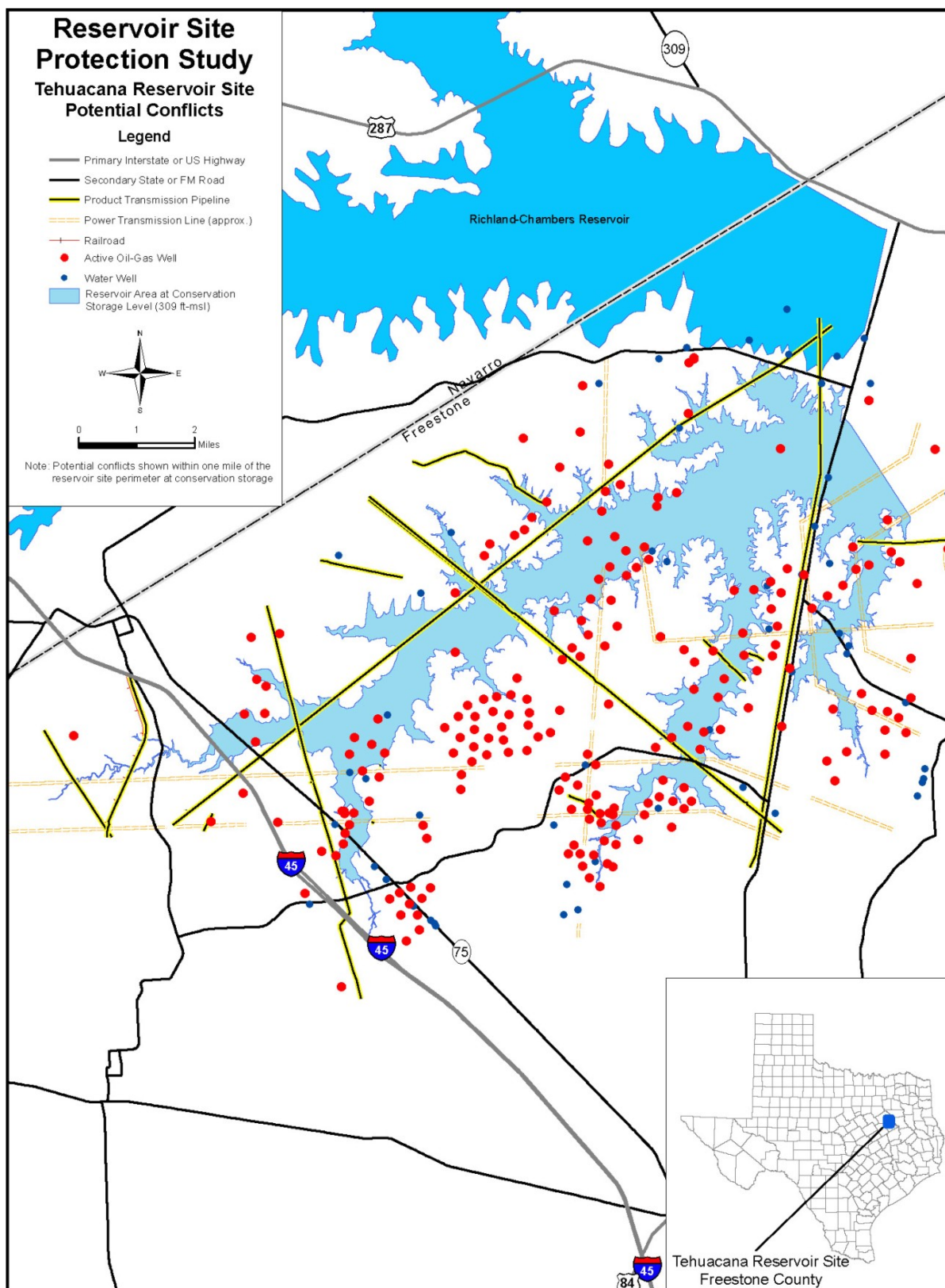
Figure 3.4.15-7. Potential Major Conflicts for Tehuacana Reservoir

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Table 3.4.15-6.
Cost Estimate - Tehuacana Reservoir @ Elevation 315 ft-msl

	SIZE	UNIT	QUANTITY	UNIT COST	COST
MOBILIZATION (5%)		LS	1	$5,525,524	**$5,525,524**
DAM & RESERVOIR CONSTRUCTION					
EMBANKMENT					
CHANNEL		CY	2,250,000	$2.00	$4,500,000
CORE TRENCH & BORROW		CY	1,764,000	$2.00	$3,528,000
FILL MATERIAL					
EMBANKMENT		CY	3,488,000	$2.50	$8,720,000
WASTE MATERIAL		CY	80,000	$2.00	$160,000
FILTER, 1 & 2 (FOUNDATION DRAINAGE)		CY	181,800	$35.00	$6,363,000
STABILIZED ROADWAY BASE		SY	59,555	$20.00	$1,191,100
CUTOFF SLURRY TRENCH		SF	514,800	$15.00	$7,722,000
SOIL CEMENT		CY	137,800	$65.00	$8,957,000
GUARD RAILS		EA	1,680	$25.27	$42,454
GRASSING		AC	34	$4,500.00	$153,000
SUBTOTAL - DAM & RESERVOIR CONSTRUCTION					**$41,336,554**
ENGINEERING & CONTINGENCIES (35% DAM & RESERVOIR)					**$14,467,794**
TOTAL - DAM & RESERVOIR CONSTRUCTION					**$55,804,347**
CONFLICTS (RELOCATIONS):					**$40,523,054**
ENGINEERING & CONTINGENCIES (35% CONFLICTS)					**$14,183,069**
TOTAL CONFLICTS (RELOCATIONS)					**$54,706,123**
CONSTRUCTION TOTAL					**$110,510,471**
LAND PURCHASE COSTS		AC	14,938	$2009	**$30,010,442**
ENVIRONMENTAL STUDIES & MITIGATION COSTS		AC	14,938	$2009	**$30,010,442**
RESERVOIR TOTAL COST					**$176,056,878**
INTEREST DURING CONSTRUCTION (36-MONTHS)					**$16,135,005**
TOTAL COST -DAM &RESERVOIR, LAND ACQUISITION, PERMITTING &MITIGATION, INTEREST DURING CONSTRUCTION					**$192,191,883**
ANNUAL COSTS					
DEBT SERVICE (6% FOR 40 YEARS)					**$12,773,368**
OPERATION & MAINTENANCE (1.5% OF DAM & RESERVOIR COSTS)					**$620,048**
TOTAL ANNUAL COSTS					**$13,393,416**
FIRM YIELD (acft/yr)					**41,900**
UNIT COST OF WATER (DURING AMORTIZATION)					
PER ACFT					**$320**
PER 1,000 GALLONS					**$0.98**

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

3.4.15.4   Environmental Considerations

The Tehuacana Reservoir site is not located on an ecologically significant stream segment as identified by the Texas Parks and Wildlife Department (TWDB, 1999) nor is it identified as ecologically unique in the 2007 State Water Plan. It is, however, located just upstream of a segment of the Trinity River identified by TPWD as ecologically significant due to a population of rare endemic Texas heelspliter freshwater mussels. The Tehuacana Reservoir site is also located immediately upstream of two Priority 5 bottomland hardwood preservation sites identified as Tehuacana Creek and Boone Fields (USFWS, 1985).

Previous water quality studies conducted for the Tarrant Regional Water District (Freese and Nichols and Alan Plummer and Associates, 1990) concluded that the flow-weighted quality data in the combined Richland-Chambers-Tehuacana Reservoir would be very comparable to existing water supply sources indicating that no significant changes to the existing treatment processes would be necessary for this reservoir. The project would inundate approximately 14,938 surface acres and 25.2 river miles of Tehuacana Creek. Part of the Tehuacana Reservoir site is underlain by lignite, and the project has been deferred in the past for that reason (Freese and Nichols and Alan Plummer and Associates, 1990).

Table 3.4.15-7 and Figure 3.4.15-8 summarize existing landcover for the Tehuacana Reservoir site as determined by TPWD using methods described in Appendix C. Existing landcover within this reservoir site is dominated by upland deciduous forest (58 percent) and grassland (20 percent). Bottomland hardwood forest, concentrated near the dam site and the upper end of the reservoir comprises about 8 percent of the inundated area. Approximately 2.7 percent of the site is presently classified as marsh or open water.
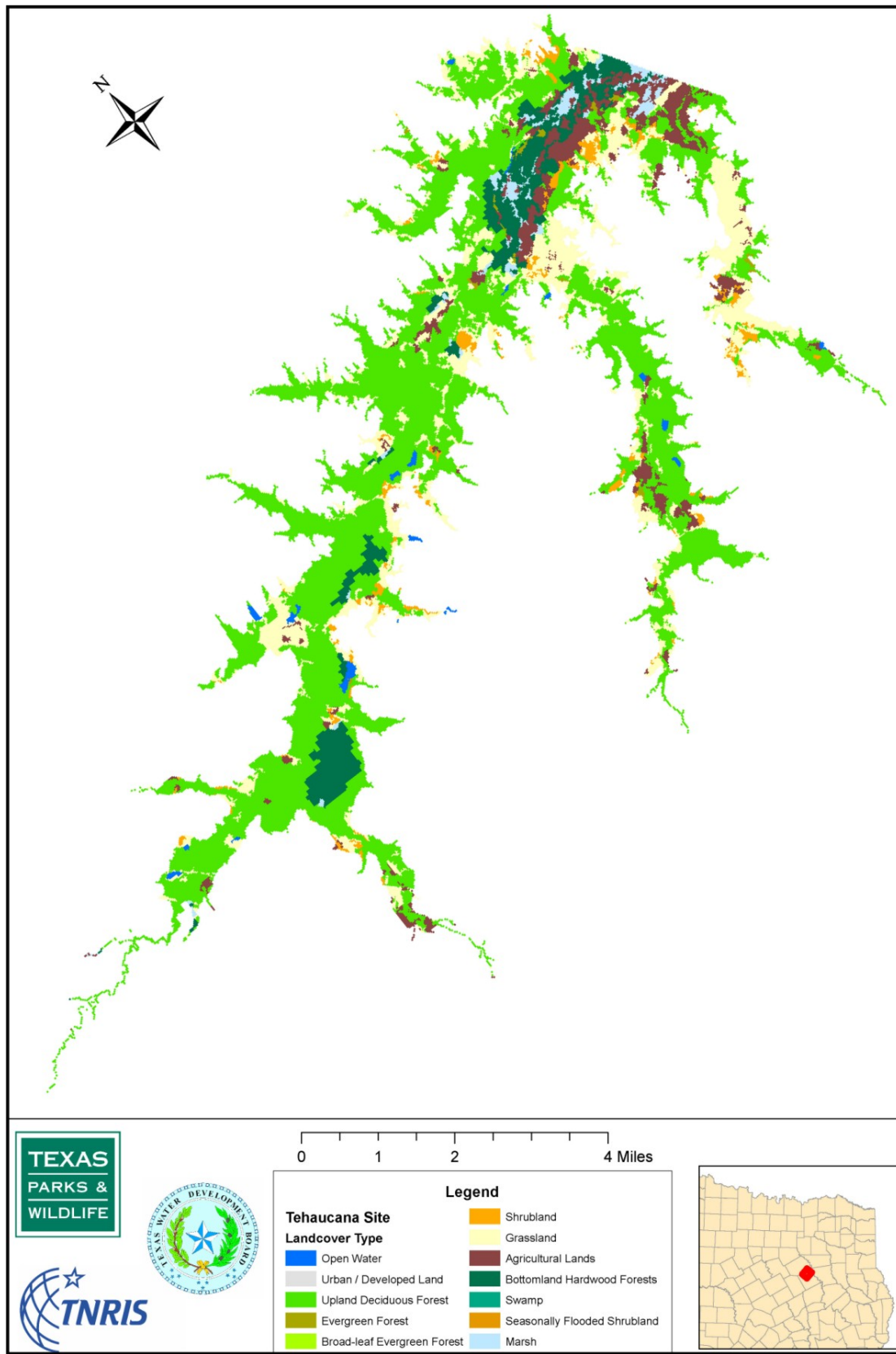
Figure 3.4.15-8. Existing Landcover for Tehuacana Reservoir

Table 3.4.15-7.
Acreage and Percent Landcover for Tehuacana Reservoir

Landcover Classification	Acreage[1]	Percent
Bottomland Hardwood Forest	1,213	8.2%
Marsh	285	1.9%
Evergreen Forest	65	0.4%
Upland Deciduous Forest	8,605	58.0%
Grassland	2,992	20.1%
Shrubland	427	2.9%
Agricultural Land	1,136	7.7%
Open Water	122	0.8%
Total	**14,845**	**100.0%**
[1] *Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.*		

3.4.16   Wilson Hollow Reservoir

3.4.16.1   Project Description

In 1986, a volumetric survey was performed by HDR Engineering, Inc. to determine the capacity of Lake Palo Pinto. The survey indicated the capacity of the lake to be 27,650 acft or about 16,450 acft less than the authorized capacity of 44,100 acft. This lesser capacity for Lake Palo Pinto was subsequently verified by the Texas Water Development Board using more sophisticated technology. In order to help restore the capacity and firm yield of Lake Palo Pinto, an off-channel reservoir site has been investigated (HDR, April 2005). The proposed off-channel reservoir is located approximately 1.6 miles north of Lake Palo Pinto at Wilson Hollow as shown in Figure 3.4.16-1. The proposed dam would be an earthfill embankment that would provide a conservation storage capacity of 22,000 acft at elevation 1,077 ft-msl and inundate 333 surface acres.
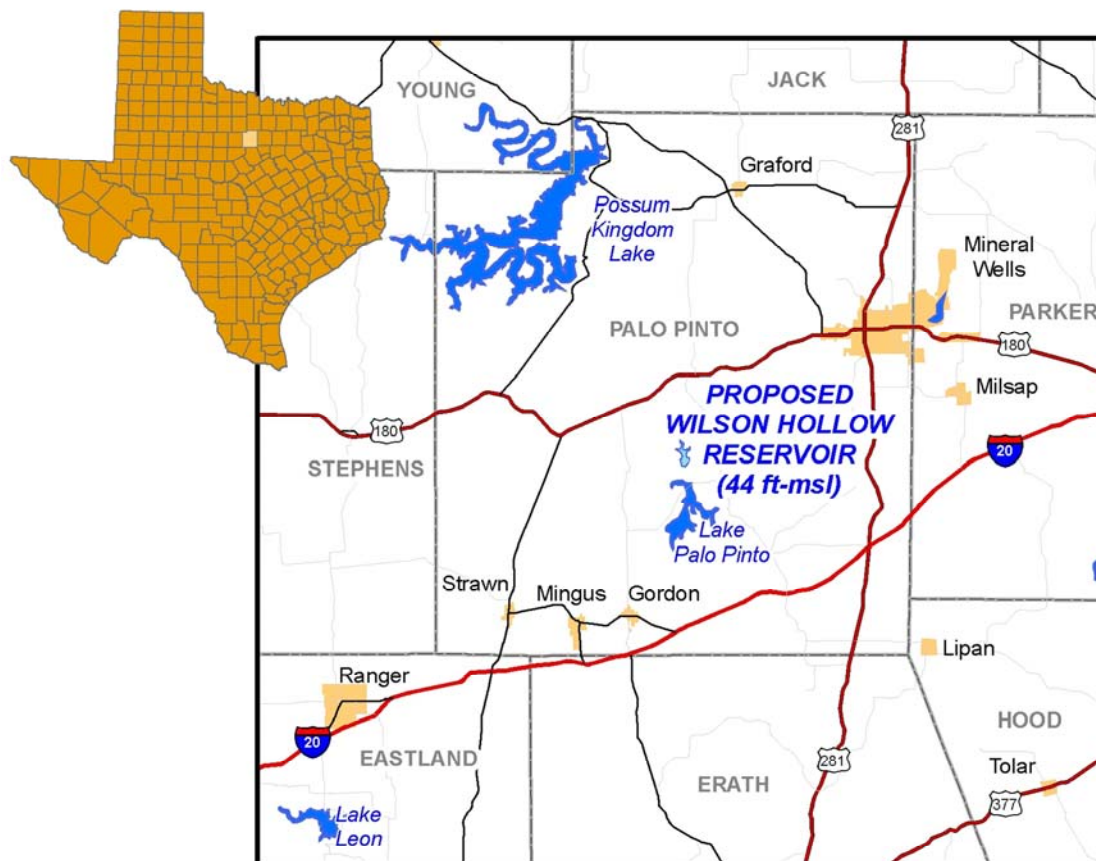
Figure 3.4.16-1. Location Map of Wilson Hollow Reservoir

The proposed off-channel reservoir would be filled by natural drainage and by pumping water from Lake Palo Pinto when it is spilling or nearly full. When the level of Lake Palo Pinto is lowered due to drought conditions, water would be released by gravity from the off-channel reservoir to Lake Palo Pinto to increase its supply capability. When both the off-channel reservoir and Lake Palo Pinto are at their conservation elevations, 1,077 ft-msl and 867 ft-msl respectively, the combined storage capacity in 2060 would be approximately 44,100 acft, the currently authorized storage capacity of Lake Palo Pinto. Wilson Hollow Reservoir will likely be constructed in two phases so that the site storage capacity is increased as the capacity of Lake Palo Pinto is decreased by sediment accumulation. The 2006 Brazos G Regional Water Plan (HDR and FNI, 2006) also identified Turkey Peak Reservoir as an alternative water management strategy to Wilson Hollow Reservoir for recovery of authorized Lake Palo Pinto storage capacity.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply prior to year 2060 total 511,124 acft/yr for counties within a 50-mile radius of the Wilson Hollow Reservoir site. The nearest major population and water demand center to the Wilson Hollow Reservoir site is Dallas-Ft Worth (79 miles).

3.4.16.2   *Reservoir Yield Analyses*

The elevation-area-capacity relationship for Wilson Hollow Reservoir is presented in Figure 3.4.16-2 and Table 3.4.16-1 and was developed from 10-ft contour, digital hypsography data from the Texas Natural Resources Information System (TNRIS). These data are derived from the 1:24,000-Scale (7.5-minute) quadrangle maps developed by the USGS. The total area inundated at each 10-ft elevation contour is shown in Figure 3.4.16-3. Surface areas and capacities associated with 1077 ft-msl are computed by linear interpolation between values for 1070 ft-msl and 1080 ft-msl and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 1077 ft-msl, Wilson Hollow Reservoir would inundate 333 acres and have a capacity of 22,000 acft.
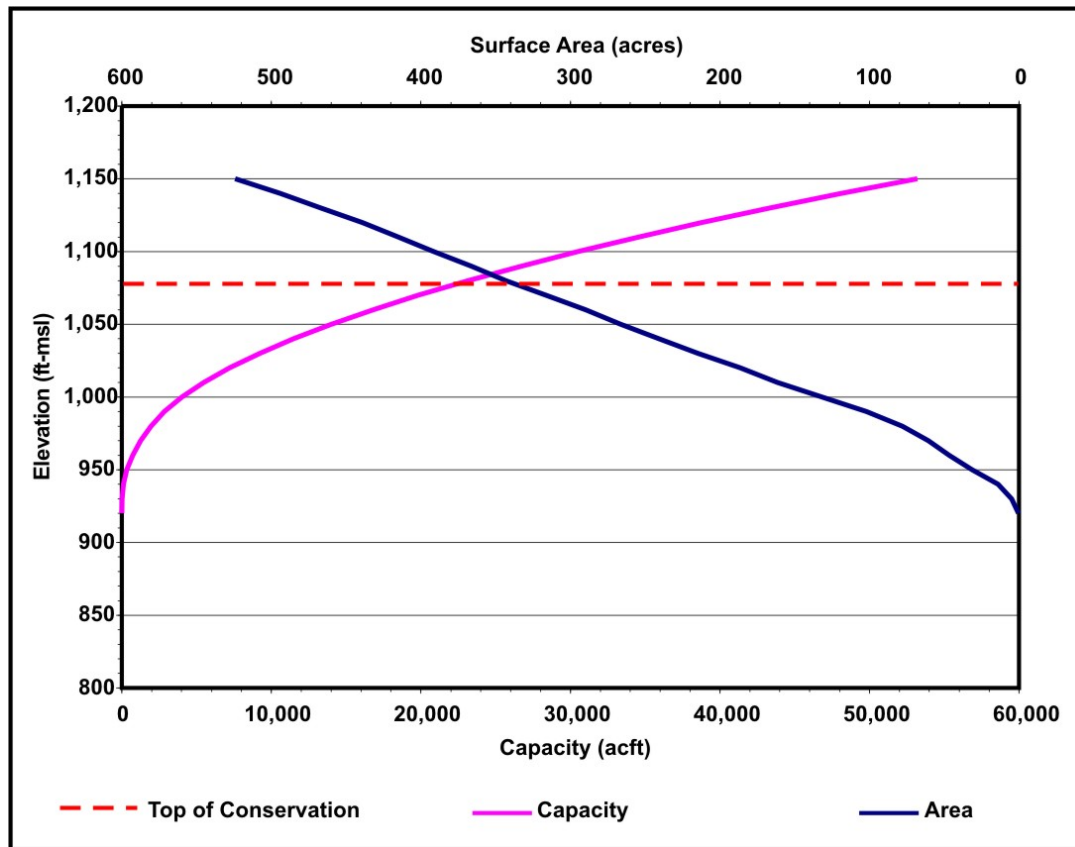
Figure 3.4.16-2. Elevation-Area-Capacity Relationship for Wilson Hollow Reservoir

Table 3.4.16-1.
Elevation-Area-Capacity Relationship for Wilson Hollow Reservoir

Elevation (feet)	Area (acres)	Capacity (acft)
920	0	0
930	5	24
940	14	115
950	31	336
960	47	724
970	61	1,259
980	78	1,951
990	102	2,849
1,000	132	4,014
1,010	162	5,477
1,020	187	7,216
1,030	215	9,221
1,040	241	11,498
1,050	266	14,034
1,060	290	16,815
1,070	317	19,845
1,077	333	22,000
1,080	343	23,143
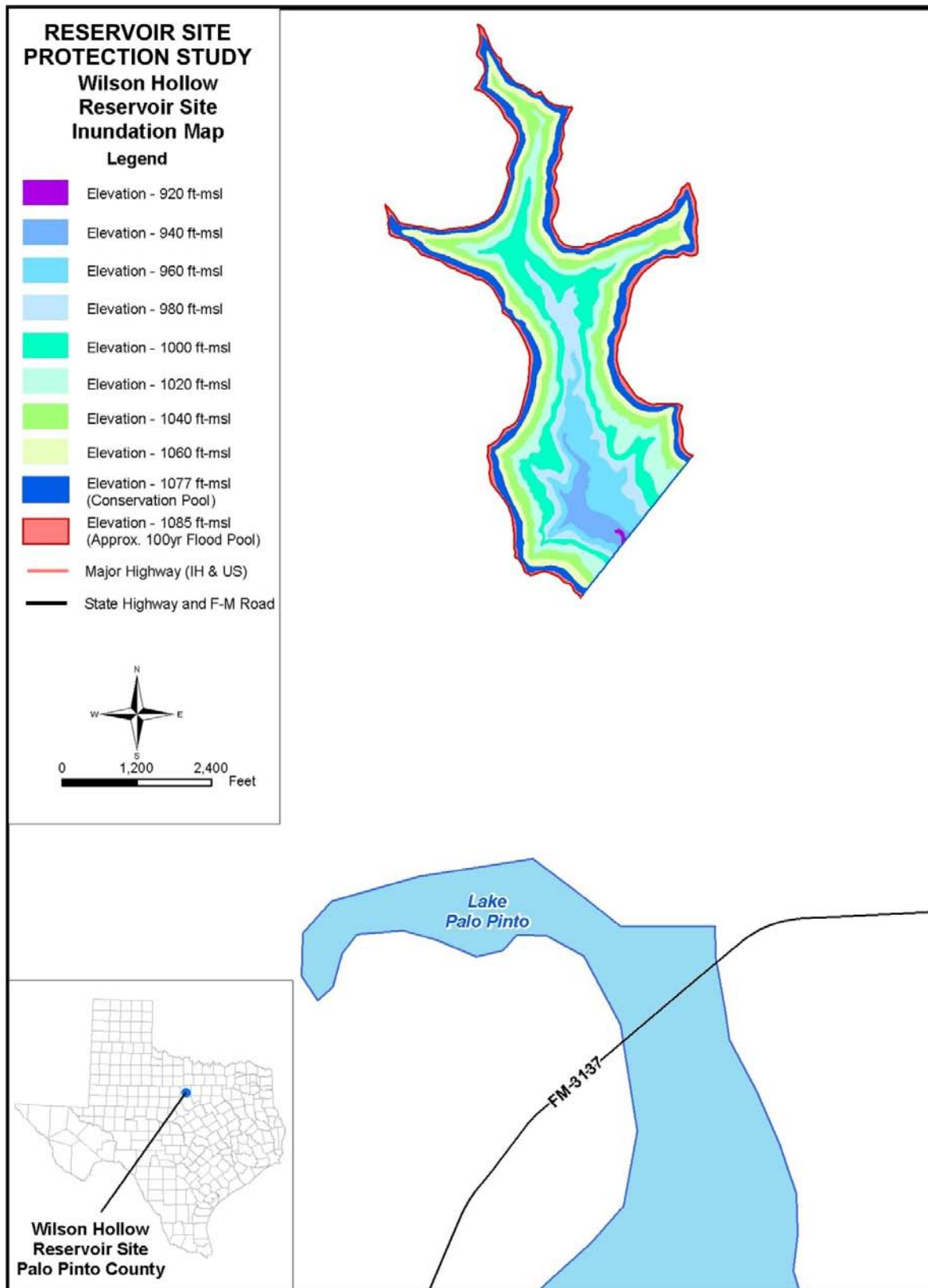
Figure 3.4.16-3. Inundation Map for Wilson Hollow Reservoir

The firm yield of Wilson Hollow Reservoir is estimated using the TCEQ Brazos River Basin Water Availability Model (Brazos WAM) (HDR, 2001) data sets and the Water Rights Analysis Package (WRAP). The Brazos WAM simulates a repeat of the natural streamflows over the 57-year period of 1940 through 1996 accounting for the appropriated water rights of the Brazos River Basin with respect to location, priority date, diversion amount, diversion pattern, storage, and special conditions including instream flow requirements.

For the purposes of this study, Lake Granbury and other senior water rights are assumed to be subordinated to Lake Palo Pinto authorized storage capacity. Specific terms of such subordination are, or will be, the subject of negotiations between the reservoir sponsor, the Brazos River Authority, and others.

Four potential conservation storage capacities are modeled for Wilson Hollow Reservoir. These conservation storage capacities are 10,000 acft, 15,000 acft, 20,000 acft, and 22,000 acft. Wilson Hollow Reservoir is simulated with the priority date of Lake Palo Pinto since it is envisioned as a project to recover "lost" storage in Lake Palo Pinto. Firm yield estimates for Wilson Hollow Reservoir for all four conservation capacities are shown in Table 3.4.16-2. Current planning initiatives envision a conservation elevation of 1077 ft-msl for Wilson Hollow Reservoir, thereby yielding an additional water supply of 5,873 acft/yr above the Year 2060 Lake Palo Pinto firm yield of 11,340 acft/yr. Figure 3.4.16-4 shows the relationship between firm yield and conservation capacity for the Wilson Hollow Reservoir / Lake Palo Pinto System. For the purposes of this study, a 54 MGD diversion intake, pump station, and pipeline were assumed to pump water up from Lake Palo Pinto to Wilson Hollow.

Wilson Hollow Reservoir was most recently studied by Region G and identified as a recommended water management strategy in the 2006 Regional Water Plan. In the Region G plan, Wilson Hollow Reservoir was evaluated at a location slightly upstream and at a smaller size (10,000 acft). Additionally, the Lake Palo Pinto / Wilson Hollow System was evaluated on a safe yield basis.
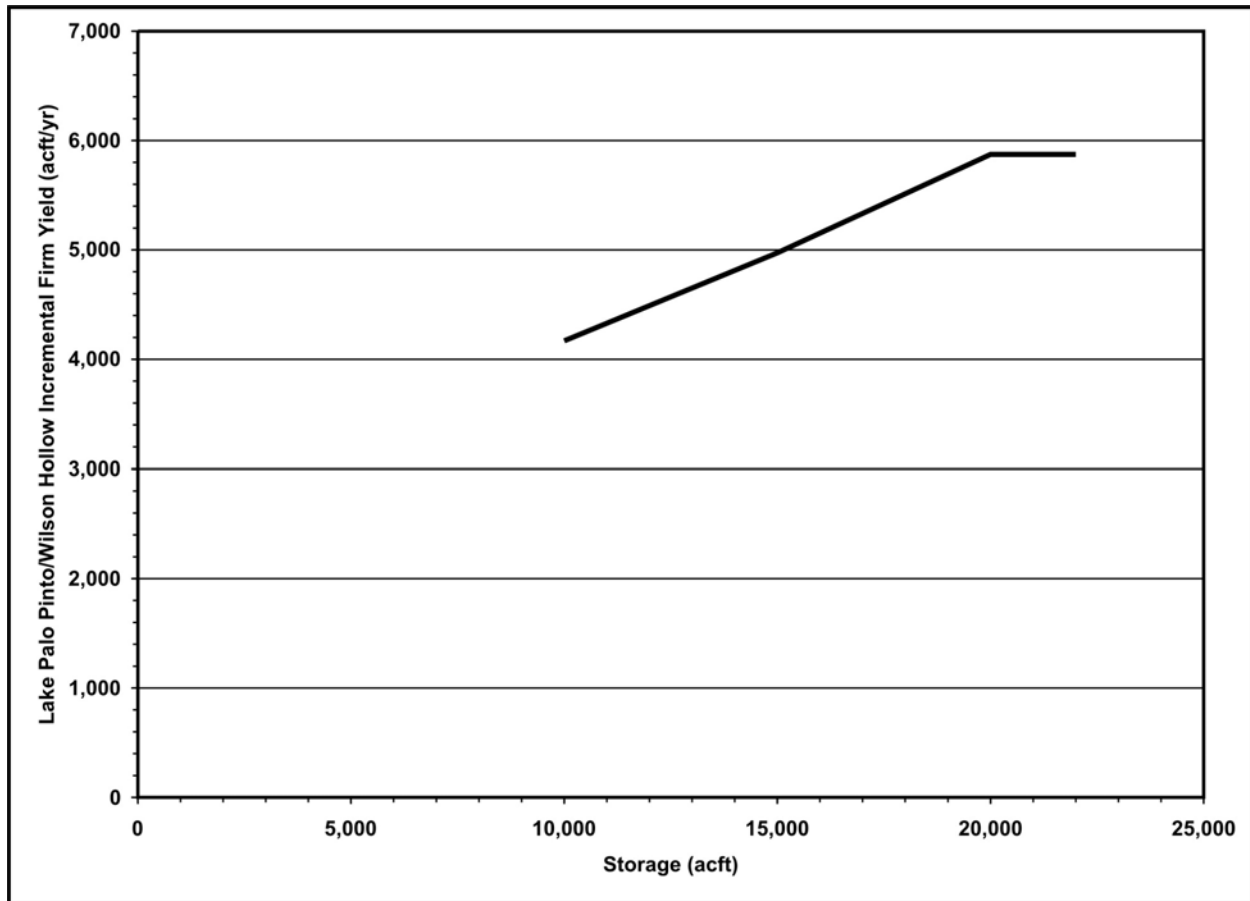
Figure 3.4.16-4. Firm Yield vs. Conservation Storage for Wilson Hollow Reservoir

Table 3.4.16-2.
Firm Yield vs. Conservation Storage for Wilson Hollow Reservoir

Wilson Hollow Conservation Capacity (acft)	Lake Palo Pinto / Wilson Hollow System Yield (acft/yr)	Wilson Hollow Incremental Firm Yield (acft/yr)
10,000	15,508	4,168
15,000	16,314	4,974
20,000	17,213	5,873
22,000*	17,213	5,873
*Ultimate proposed conservation storage.		

Figure 3.4.16-5 illustrates storage fluctuations through time for Wilson Hollow Reservoir and Figure 3.4.16-6 shows combined system storage in Lake Palo Pinto and Wilson Hollow Reservoir. The storage frequency curve in Figure 3.4.16-5 indicates that the reservoir would be full about 30 percent of the time, more than half full about 80 percent of the time, and empty about 7 percent of the time. As shown in Figure 3.4.16-6, however, the system of reservoirs would be above 50 percent of capacity about 90 percent of the time.
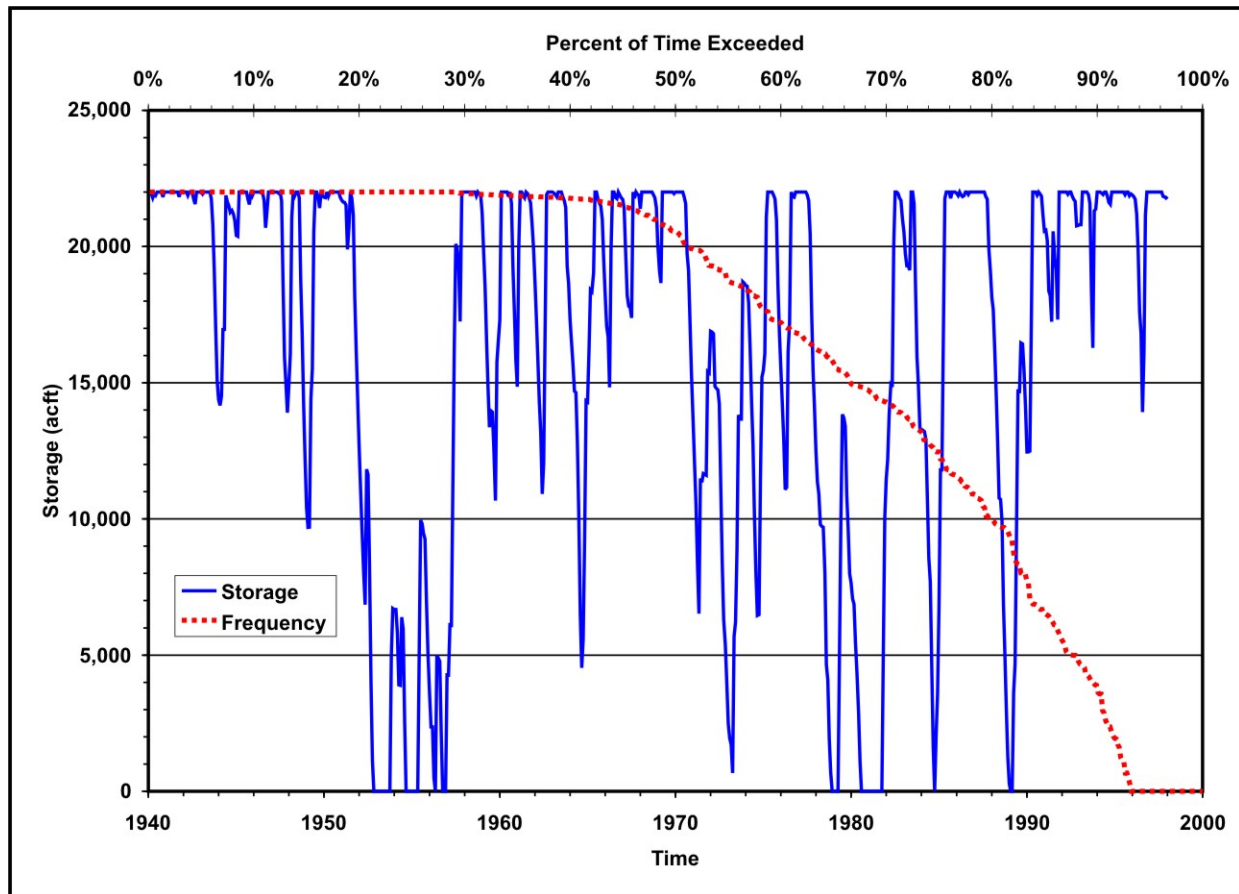
Figure 3.4.16-5. Simulated Storage in Wilson Hollow Reservoir
(Conservation Elevation = 1077 ft-msl, Incremental Diversion = 5,873 acft/yr)
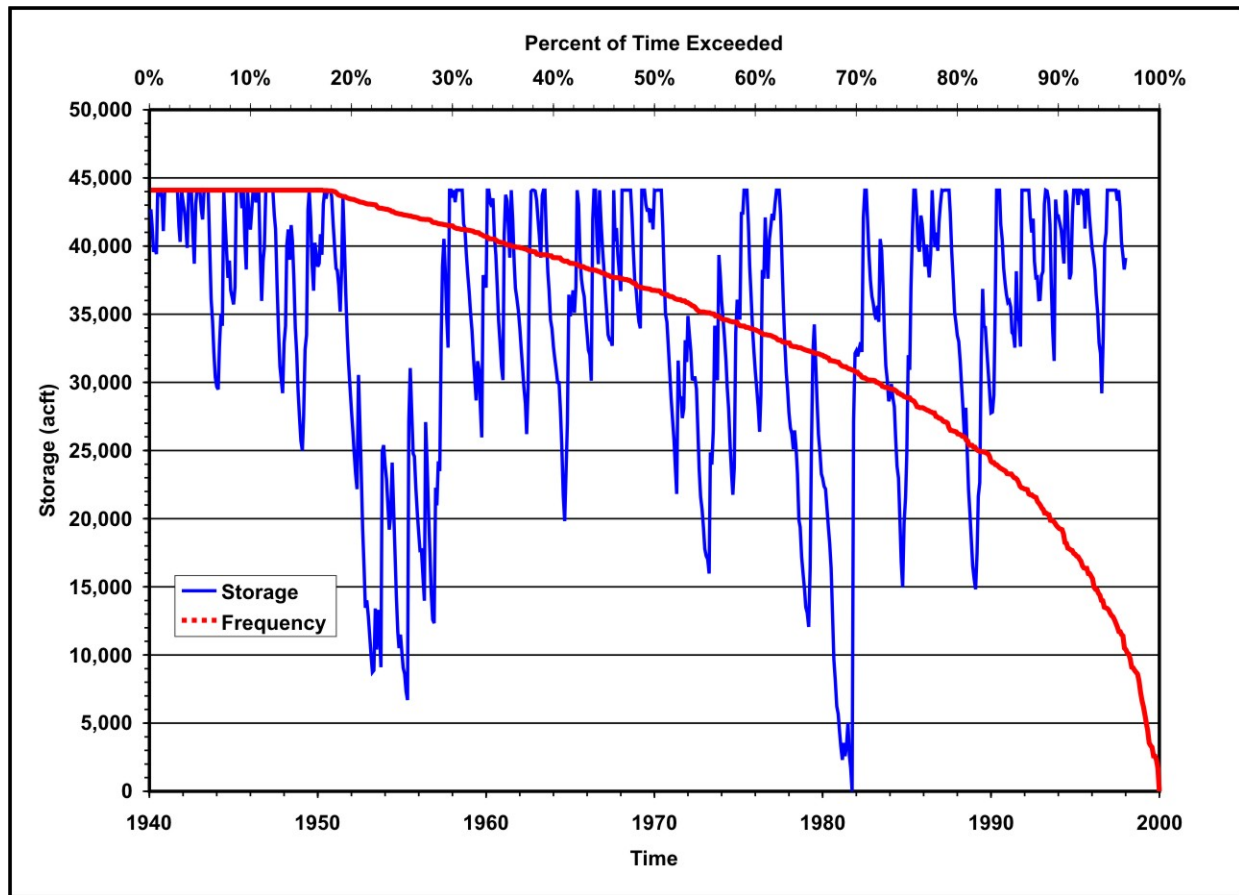
Figure 3.4.16-6. Simulated System Storage for Lake Palo Pinto and Wilson Hollow Reservoirs (System Diversion = 17,213 acft/yr)

3.4.16.3   Reservoir Project Cost Estimates

Costs for Wilson Hollow Reservoir assume a zoned earthen embankment. The dam is estimated to be approximately 2,500 feet in length and have a maximum height of approximately 168 feet. Diversion works from Lake Palo Pinto to Wilson Hollow Reservoir include a 54 MGD intake and pump station, a 1.5 mile, 54-inch pipeline, and a stilling basin.

Figure 3.4.16-7 shows the major conflicts within the conservation pool of Wilson Hollow Reservoir. Potential conflicts for Wilson Hollow Reservoir are limited to existing gas infrastructure. Resolution of facility conflicts represents less than 1 percent of the total construction cost.
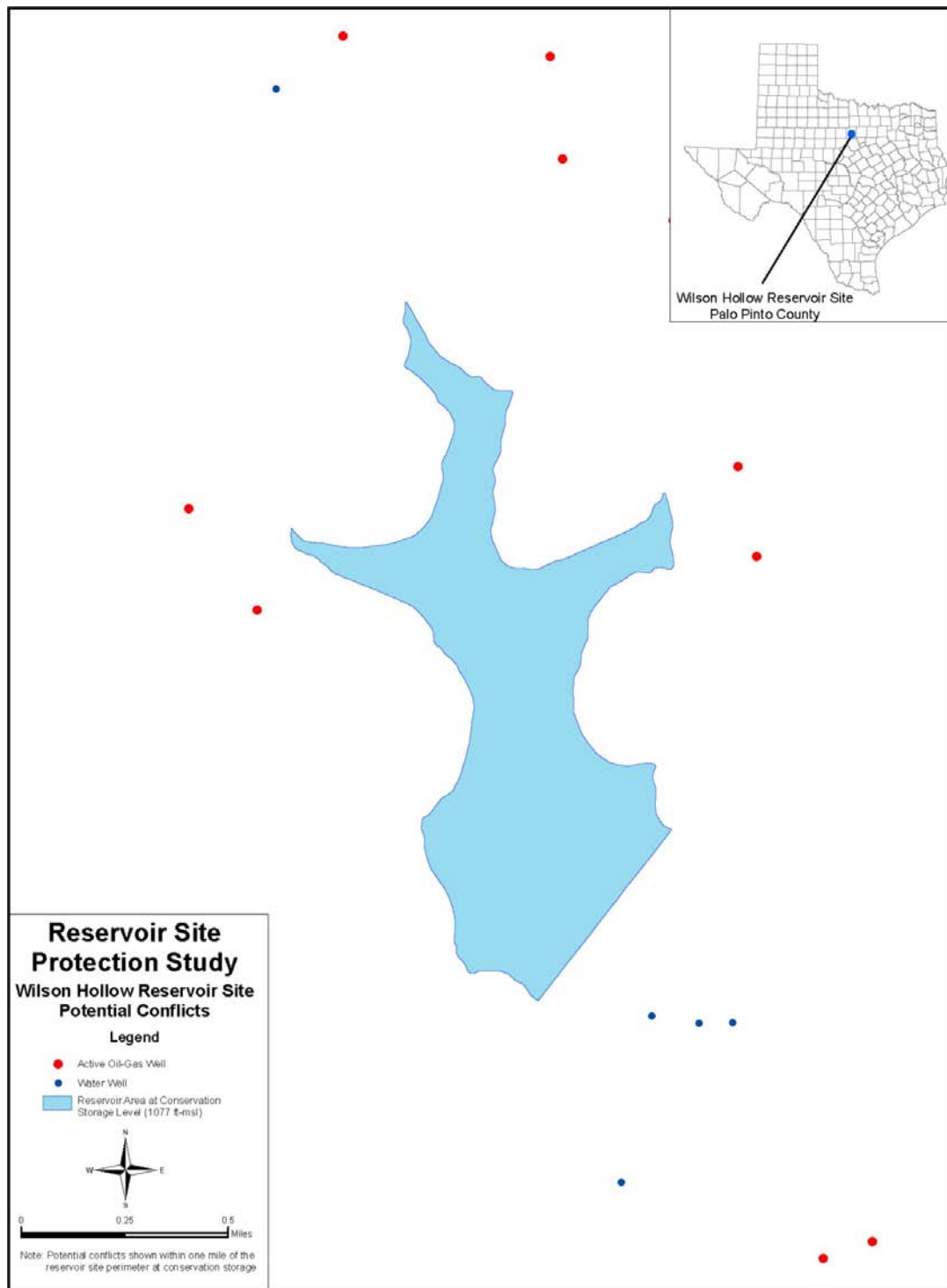
Figure 3.4.16-7. Potential Major Conflicts for Wilson Hollow Reservoir

A summary cost estimate for Wilson Hollow Reservoir at elevation 1077 ft-msl is shown in Table 3.4.16-3. Dam and reservoir costs total about $47 million, while relocations total another $540,000. Land, which includes mitigation lands, totals about $3.4 million. The

diversion intake, pump station, and pipeline from Lake Palo Pinto to Wilson Hollow Reservoir adds another $10.5 million. Annual costs for Wilson Hollow Reservoir are approximately $5.4 million during the 40-year debt service period, giving the project a unit cost of raw water at the reservoir of $920/acft ($2.82 per 1000 gallons).

Table 3.4.16-3.
Cost Estimate – Wilson Hollow Reservoir @ Elevation 1077 ft-msl

	Quantity	Unit	Unit Price	Cost
Dam & Reservoir				
Mobilization (5%)	1	LS		$1,595,016
Care of Water During Construction (3%)	1	LS		$957,009
Cutoff Trench	1	LS	$1,242,866	$1,242,866
Embankment	1	LS	$21,019,975	$21,019,975
Drains & Filters	1	LS	$4,179,930	$4,179,930
Grouting and Foundation Preparation	1	LS	$494,517	$494,517
Geocomposite Liner/ Riprap	1	LS	$4,313,025	$4,313,025
Outlet Works Tower and Conduit	1	LS	$650,000	$650,000
Engineering Contingencies (35%)				$12,058,318
Subtotal Dam & Reservoir				**$46,510,657**
Pump & Pipeline				
Pump Station & Intake (54 MGD)	1	LS	$5,708,000	$5,708,000
Pipeline (54-inch)	7794	LF	$240	$1,870,560
Stilling Basin (83.5 cfs)	1	LS	$252,588	$252,588
Engineering Contingencies (35%)				$2,740,902
Subtotal Pump & Pipeline				**$10,572,049**
Conflicts				
Gas Infrastructure	1	LS	$400,000	$400,000
Engineering Contingencies (35%)				$140,000
Subtotal Conflicts				**$540,000**
Land				
Land Acquisition	400	AC	$4,250	$1,700,000
Environmental Studies and Mitigation Lands	400	AC	$4,250	$1,700,000
Subtotal Land				**$3,400,000**
CONSTRUCTION TOTAL				**$61,022,706**
Interest During Construction (36 months)				**$7,322,725**
TOTAL COSTS				**$68,345,430**
ANNUAL COSTS				
Debt Service (6% for 40 Years)				$4,542,237
Operations & Maintenance				$861,591
Pumping Energy				$550,276
Total Annual Costs				**$5,403,829**
Firm Yield (acft/yr)				**5,873**
Unit Costs of Water ($/acft/yr)				**$920**

Units: AC = Acre; CY = Cubic Yard; EA = Each; LB = Pound; LF = Linear Foot; LS = Lump Sum; SF = Square Foot; and SY = Square Yard.

3.4.16.4   Environmental Considerations

Wilson Hollow Reservoir is not located on or immediately upstream of any ecologically significant stream segments as recommended by Texas Parks and Wildlife Department (TPWD, 1999).   The reservoir will inundate 333 acres of land.   Table 3.4.16-4 and Figure 3.4.16-8 summarize existing landcover for the Wilson Hollow Reservoir site as determined by TPWD using methods described in Appendix C.   Existing landcover within this reservoir site is 96 percent upland deciduous forest with one small homestead near the dam site.

Table 3.4.16-4.
Acreage and Percent Landcover for Wilson Hollow Reservoir

Landcover Classification	Acreage[1]	Percent
Upland Deciduous Forest	330	96.0%
Urban / Developed Land	14	4.0%
Total	**344**	**100.0%**
[1] Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.		
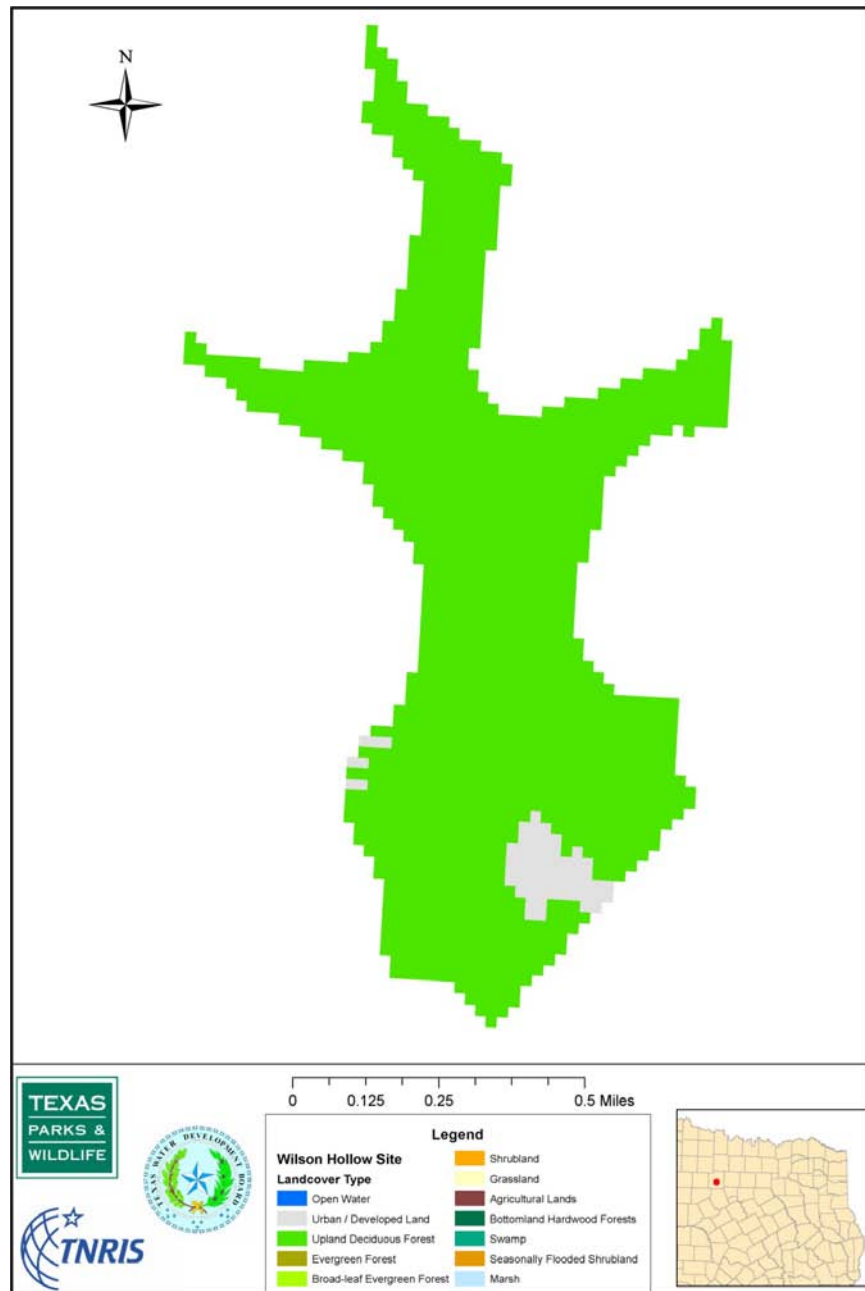
Figure 3.4.16-8. Existing Landcover for Wilson Hollow Reservoir

Section 4
Summary and Recommendations

4.1   Comparison of Reservoir Sites Recommended for Protection

Information relevant to the criteria adopted for the reservoir site screening process discussed in Section 2 has been updated from the technical evaluations of 16 reservoir sites recommended for protection and summarized in Table 4.1-1. Observations and comparisons of these 16 reservoir sites are presented in the following paragraphs in the order of relative importance for the screening process that was applied to about 150 sites and discussed in Section 2.

4.1.1   Recommended to Meet Needs or as a Unique Reservoir Site in the 2007 State Water Plan

All of the reservoir sites recommended for protection, with the exceptions of Cuero II (Sandies Creek), George Parkhouse I, and George Parkhouse II, are recommended water management strategies and/or are recommended for designation as unique reservoir sites in the 2007 State Water Plan. The Parkhouse I and II Reservoirs are identified as alternative water management strategies for several major water suppliers in the 2006 Region C Water Plan. The Cuero II reservoir site is not explicitly mentioned in the 2006 Region L Water Plan, though it might be considered Additional Storage which is referenced therein as a water management strategy in need of further study and funding prior to implementation.

4.1.2   Firm Yield

The largest firm yield or dependable supply during a drought of record (602,000 acft/yr) can be provided by the Marvin Nichols IA reservoir site. Depending upon the ultimate development of other sites recommended for protection in the Sulphur River Basin (e.g., Parkhouse I, Parkhouse II, and/or Ralph Hall) and their priorities relative to Marvin Nichols IA, the firm yield of Marvin Nichols IA could be as low as 460,800 acft/yr (Appendix A). The Brushy Creek reservoir site provides the least firm yield (1,380 acft/yr) among the sites recommended for protection, however, it is the recommended water supply strategy for the City of Marlin.

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Table 4.1-1.
Comparison of Reservoir Sites Recommended for Protection

Reservoir Site	River Basin	Region	Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	Firm Yield (acft/yr)	Unit Cost of Water - Raw @ Reservoir ($/acft/yr)	Special Considerations (Permitted)	Ecologically Significant Stream Segment (# Criteria)	Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2060 Water Supply Needs within 50 miles (acft/yr)	Least Distance to Major Demand Center (miles)	System Operations Opportunity	Water Quality Concerns (Treatment)	Yield / Surface Area
Bedias	Trinity	G & H	Yes	75,430	$232	No	No Impact	Just Upstream (6)	284,552	85	Yes	No	7.5
Brownsville Weir	Rio Grande	M	Yes	20,643	$181	Yes	Inundating (4)	No Impact	223,489	29	Yes	No	34.4
Brushy Creek	Brazos	G	Yes	1,380	$484	Yes	No Impact	No Impact	246,820	83	No	No	2.0
Cedar Ridge	Brazos	G	Yes	36,891	$230	No	No Impact	No Impact	17,240	146	Yes	No	6.0
Cuero II	Guadalupe	L	No	71,437	$501	No	No Impact	No Impact	346,140	71	Yes	No	2.7
Fastrill	Neches	I	Yes	134,038	$152	No	Inundating (3)	Inundating (1)	136,476	127	Yes	No	5.4
Lower Bois D'Arc	Red	C	Yes	126,280	$140	No	Inundating (3)	Inundating (4)	728,028	80	Yes	No	7.6
Marvin Nichols IA	Sulphur	D	Yes	602,000	$61	No	Indirect (2)	Inundating (1)	103,879	124	Yes	No	8.9
Nueces Off-Channel	Nueces	N	Yes	39,935	$432	No	No Impact	No Impact	159,640	56	Yes	No	7.5
Palmetto Bend II	Lavaca	P	Yes	22,964	$515	Yes	Indirect (2)	No Impact	79,857	93	Yes	No	5.0
Parkhouse I	Sulphur	D	No	122,000	$174	No	No Impact	Upstream (1)	561,591	93	Yes	No	4.2
Parkhouse II	Sulphur	D	No	144,300	$107	No	No Impact	Upstream (1)	473,850	94	Yes	No	10.0
Ralph Hall	Sulphur	C	Yes	32,940	$430	No	No Impact	No Impact	419,136	72	Yes	No	4.3
Ringgold	Red	B	Yes	32,800	$273	No	No Impact	No Impact	313,933	96	Yes	No	2.2
Tehuacana	Trinity	C	Yes	41,900	$320	No	Indirect (3)	Just Upstream (5)	890,895	79	Yes	No	2.8
Wilson Hollow	Brazos	G	Yes	5,873	$920	No	No Impact	No Impact	511,124	79	Yes	No	17.6

4.1.3 Unit Cost of Water

The Marvin Nichols IA site provides firm raw water supply at the reservoir for the least unit cost among the reservoir sites recommended for protection. Even with potential reductions in firm yield due to prior development of upstream reservoirs, Marvin Nichols IA would still have the least unit cost for additional firm water supply. The greatest unit cost is associated with the Wilson Hollow site which is an off-channel reservoir including pumping and transmission facilities to move water from Lake Palo Pinto. It is important to remember that costs reported in this study include neither transmission from the source reservoir to the ultimate user nor treatment to drinking water standards.

4.1.4 Special Considerations

Permits have been issued by the Texas Commission on Environmental Quality (TCEQ) or a predecessor regulatory agency for reservoirs at the Brownsville Weir, Brushy Creek, and Palmetto Bend II sites. A water rights application is pending at TCEQ for the Ralph Hall site and water rights applications are in various stages of preparation for the Cedar Ridge, Fastrill, Lower Bois d'Arc Creek, and Wilson Hollow sites.

4.1.5 Ecologically Significant Stream Segments

Six of the 16 reservoir sites recommended for protection are expected to have some effect upon stream segments identified as ecologically significant by the Texas Parks & Wildlife Department (TPWD). The Brownsville Weir, Fastrill, and Lower Bois d'Arc Creek sites would affect recommended segments by inundation, while the Marvin Nichols IA, Palmetto Bend II, and Tehuacana sites could have indirect effects upon recommended segments as a result of changes in flow regime below the reservoirs.

4.1.6 Terrestrial Impacts

Seven of the 16 reservoir sites recommended for protection are expected to have some effect upon prioritized bottomland hardwood preservation sites identified by the U.S. Fish & Wildlife Service (USFWS). The Fastrill, Lower Bois d'Arc Creek, and Marvin Nichols IA sites would affect such bottomland hardwood preservation sites by inundation, while the Bedias and Tehuacana sites would be located immediately upstream of potential preservation sites. Although the Parkhouse I and Parkhouse II sites would be located some distance upstream of a

prioritized bottomland hardwood preservation site, detailed hydrological and biological studies would likely be required to assess potential reservoir impacts. Development of reservoir projects at all 16 of the sites recommended for protection in this study would significantly affect only two of 14 Priority 1 bottomland hardwood preservation sites in Texas. Since publication of the prioritized bottomland hardwood preservation sites by USFWS in 1985, no major reservoirs have been constructed that consequentially affect any of the 14 Priority 1 sites.

4.1.7   Water Supply Needs within 50 Miles

The Lower Bois d'Arc Creek, Parkhouse I, Parkhouse II, Ralph Hall, Tehuacana, and Wilson Hollow reservoir sites have the greatest projected needs for additional water supply at year 2060 for counties within (or partially within) a 50-mile radius of the sites. The Cedar Ridge and Palmetto Bend II sites have the least projected needs for potential users geographically proximate to the reservoir sites. It is noted, however, that projected needs near the Cedar Ridge site could be underestimated because existing reservoirs serving users in the area are in the midst of a drought more severe than that experienced in the 1950s.

4.1.8   Least Distance to a Major Demand Center

Among the 16 reservoir sites recommended for protection, the Brownsville Weir and Nueces Off-Channel reservoir sites are the closest to some of the largest current population centers in Texas, while the Cedar Ridge, Fastrill, and Marvin Nichols IA sites are the most distant.

4.1.9   System Operations Opportunity

Each of the 16 reservoir sites recommended for protection, with the exception of Brushy Creek, presents some opportunity for enhancement of firm yield through system operations with one or more existing reservoirs or alternative water supply sources.

4.1.10 Water Quality Concerns

None of the 16 reservoir sites recommended for protection exhibit water quality characteristics expected to significantly affect costs of treatment to drinking water standards.

4.1.11 Yield per Unit Surface Area

The Brownsville Weir and Wilson Hollow reservoir sites, though relatively small, are the most efficient in terms of firm yield per unit of inundated surface area.

4.2   Reservoir Site Acquisition Program

Based on the screening process described in Section 2 and technical evaluations presented in Section 3, 16 reservoir sites are recommended for protection through legislative designation as being of unique value for the construction of a reservoir. Beyond such designation, the Texas Legislature could choose to create a reservoir site acquisition program in order to exercise greater control over federal, state, or local government actions that would significantly impact the feasibility of future reservoir construction for water supply purposes. Table 4.2-1 summarizes the conservation, or normal, pool areas for the 16 reservoir sites evaluated in detail in this study, as well as the estimated costs for acquisition in 2005 dollars. As shown in Table 4.2-1, acquisition of all sites up to the conservation storage level would entail purchase of about 244,000 acres at an estimated capital cost of about $428,000,000 for land only. This capital cost equates to an annual cost of about $28,400,000 assuming a 40-year debt service period and an annual interest rate of 6 percent.

A reservoir site acquisition program should include sites that the Legislature has already designated as being of unique value for the construction of a reservoir. These designated sites are: Allens Creek on Allens Creek near the confluence with the Brazos River in Austin County; Columbia on Mud Creek, a tributary of the Angelina River, in Cherokee and Smith Counties; and Post on the north fork of the Double Mountain Fork of the Brazos River in Garza County. As land for Allens Creek has already been purchased, only Columbia and Post need be included in a reservoir site acquisition program. Addition of the Columbia and Post sites (up to conservation storage level) would bring the reservoir site acquisition program to a total of about 256,500 acres at an estimated capital cost of about $447,000,000 (Table 4.2-1) and an annual cost of about $29,700,000.

Consideration may also be given to protection and/or acquisition of five additional sites recommended for designation as unique reservoir sites in the 2007 State Water Plan, but not technically evaluated in this study. These sites are: Lake 07 and Lake 08 on the North Fork of the Double Mountain Fork of the Brazos River in Lubbock County; and Little River Reservoir

and Little River Off-Channel on, or adjacent to, the Little River, a tributary of the Brazos River in Milam County.

Table 4.2-1.
Reservoir Site Acquisition Program

Reservoir	Conservation Pool Elevation (ft-msl)	Conservation Pool Area (acres)	Land Unit Cost[1] ($/ac)	Conservation Pool Land Cost[1] ($)
Bedias	210	10,000	$3,288	$32,880,000
Brownsville Weir	26	600 / 0[2]	$0[2]	$0[2]
Brushy Creek	380.5	697 / 0[3]	$0[3]	$0[3]
Cedar Ridge	1430	6,190	$850	$5,261,500
Cuero II	232	28,154	$3,100	$87,277,400
Fastrill	274	24,948	$1,825	$45,530,100
Lower Bois d'Arc	534	16,526	$2,675	$44,207,050
Marvin Nichols IA	328	67,392	$1,201	$80,937,792
Nueces Off-Channel	275.3	5,294	$1,450	$7,676,300
Palmetto Bend II	44	4,564	$1,627	$7,425,628
Parkhouse I	401	28,855	$1,201	$34,654,855
Parkhouse II	410	14,387	$1,201	$17,278,787
Ralph Hall	551	7,605	$2,675	$20,343,375
Ringgold	844	14,980	$850	$12,733,000
Tehuacana	315	14,938	$2,009	$30,010,442
Wilson Hollow	1077	333	$4,250	$1,415,250
Total		**244,166**		**$427,631,479**
Columbia[4]	315	10,000	$1,825	$18,250,000
Post[4]	2,420	2,283	$566	$1,292,278
Grand Total		**256,449**		**$447,173,657**

[1]Land costs in 2005 dollars.

[2]All of the inundated area associated with the Brownsville Reservoir lies within the channel portion of the Rio Grande and is managed and controlled by the United States and Mexican Sections of the International Boundary and Water Commission for flood protection purposes; therefore, it is anticipated that purchase of this land will not be necessary.

[3]All of the land to be inundated by Brushy Creek Reservoir has been purchased by the City of Marlin.

[4]Texas Legislature has designated this site as being of unique value for the construction of a reservoir.

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Additional acreage for project facilities and above the conservation storage level up to the 100-year or standard project flood level is usually purchased around the perimeter of a reservoir. Comprehensive hydrologic and hydraulic studies that define these flood levels, however, are typically a part of final design and have not been undertaken for most of the 18 reservoir sites recommended for protection and/or acquisition. Implementation of a reservoir site acquisition program will also necessarily entail substantial additional costs for title research, negotiations, land surveying, and legal proceedings.

As an important part of this reservoir site protection study, TPWD performed landcover classifications for each of the 16 reservoir sites selected for technical evaluation. Documentation of resource information and pertinent assumptions for the landcover classifications is included in Appendix C. Figure 4.2-1 summarizes landcover classification by percentage for the potential acquisition program lands including all 16 reservoir sites technically evaluated herein up to their conservation protection storage levels. As shown in Figure 4.2-1, the predominant landcovers are Grassland (30 percent) and Upland Deciduous Forest (23 percent). Approximately 19 percent of the acquisition program lands are classified as Bottomland Hardwood Forest with more than 75 percent of such forests located in the Marvin Nichols IA and George Parkhouse I reservoir sites. Only about 7 percent of the acquisition program lands are classified as Agricultural Land.
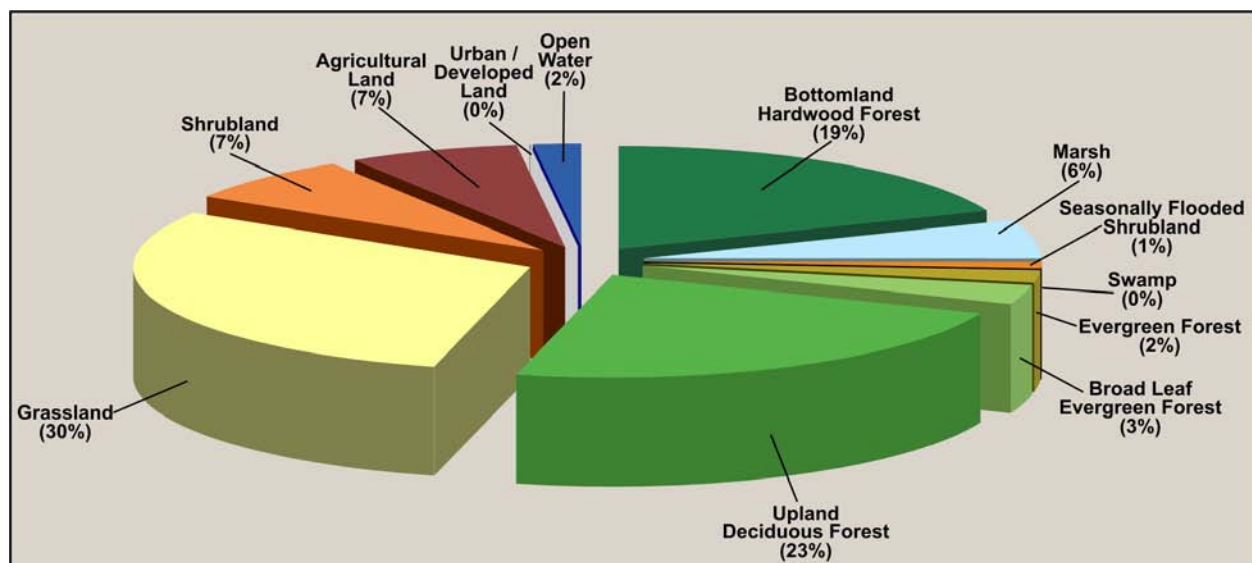
Figure 4.2-1. Landcover Classification for 16 Reservoir Sites

4.3   Recommendations

- Legislatively designate the 16 sites technically evaluated and recommended in this study as unique.

- Conduct more detailed studies to define total lands for protection including reservoir flood pools and land required for project facilities.

- Consider further investigation (including updated landcover assessments) and potential protection of bottomland hardwood preservation sites for mitigation of habitat losses associated with future reservoir development.

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Appendix A
Firm Yield Sensitivity for the
Sulphur River Basin Reservoir Sites

MEMORANDUM

TO: Texas Water Development Board

FROM: Andres Salazar, Ph.D., P.E.

SUBJECT: Firm Yield Sensitivity for the Sulphur River Basin Reservoir Sites

DATE: December 15, 2006

The initial screening process of the Reservoir Site Acquisition Study prepared for the Texas Water Development Board recommended 16 reservoirs for further detailed evaluation. Four of the reservoirs are located in the Sulphur River Basin. These reservoirs are Ralph Hall, George Parkhouse I, George Parkhouse II, and Marvin Nichols IA, and are shown on Figure 1.

Firm yield analyses were performed for each of these four reservoirs assuming stand-alone operations and excluding other potential reservoir sites identified in this study. However, if more than one of the proposed reservoirs are built, the firm yield of the reservoirs permitted with junior priority relative to the others may decrease substantially. This memorandum summarizes the results of a sensitivity analysis performed to assess the relative priority effects of various Sulphur River Basin reservoirs upon one another. The results of the stand alone yield analyses are discussed in Section 3.4 of the main report.

For the recommended conservation capacities shown in Table 1, the yields of Ralph Hall, Parkhouse I, Parkhouse II, and Marvin Nichols IA were determined assuming that all four reservoirs are built. Each reservoir was analyzed as the most junior in relation to the other three in at least one combination.

Four priority combinations were analyzed, which are listed in Table 2. In each combination, the yield of each reservoir was calculated assuming that senior reservoirs are operating at their firm yield. Ralph Hall Lake is already in the permitting process and very likely would be permitted before any of the other proposed reservoirs. Therefore, Ralph Hall is included as the most senior reservoir in three of the four scenarios. Scenario 4 has Ralph Hall with the most junior priority to obtain the worst case scenario for this reservoir.

Parkhouse I, Parkhouse II, and Marvin Nichols IA reservoirs are assumed to be passing inflows for environmental protection in accordance with the Texas Water Development Board's Consensus Criteria for Environmental Flow Needs. Lake Ralph Hall is assumed to be passing flows calculated with the Lyons method because this was the method used in the permit application. Environmental flow restrictions for each reservoir are listed in Attachment 1.

Figure 1. Location Map
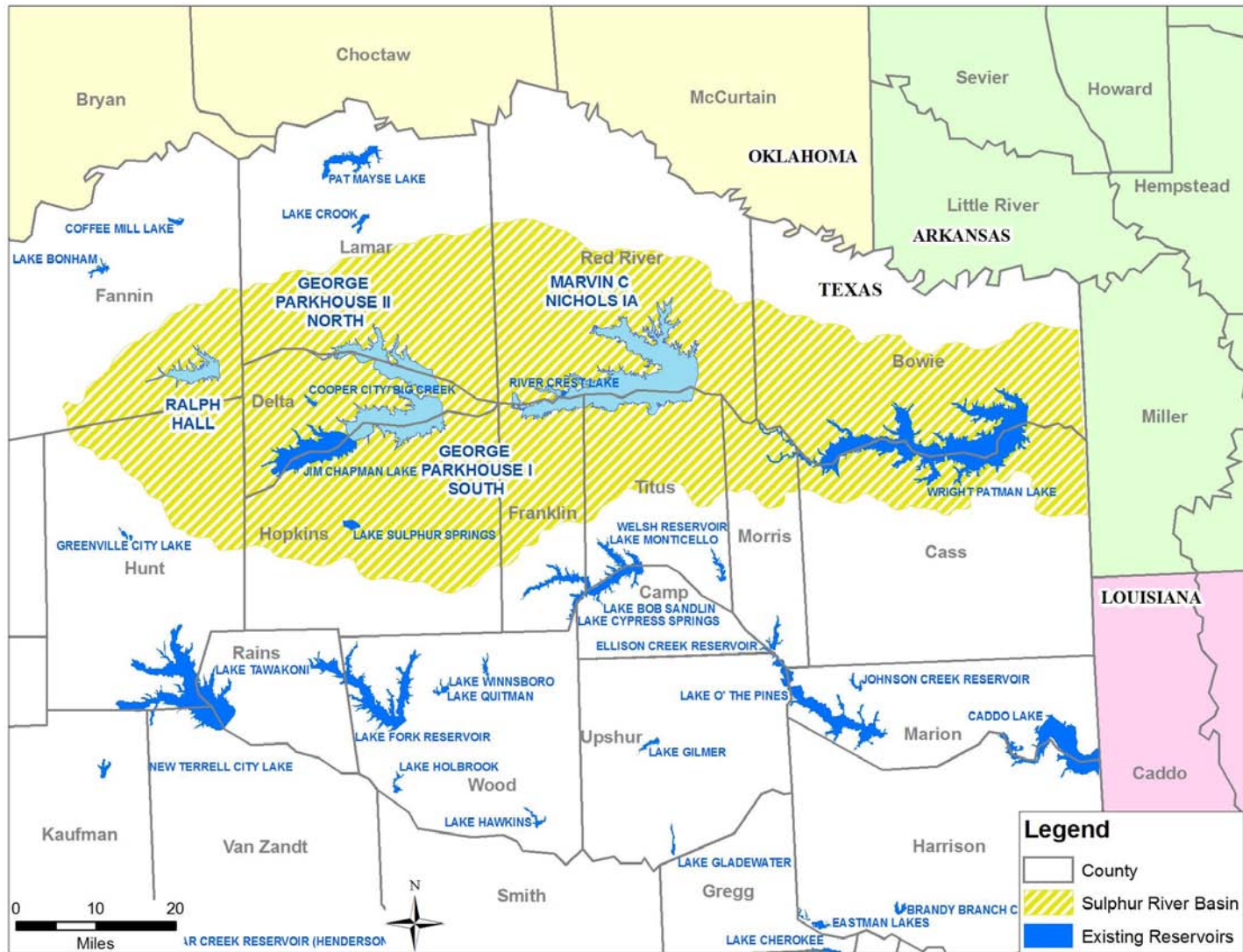
Table 1
Proposed Reservoirs in Sulphur River Basin

Reservoir	Conservation Elevation (msl)	Capacity (Acre-feet)	Area (Acres)
Ralph Hall	551.0	160,235	7,605
Parkhouse I	401.0	651,712	28,855
Parkhouse II	410.0	330,871	14,387
Marvin Nichols IA	328.0	1,562,669	67,392

Table 2
Relative Priority Combination Analyzed

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Most Senior	Ralph Hall	Ralph Hall	Ralph Hall	Parkhouse I
	Parkhouse I	Marvin Nichols IA	Parkhouse II	Parkhouse II
	Parkhouse II	Parkhouse I	Marvin Nichols IA	Marvin Nichols IA
Most Junior	Marvin Nichols IA	Parkhouse II	Parkhouse I	Ralph Hall

This sensitivity analysis used the permitting scenario (Run 3) of the Water Availability Model of the Sulphur River Basin (dated July 15, 2004) obtained from TCEQ (RJ Brandes 1999 and TCEQ 2006) and modified as necessary. A control point and reservoir were added at each dam location. These new control points were entered as primary control points, with known naturalized inflows.

In the WAM Models, flows at ungaged locations are usually calculated using the drainage area ratio method with known flows at gaged locations. The drainage areas of the Sulphur WAM were calculated by the University of Texas Center of Research in Water Resources (CRWR). These areas are different from values published from U.S. Geological Survey. In some cases, the difference is more than 10 percent. Preliminary yield studies conducted in this study determined that the flows calculated using the Sulphur WAM with the drainage area ratio method is different from previous hydrologic studies because of differences in the drainage areas. The USGS values are widely accepted and are more accurate than the CRWR values. Therefore, for purposes of estimating the firm yields under different priority scenarios, naturalized flows at the reservoir sites were calculated using the drainage area ratio method with drainage areas obtained from the USGS rather then CRWR.

The scope of work of this study does not include a verification or modification of the drainage areas of the Sulphur WAM Model. However, entering the naturalized flow at the reservoir sites is sufficient to produce accurate estimates of firm yields.

Evaporation rates are based on data from the Texas Water Development Board (2006), with adjustment to remove the portion of he precipitation on the surface area that is accounted for in

the naturalized flows. Attachment 2 shows the gages and equations used for calculating the naturalized flows and evaporation rates.

Results

Table 3 shows the firm yield of each reservoir under the different combinations of priority. These results present the impacts of relative priorities of potential future water rights in the Sulphur River Basin. This sensitivity analysis does not include evaluation of the potential for increased yields through system operations with existing reservoir or other future reservoirs. Key results are summarized as follows:

1. The yield of Ralph Hall Lake could be reduced to 2,700 acre-feet per year (or a total reduction of 92%) if it is junior to all other proposed reservoirs.

2. Ralph Hall Lake would have minimal impact on Parkhouse I Lake, reducing the yield by 400 acre-feet per year.

3. Ralph Hall Lake would have substantial impact on Parkhouse II Lake, reducing the yield by 26,900 acre-feet per year, which is 18% of the stand-alone yield.

4. Ralph Hall Lake would reduce the yield of Marvin Nichols IA by 17,900 acre-feet per year, which is 3% of the stand-alone yield. This result assumes Parkhouse I and Parkhouse II are not built or have junior priority.

5. If Parkhouse I Lake is built as the most junior reservoir, its yield would be 48,400 acre-feet per year, which is 73,600 acre-feet per year less than the stand-alone yield (a reduction of 60%).

6. If Parkhouse II Lake is built as the most junior reservoir, its yield would be 32,100 acre-feet per year, which is 112,200 acre-feet per year less than the stand-alone yield (a reduction of 78%).

7. The yield of Marvin Nichols IA Reservoir would be reduced by 141,200 acre-feet per year (or a reduction of 23%) if all of the proposed upstream reservoirs are built with senior priority.

In summary, sequential development of these four reservoir sites in an upstream to downstream priority order provides the greatest total firm yield among the scenarios evaluated. Cooperative development and system operations of reservoirs at some or all of these sites will maximize total firm yield.

Table 3
Firm Yield of the Proposed Reservoir under Different Combination of Priority
(Values are Acre-Feet per Year)

	Stand Alone Yield	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Ralph Hall	33,700	33,700	33,700	33,700	2,700
Parkhouse I	122,000	121,600	60,600	48,400	122,000
Parkhouse II	144,300	117,400	32,100	117,400	140,400
Marvin Nichols IA	602,000	460,800	584,100	503,800	465,500
Total	**NA***	**733,500**	**710,500**	**703,300**	**730,600**

* Total does not apply because only one reservoir is operating and others are excluded.

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ATTACHMENT 1
Inflow Bypass for Environmental Protection

Table A1-1
Monthly Streamflow Statistics for Ralph Hall using the Lyons Method for Environmental Flow Needs

Month	AF	cfs
Jan	211	3.43
Feb	325	5.85
Mar	486	7.90
Apr	365	6.13
May	324	5.27
Jun	144	2.42
Jul	22	0.36
Aug	6	0.10
Sep	7	0.12
Oct	14	0.23
Nov	81	1.36
Dec	180	2.93
Total	2,164	
Average	180.4	3.00

Table A1-2
Monthly Streamflow Statistics for G. Parkhouse I (South) using the Consensus Criteria for Environmental Flow Needs

	Median		25th Percentile		7Q2	
Month	AF	cfs	AF	cfs	AF	cfs
Jan	1,919	31.2	318	5.2	0	0.0
Feb	3,596	64.2	794	14.2	0	0.0
Mar	3,748	60.9	800	13.0	0	0.0
Apr	2,697	45.3	638	10.7	0	0.0
May	4,687	76.2	741	12.0	0	0.0
Jun	1,854	31.1	294	4.9	0	0.0
Jul	233	3.8	22	0.4	0	0.0
Aug	47	0.8	0	0.0	0	0.0
Sep	72	1.2	0	0.0	0	0.0
Oct	180	2.9	9	0.2	0	0.0
Nov	696	11.7	88	1.5	0	0.0
Dec	1,916	31.1	177	2.9	0	0.0
Total	21,644		3,879		0	
Average	1,804	30.0	323	5.4	0	0.0

Table A1-3

**Monthly Streamflow Statistics for G. Parkhouse II (North) using
the Consensus Criteria for Environmental Flow Needs**

	Median		25th Percentile		7Q2	
Month	**AF**	**cfs**	**AF**	**cfs**	**AF**	**cfs**
Jan	2,396	39.0	532	8.6	0	0.0
Feb	3,266	58.3	1,096	19.6	0	0.0
Mar	3,333	54.2	1,045	17.0	0	0.0
Apr	3,129	52.6	1,049	17.6	0	0.0
May	3,289	53.5	874	14.2	0	0.0
Jun	1,175	19.7	205	3.4	0	0.0
Jul	183	3.0	12	0.2	0	0.0
Aug	50	0.8	0	0.0	0	0.0
Sep	66	1.1	0	0.0	0	0.0
Oct	174	2.8	3	0.1	0	0.0
Nov	920	15.4	73	1.2	0	0.0
Dec	2,068	33.6	243	4.0	0	0.0
Total	20,046		5,132		0	
Average	1,671	27.8	428	7.2	0	0.0

Table A1-4

**Monthly Streamflow Statistics for Marvin Nichols IA using the
Consensus Criteria for Environmental Flow Needs**

	Median		25th Percentile		7Q2	
Month	**AF**	**cfs**	**AF**	**cfs**	**AF**	**cfs**
Jan	13,845	225.1	3,419	55.6	69	1.1
Feb	21,947	391.6	6,659	118.8	63	1.1
Mar	31,133	506.2	8,975	145.9	69	1.1
Apr	19,656	330.2	6,143	103.2	67	1.1
May	32,113	522.1	6,092	99.0	69	1.1
Jun	11,994	201.5	3,110	52.3	67	1.1
Jul	2,564	41.7	552	9.0	69	1.1
Aug	911	14.8	220	3.6	69	1.1
Sep	1,011	17.0	123	2.1	67	1.1
Oct	1,562	25.4	251	4.1	69	1.1
Nov	5,055	84.9	1,083	18.2	67	1.1
Dec	11,641	189.3	2,201	35.8	69	1.1
Total	153,432		38,827		814	
Average	12,786	212.5	3,236	54.0	68	1.1

ATTACHMENT 2
Calculation of Naturalized Flows

Table A2-1 Gages Used in the Calculation of Naturalized Flows

Control Point	Name	USGS Drainage Area (sq. miles)	Sulphur WAM Drainage Area (sq. miles)
Existing Control Points			
A10	South Sulphur River near Cooper	527	541
B10	North Sulphur River near Cooper	276	311
C10	Sulphur River near Talco	1,365	1,381
D10	White Oak Creek near Talco	494	546
E10	Sulphur River near Darden	2,774	2,849
New Control Points			
B25	Ralph Hall	102	NA
C200	Parkhouse I	655	NA
C105	Parkhouse II	421	NA
E175	Marvin Nichols IA	1,889	NA

Derivation of Natural Flows and Evaporation Rates

1- Ralph Hall

Natural Flow (Calculated by the WRAP Model)

$$\text{Ralph Hall} = \frac{\text{B10}}{311\,\text{sq.miles}} \times 102\,\text{sq.miles}$$

Evaporation

Ralph Hall Evaporation = Control Point A70.
(Adjusted for effective runoff by the WRAP Model)

2- Parkhouse I

Natural Flow (Entered as primary control point)

$$\text{Parkhouse I} = \text{A10} + \frac{\text{C10} - \text{B10} - \text{A10}}{562\,\text{sq.miles}} \times 128\,\text{sq.miles}$$

Evaporation

Parkhouse I Evaporation = Net Quadrangle 412 + [Nat Flow C200] / 655

3- Parkhouse II

<u>Natural Flow</u> (Entered as primary control point)

$$\text{Parkhouse II} = \text{B10} + \frac{\text{C10} - \text{B10} - \text{A10}}{562\,\text{sq.miles}} \times 145\,\text{sq.miles}$$

<u>Evaporation</u>

Parkhouse II Evaporation = Net Quadrangle 412 + [Nat Flow C105] / 421

4- Marvin Nichols IA

<u>Natural Flow</u> (Entered as primary control point)

$$\text{Marvin Nichols IA} = \text{C10} + \frac{\text{E10} - \text{D10} - \text{C10}}{915\,\text{sq.miles}} \times 524\,\text{sq.miles}$$

<u>Evaporation</u>

Marvin Nichols Evaporation = 0.5 x (Net Quadrangle 412 + 413) + [Nat Flow E175] /1889

Appendix B
An Assessment of Potential Impacts to
Archaeological and Cultural Sites
Relating to Reservoir Site
Acquisition Development

**AN ASSESSMENT OF POTENTIAL IMPACTS TO
ARCHEOLOGICAL AND CULTURAL SITES
RELATING TO RESERVOIR SITE
ACQUISITION AND DEVELOPMENT**

by
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INTRODUCTION

The Texas Water Development Board plans for systematic water resource development in the State of Texas and financially assists construction of resulting development. As part of current state-wide planning efforts, the development feasibility is being examined for sixteen localities across Texas. The State Water Plan designates these localities as unique sites with the highest priority for acquisition and development of future surface water reservoirs. The feasibility of developing these sites is being examined to enable acquisition that will prevent conflicts to their eventual development as water supply reservoirs.

One aspect of reservoir feasibility assessment is determining the potential for adverse impacts to cultural resources, including archeological sites and other historic properties. State and Federal historic preservation statutes require appropriate impacts assessment prior to facility development on public property or using public funds. Impacts assessment includes identification of historic properties and assessment of their historic or cultural significance. If impacts to significant historic properties are unavoidable, then data recovery must be undertaken to offset damage resulting from development.

CURRENT ASSESSMENT METHODOLOGY

Environmental review staff with the Board's Office of Project Construction and Financial Assistance (OPFCA) assisted the Office of Planning in the current assessment of reservoir sites.

Planning staff provided maps showing plotted locations for the sixteen designated unique reservoir sites. Three other sites were included that have not been designated as unique reservoir sites. The sites are shown in Figure 1. The OPFCA archeological staff developed quantitative measures of potential for impacts to historic properties that was specific to the regions of Texas where the reservoir sites are located.

To develop the quantitative measures of potential impacts to historic properties, OPFCA staff archeologists began with an examination of county-level summary data for the study area. This area included twenty seven counties that contain all or part of the proposed reservoir sites. Data in the Texas Historical Commission's (THC) on-line Archeological Sites Atlas were accessed to obtain summary statistics for historic property categories that might be potentially affected by reservoir development. These included both historic and prehistoric recorded archeological sites, historic cemeteries, and historic industrial or military sites. Communications with staff in the THC Archeology Division clarified details about the contents of existing data sets. The THC archeological staff also supplied their assumptions about the numeric relationship between total numbers of recorded archeological sites in counties and the percentage that is significant enough to be considered eligible for inclusion in the National Register of Historic Places.

Based on the THC assumptions and data about sensitive sites, the categories used to derive quantitative measures of potential for impacts to historic properties included sites potentially eligible for inclusion in the National Register of Historic Places, historic cemeteries, sawmills and military sites. The measures themselves were calculated averages of sensitive sites for regions and the study area. Variance of county-level data for the total number of sensitive sites was compared to both regional and study area averages.

A literature search focused on several syntheses published by the THC and the U. S. Army Corps of Engineers Southwest Region. Specific sources included Guy (1990); Kenmotsu and Perttula (1993); and Mercado-Allinger, *et al.* (1996). While a significant amount of archeological work has occurred in the decade since publication of the most-recent volume, the basic interpretations of these sources remain valid for the characteristics and context of historic properties in appropriate regions of Texas.

The literature search included geo-archeological publications that investigated the physiographic context of historic properties. The physical context includes the location of cultural resources in a landscape that has both physical and biological constituents. The biological constituents of the landscape provided a strong attraction for prehistoric or early historic residents who were intent on securing food and other resources. Physical constituents, such as water and clay sources, are also important attractions for those who must live close to the resources offered by a region.

For the current assessment, the physical constituents were viewed as most important. The association between soils and geomorphology is especially valuable as an indicator when determining the potential presence, characteristics, and long-term survival of historic properties. Physical conditions affect how archeological sites are formed and the probability of whether the contents of those sites will survive. Arguments supporting these points were developed by Collins and Bousman (1993) especially for an assessment of factors affecting archeological site formation and survival in Northeast Texas. Their conclusions remain valid and are incorporated into the methodology as devices that allow better interpretation of site distribution data aggregated at the county level.

RESULTS OF THE CURRENT ASSESSMENT

The nineteen reservoir sites identified by the Board's Planning staff were found to include parts of twenty seven counties. To efficiently make the best use of allotted time and resources, OPFCA archeologists used existing publications and available data sources to the maximum extent possible. A summary of previous archeological work and results reported by Guy (1990) is found in Table 1.

The literature search revealed the evolving scale and sophistication of previous archeological investigations in the central and eastern portions of Texas. These investigations were associated with planning for construction of fifty-four reservoirs in an area that partially overlaps with the current study area. The implications for the current study that the Guy (1990) summary bring to light concerning the evolving scale and sophistication of previous research will be discussed in

the Discussion section. Just over 5,000 archeological sites were recorded during reconnaissance or intensive surveys for these reservoirs between World War II and 1986. Of the sites recorded, only about 130 have been determined to be eligible for inclusion in the National Register of Historic Places. Table 2 aggregates Table 1's reservoir survey results by region.

The survey intensity and extent at each reservoir site cannot be determined from the secondary literature sources examined. The results of later surveys do indicate greater numbers of recorded sites. An example of change through time in archeological surveys necessary prior to reservoir construction and their results is the comparison between archeological work done during the quarter century between 1948 and 1984. No archeological sites were located at Lake Benbrook (Tarrant County) in 1948. The 1959 – 1961 archeological survey at Navarro Mills Reservoir in Hill and Navarro counties recorded 19 sites. One of these was subsequently excavated. The 1979 – 1984 investigations at Richland Creek Reservoir (Freestone and Navarro counties) recorded 1,001 sites, tested the significance of 270, and excavated the 53 found to be eligible for inclusion in the National Register of Historic Places.

Historic property categories identified during examination of county-level data in the THC's on-line Archeological Sites Atlas included archeological sites, State Archeological Landmarks, and sites listed on the National Register of Historic Places. Data from the twenty site counties included in the current examination are found in Table 3 for each of these categories. The existing data for these counties includes 7,250 recorded archeological sites, 298 State Archeological Landmarks, and 255 sites listed on the National Register of Historic Places.

For the purposes of the current study, significant other data are reported in the Archeological Sites Atlas for numerous historic sites that are typically not recorded as archeological sites. Most common are historic cemeteries. Sawmills also are numerous, especially in eastern parts of the state. Military sites are reported, but are less common. The Atlas data for the twenty seven counties included entries for 3,042 historic cemeteries, 907 sawmills, and 25 military sites.

Proposed reservoir sites and associated county-level data are aggregated into four regional groups on the basis of shared physiography and characteristics of historic properties. Frequency

data for the regional groups better illustrate the regional variation in individual data categories. The four groups are shown in Figure 2 and Table 4.

The northeast regional group contains 3,296 previously recorded archeological sites in its ten counties. These sites are 45 percent of the total reported in the Atlas for the twenty seven counties used in the current study. A similar percentage of historic properties found in northeastern Texas are listed on the National Register of Historic Places (118 properties). Over half of the historic cemeteries (1,634) reported in the current study are located in these ten counties. Reflecting the forested landscape found by early historic immigrants to the region, almost 81 percent of the historic sawmills are found in this regional group. They include 734 individual listings from the Texas Forestry Museum records that were compiled in the Atlas. Three of the 25 military sites (12 percent) reported in the study area are found in the counties making up this regional group.

The ten-county south central regional group contains 2,520 previously recorded archeological sites, or about 35 percent of the Atlas-reported total. A similar percentage of historic properties found in the region are listed on the National Register of Historic Places (94 properties). The 1,128 historic cemeteries in the ten-county south central regional group represent 37 percent of the total number listed in the Atlas for the current study. The 173 historic sawmills in this region are the remainder of those reported in the Atlas for counties in the current study area. Four of the 25 military sites (16 percent) reported in the study area are found in the counties making up this regional group.

Ten counties in the northwest regional group span the Rolling Plains and High Plains. They contain 1,231 previously recorded archeological sites, or about 17 percent of the Atlas-reported total. Most of these sites are clustered in Garza and Palo Pinto counties. Listed National Register-eligible sites in the region include 21 historic properties. Historic cemeteries are much fewer in number in this region, numbering 104. These represent 3.5 percent of the total number of historic cemeteries listed in the THC Atlas database for counties in the current study area. Nine of the 25 military sites (36 percent) reported in the study area are found in this regional group of counties.

Cameron County in far South Texas is the last county under consideration. The county's archeological sites include 203 previously recorded sites listed in the Archeological Sites Atlas. Twenty-two (22) historic properties from Cameron County are listed on the National Register of Historic Places. European settlement in the county since the mid-18th century is reflected in the 176 historic cemeteries within its borders, almost 6 percent of the total historic cemeteries in the 27 county study area. Nine of the 25 military sites (36 percent) reported in the study area are found in the county.

The THC's long experience in administering state and federal historic preservation programs gives its staff significant insight into the relationship among classes of historic properties. Its Archeology Division staff estimate a ratio of one site potentially significant enough to be eligible for listing in the National Register of Historic Places for every 5 recorded sites currently found in the Archeological Sites Atlas. While professional and avocational archeologists continue to record new archeological sites throughout Texas, the current value of 7,250 previously recorded sites in the 27 county study area would yield a value of 1,451 sites that would be potentially significant enough to be eligible for listing in the National Register. The northeast region contains 660 of the 1,451 archeological sites that are potentially eligible for listing. Just over 500 sites in the south central region would be potentially eligible for the National Register designation. About 250 sites in the northwest region would be eligible, as would 41 in the far south.

The 255 sites currently listed in the National Register of Historic Places in the study area represent less than 20 percent of the sites potentially eligible for listing in these counties. The difference between sites potentially eligible for listing and those actually listed is found Table 4. The value of the differential between actual listing and potential eligible for listing ranges between 8.5 and 53.6 percent for the four regions. This discrepancy between listed and potentially eligible sites has implications for reservoir development that will be discussed in the Discussion section.

DISCUSSION

The examination of frequency and distribution data for historic properties from the 27 county study area indicated that significant numbers of sensitive historic properties are present. Sensitive historic properties include archeological sites and historic structures that are eligible under national criteria of significance for listing in the National Register of Historic Places. While both archeological sites and historic structures may be listed on the National Register of Historic Places, most listed properties represent standing structures rather than archeological components. For both archeological site and National Register property categories in the THC's database, the reported frequencies represent a minimum number. A much higher frequency of sites significant enough to warrant listing is evident when the difference between currently listed National Register properties and all eligible sites is considered. Nearly 1,200 potential National Register sites remain unlisted in the study area. An important consideration for potential development projects is that state and federal historic preservation statutes grant National Register-eligible sites the same protections against unauthorized adverse impacts as listed sites. Historic preservation statutes apply to any public funding that enables development projects to be built and to any permitting necessary before construction. The protections insured by statute will require that the National Register-eligible sites be avoided by reservoir construction or that data recovery measures for them be included in development plans. Applicable statutes include the Texas Antiquities Code, (Title 9, Natural Resource Code, Chapter 191); the Archeological and Historic Preservation Act of 1974, Public Law 93-191; the Historic Sites Act; and the National Historic Preservation Act of 1966, Public Law 89-665, as amended.

Sensitive historic properties also include cemeteries. Over 3,000 cemeteries are reported in the Archeological Sites Atlas separately from archeological sites in the study area. These cemeteries are historic in age and contain the interred remains of Euro-Americans, Native Americans, or African-Americans. Within each regional area, some counties contain higher frequencies of recorded historic cemeteries. In the northeast region, Anderson, Fannin, and Smith each contain over 300 cemeteries. Red River, Lamar, and Cherokee counties each contain between 100 and 135 cemeteries. In south central Texas, Austin County is the oldest county in its region. This former seat of the Austin Colony contains 315 cemeteries, the highest number of any county in

the region. Freestone and Grimes counties also contain between about 150 and 225 cemeteries. Except for sparsely populated Live Oak County, other counties in this region contain between 50 and 100 recorded cemeteries. The northwest region has one county that contains almost 40 percent of its historic cemeteries, Palo Pinto. Clay and Haskell counties also contain between 15 and 25 recorded historic cemeteries. The centuries-old Hispanic settlement in Cameron County of far southern Texas contains well over 150 historic cemeteries.

Any reservoir construction affecting historic cemeteries will be required by statute to consider adverse impacts to them. At least two state statutes apply to construction that may impact historic cemeteries: Title 8 of the Health and Safety Code, Chapters 694 – 715 (relating to regulation of cemeteries); and Title 9 of the Natural Resource Code, Chapter 191 (the Antiquities Code of Texas). In addition, several federal statutes and executive orders apply. These include the Archeological and Historic Preservation Act of 1974, Public Law 93-191; the Historic Sites Act; the National Historic Preservation Act of 1966, Public Law 89-665, as amended; and Executive Order 11953, Protection and Enhancement of the Cultural Environment. The Native American Graves Protection and Repatriation Act of 1990, Public Law 101-601, will also apply if any historic Native American cemeteries or identified individual graves are to be affected. This act requires consultation with current Native American tribes before impacts to Native American cemeteries or graves may occur during planned construction. Similar requirements apply to previously unknown graves discovered during construction.

The total frequency and distribution of prehistoric Native American graves is unknown in the study area and is not represented in the Archeological Sites Atlas data for cemeteries. In many prehistoric Native American graves, most human skeletal material has deteriorated, especially in eastern Texas. Only associated grave offerings, such as pottery or stone tools, remain as sensitive, identifiable contents. Prehistoric Native American graves represent a culturally-sensitive issue that is subject to the protections of federal statute under the Native American Graves Protection and Repatriation Act of 1990, Public Law 101-601. The consultation requirements imposed by this statute were discussed under historic cemeteries and will apply to any reservoir construction contemplated for the sites under consideration.

The effect of advancements in archeological field methods during the past 60 years on survey results was briefly mentioned in the Results section. The total number of sites found during surveys has increased as methods came into use that allowed detection of sites that were previously overlooked. The advancements in methodology have been accompanied by significant increases in the standards necessary to insure statutory compliance.

Archeological surveys still do not completely examine large project areas, but rely on systematic or statistical sampling to insure that a large enough area is thoroughly examined to record most sites and to assess the impacts to significant historic properties that are protected by statutes. The sampling surveys replace reconnaissance survey typically used up until about the mid-1980s. Archeologists now use geomorphic characterization to develop probability models that guide sampling for survey efforts, to date landforms within survey efforts, and to assess the extent and scope of prior disturbance.

Geomorphic characterization allows survey to be concentrated within portions of a project's landscape. Appropriate use of this method allows specific survey techniques to be used where they are most productive. Resources can be allocated using geomorphic characterization into areas best suited for trenching to locate deeply buried sites or systematic pedestrian survey and shovel-testing to locate shallowly buried sites. Use of geomorphic characterization also allows areas that may be much less productive or extensively disturbed by natural causes to be deemphasized.

A recent example is the Phase Ia sample survey of about 10% at the proposed Lake Columbia site in 2006 (Owens, *et al.,* in preparation). Geomorphic characterization helped project archeologists to stratify the project area and focus initial survey efforts onto landforms containing historic properties that could be located quickly using the basic pedestrian walkover and shovel testing survey techniques typically used to find and record sites. Previous to the Phase Ia archeological survey, no archeological sites or historic structures had been recorded in the area and no professional archeological survey had ever been done within the lake basin. The results from archeological survey of almost 1,300 acres recorded 37 new archeological sites, 25 occurrences of isolated artifacts, and 7 historic properties recorded on the basis of standing

structures only. The historic properties with standing structures included a significant late-19th century African-American freedmen's community. The rate of about 3 sites recorded in each 100 acres surveyed within the reservoir area compares closely with data from archeological survey of Lake Gilmer in Upshur County in the early 1990s reported by Parsons, *et al.* (1992).

Large development projects implemented in the 1980s and 1990s included reservoirs and surface mines that provide fuel to power plants in eastern Texas. The results of archeological surveys conducted within portions of the current study area during this era show the effects of more stringent methodologies and regulatory compliance standards. Increasing numbers of archeological sites were recorded, tested, and excavated to mitigate impacts to significant sites.

Data are readily available for the ten counties in northeast Texas that fall within the Texas Historical Commission's northeast planning region. Perttula and Kenmotsu (1993:Table 2.1.1) report that these counties had a total of 1,527 archeological sites recorded in 1991. That total did not include all sites reported from the Cooper Lake survey. The sites in northeast Texas included 128 that were listed as significant and that would warrant state and federal statutory protections. Research for the current 2006 reservoir site feasibility study found an increase of 215 percent in the total number of recorded archeological sites in the northeast region. A five-fold increase in the number of significant sites is also evident in a comparison of data for sites that would poten-tially be eligible for listing in the National Register of Historic Places.

Partial data from 1991 are available for the south central region from Perttula and Kenmotsu (1993:Table 2.1.1). Their data are specifically for Madison and Walker counties at the region's eastern edge. Recorded archeological sites have increased since 1991 in Madison County by over 500 percent and by 200 percent in Walker County. No significant sites were reported in 1991 for these counties.

Quantitative measures of potential impacts were derived for the study area and the regional subsets of counties within it. The measures are averages calculated for the total number of sensitive sites in each county, allowing comparison between the study area and regions (see Table 5). Degree of variation from both the regional and study area averages is also presented in

Table 5. Counties and regions that have a higher potential for impacts to sensitive cultural resources are identifiable in Table 5 using the degree of variation and the difference between regional and study group averages.

On a regional basis, the northeastern region has the highest potential for reservoir site acquisition and eventual construction to cause impacts to sensitive sites. The northeast regional average is 50 percent higher than that for all twenty-seven counties in the study area. Within this region, the values for three counties greatly exceed both regional and study area averages. The values for Anderson, Cherokee, and Smith counties indicate a very strong potential for impacts to sensitive cultural resources that would be caused by development projects. While considerably lower, values for Red River and Titus counties also exceed the study area average. These values indicate a potential for impacts to sensitive cultural resources that correlates well with the results from previous archeological work. Caddoan sites and historic cemeteries are very frequent in the region, as are sawmills.

The far southern region has the next highest potential for potential impacts to sensitive cultural resources. Cameron County, the single county within the region, has a potential similar to Titus County in the northeastern region. Cameron County's values are based primarily on the historic cemeteries that can be used to indicate a potential frequency for other sensitive historic period sites occupied over the past 250 years.

The south central region has a lower potential for impacts to sensitive cultural resources. The value for its regional average is about 10 percent below the average for the study area average. Within the region, four counties have a much stronger potential. Austin and Freestone counties greatly exceed both the regional and study area average for sensitive sites, primarily due to a large number of historic cemeteries. Grimes County also has similar characteristics. Walker County's large number of recorded historic saw mills yields a strong tendency for impacts to sensitive cultural resources.

The northwest region has the lowest potential impacts to cultural resources that may be sensitive. Four of its counties have had few archeological sites or cemeteries recorded. Two counties have

a stronger potential, mainly due a larger number of sites that may be eligible for listing on the National Register of Historic Preservation. Garza and Palo Pinto counties have many more recorded archeological sites, most likely due to factors related to their physiographic settings.

The scope and cost of future water resource development projects historic preservation compliance is problematic. Large archeological projects are usually driven by the need for development projects to comply with historic preservation statutes. Their project budgets focus on work within the area of affect defined by the development project. While systematic academic archeological research projects have been undertaken throughout Texas for over a century, they are usually focused on much smaller areas. Some research projects are carried out over a span of decades. A good example of these focused, long-term research projects is the excavation of the George C. Davis site. This is an important complex of Caddoan ceremonial mounds within Caddo Mounds State Park in Cherokee County. Excavations at this location have been undertaken periodically by research archeologists from the University of Texas at Austin since the 1930s.

The frequency, characteristics, and significance of archeological sites are currently unknown in much of the state because these areas have never received any professional archeological attention. An example of this type of data gap is the Lake Columbia site where initial archeological surveys occurred recently and only sampled a small percentage of the reservoir basin. Many areas of the state also suffer from incomplete data where professional archeological work occurred decades ago under less stringent statutory or regulatory standards. Additional work will be necessary to comply with current statutory requirements where development projects have not yet been built.

Archeological work is labor-intensive and destroys its primary data during excavations, whether the work is undertaken as pure research or to comply with statutory requirements. Sophisticated techniques, such as geomorphic characterization and ground-penetrating radar, help guide archeological field survey, testing, and excavation efforts. Use of such sophisticated techniques can be expensive in their own right because of equipment or consultant costs. They can limit the unnecessary destruction of the historic properties that make up the archeological record. Judi-

cious use of these techniques focuses work on productive problems where such effort is not wasted. Cost estimates for archeological field projects are based on a specification of survey rates per day or excavation rates of 10-cm levels per day. Appropriate use of sophisticated techniques controls project costs when it allows archeological project managers to focus labor on productive problem areas. It also allows them to be more sophisticated in their interpretation of results from archeological fieldwork.

CONCLUSIONS

Feasibility assessment for systematic water resource development at nineteen sites across the state must include a complete assessment of the potential impacts to historic properties protected under state and federal law. Statutory requirements for permitting and public funding of reservoir construction mandate identification, assessment of significance against national criteria, and data recovery at historic properties meeting those significance criteria if impacts to the properties cannot be avoided. The twenty-seven county project area now contains a total of 7,250 recorded archeological sites. If THC estimates are correct, then their existing data significantly underreports historic properties potentially eligible for listing on the National Register of Historic Places. Less than 20 percent of 1,451 sites meeting eligibility criteria are now listed within the study area for the current assessment. Within this area, a potential of almost 1,200 sites that could meet these criteria may remain, based strictly on the total number of sites now reported. Most of the nineteen reservoir basins under consideration have never had an archeological survey or at best have been incompletely examined. Without adequate archeo-logical fieldwork, an unknown number of very significant sites are left within the reservoir basins. The importance for the current assessment is that these are the sites that will be subject to the bulk of historic preservation statutory compliance requirements. Compliance will require avoidance of impacts or expensive and time-consuming data recovery.

The characteristics of historic period sites vary widely. Many are not recorded separately as archeological sites because they have standing structures. Texas Historical Commission data indicate that historic period cemeteries and sawmills are present in large numbers in several regions. The northeast, south central, and far southern regions contain counties with a long

period of substantial Euro-American occupation. Existing data indicate that these counties have a higher probability of containing significant historic properties not recorded as archeological sites that will receive protection under state and federal historic preservation statutes.

The final consideration in this assessment is that extensive consultation with Native American tribes will be necessary to comply with the requirements of federal statutes. Before they may authorize construction permits or financial assistance for reservoir construction, federal agencies are obligated to consult with tribes to insure that Native American graves are protected. State agencies building or financially assisting construction of major construction projects, such as highways, are already operating within these requirements.

The object of an agency's tribal consultation is to develop agreed-upon protocols for determining cultural affinity within a project area for human skeletal remains or grave goods from interments that are not obviously Euro-American.   The consultation process also develops treatment protocols for Native American graves that might be encountered during archeological work or subsequent construction. Potential scopes and costs of Native American consultation for the nineteen reservoir sites under consideration will remain an unknown for the immediate future.

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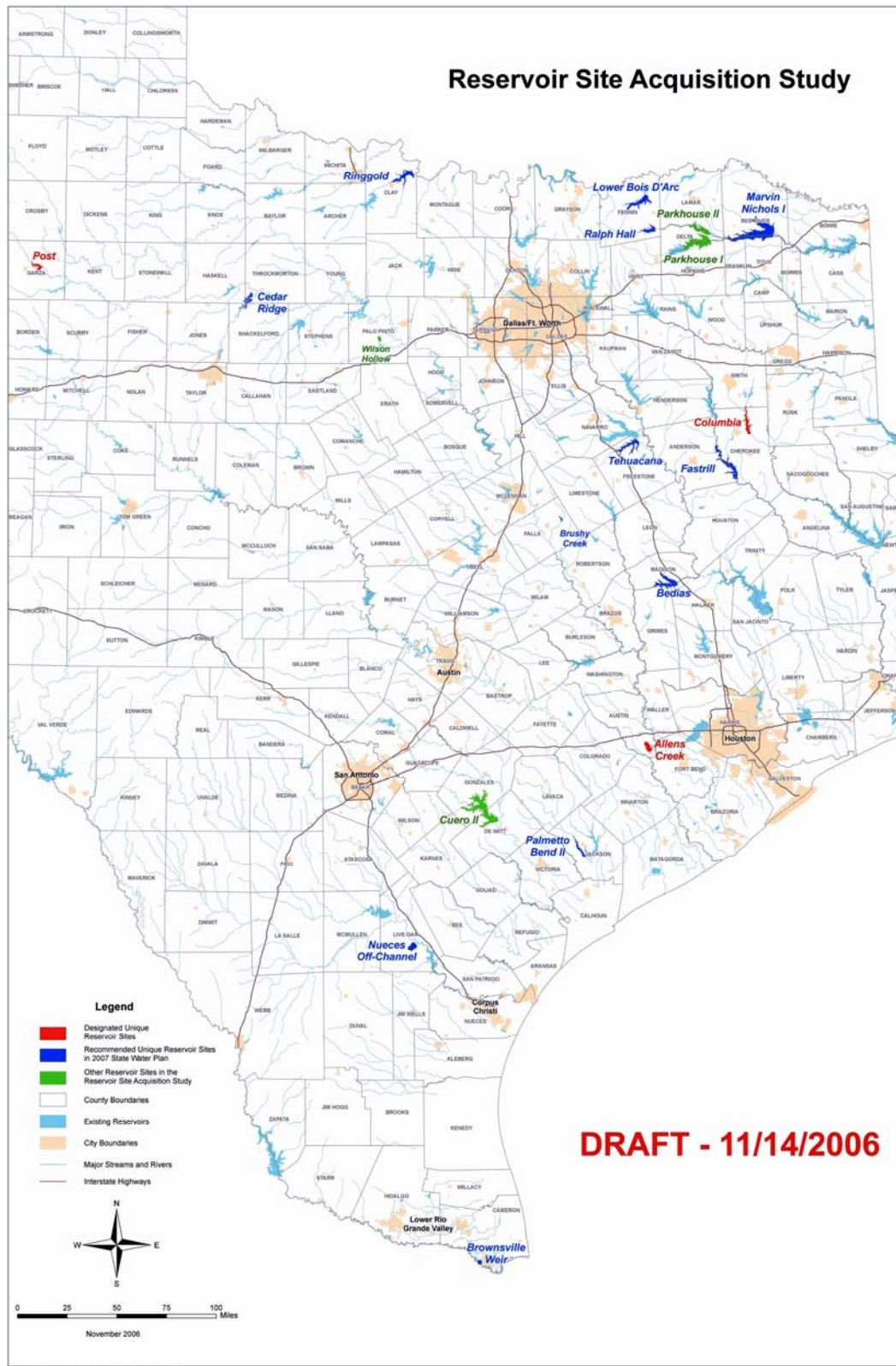
Figure 1: Location of Proposed Reservoir Sites Considered in the Current Study.

Table 1: Synopsis of Previous Reservoir Archeological Investigations in Eastern and Central Texas.

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Addicks	Harris	1947, 1964, 1982 - 86	76 (1982 - 86 only)			36
Aquilla	Hill	1972 - 1975, 1977 - 80, 1982 - 83	131	43	19	
Aubrey (Lake Ray Roberts)	Cooke, Denton, Grayson	1972 - 73, 1980 - 83, 1985 - 86	381	60	13	31
Bardwell	Ellis	1963, 1965	15	6	1	1
Barker	Fort Bend, Harris	1983 - 1985	75	6	3	33
B. A. Steinhagen	Jasper, Tyler	1947 - 48	7			
Bayou Loco (Nacogdoches)	Nacogdoches	1972, 1975 - 76	16	4	2	1
Bedias	Grimes, Madison, Walker	1985 - 86	11			
Benbrook	Tarrant	1948	0			
Big Cow Creek	Jasper, Newton	1975 - 76	7			
Big Pine	Lamar, Red River	1971 - 72, 1974 - 75	116	8	2	2
Big Sandy	Upshur, Wood	1980, 1985	129	12		
Blackburn Crossing (Lake Palestine)	Anderson, Cherokee, Henderson, Smith	1957, 1969 - 70, 1975	133		12	
Bois D'Arc	Fannin	1968	13			
Bosque	Bosque	1986	146			
Brushy Creek	Fannin, Grayson	1960	10			
Caddo	Harrison, Marion	1920, 1931, 1950s, 1957, 1968, 1974, 1977, 1983	60	1	2	
Cedar Creek	Henderson, Kaufman	1961, 1963 - 64	33	1	1	
Cleveland	San Jacinto	1985	4			
Cooper	Delta, Hopkins	1951, 1953, 1955, 1959, 1964, 1970, 1972 - 76, 1986	160	32	17	
Cypress Springs	Franklin	1968 - 69	17			

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Denison Dam (Lake Texoma)	Cooke, Grayson	1972	158	11		
Ferrels Bridge (Lake O' the Pines)	Camp, Harrison, Marion, Morris, Upshur	1951, 1957 - 60, 1974	75	25	11	
Flat Creek	Henderson	1959	1			
Forney (Lake Ray Hubbard)	Collin, Dallas, Kaufman, Rockwall	1940s, 1950s, 1963 - 65	33	6	3	
Garza-Little Elm (Lake Lewisville)	Denton	1940s, 1950s, 1948 , 1951, 1956, 1973, 1979 - 80, 1986				
Grapevine	Denton, Tarrant	1948, 1975	12	2		
Honea (Lake Conroe)	Montgomery, Walker	1965, 1967	34		4	
Iron Bridge (Lake Tawakoni)	Hunt, Rains, Van Zandt	1957, 1958, 1960	22		3	
Lake Creek	Montgomery	1985 - 86	46			
Lake Fork	Hopkins, Rains, Wood	1975 - 76, 1978 - 79	130	67	11	
Lakeview (Joe Pool Lake)	Dallas, Ellis, Tarrant	1977 - 81, 1984 - 86	42	23	19	14
Lake Lavon	Collin	1940s, 1948, 1950 - 51, 1959 - 60, 1964, 1969, 1973 - 74	34	9	5	
Lake Livingston	Polk, San Jacinto, Trinity, Walker	1961 - 66, 1968 - 69	160	3	6	
Marshall (Little Cypress)	Harrison, Upshur	1981, 1986	18			
McGee Bend (Lake Sam Rayburn)	Angelina, Jasper, Nacogdoches, Sabine, San Augustine	1948, 1956 - 58, 1960 - 62	81	11	10	
Millican	Brazos, Grimes, Leon, Madison	1971, 1973, 1981 - 82	188			
Mineola	Rains, Van Zandt, Wood	1971	91			

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Navarro Mills	Hill, Navarro	1959, 1961	19		1	
Pat Mayse	Lamar	1965, 1967	23	5	4	
Ponta	Cherokee, Nacogdoches, Rusk	1968	10			
Richland Creek	Freestone, Navarro	1979 - 84	1001	270	53	
Rockland	Angelina, Polk, Trinity, Tyler	1954	10			
Somerville	Burleson, Lee, Washington	1961, 1963 - 64	29		1	
Tennessee Colony	Anderson, Freestone, Henderson, Navarro	1971 - 72, 1974 - 77	326	14		
Texarkana (Lake Wright Patman)	Bowie, Cass	1949, 1952, 1963, 1970	190		4	
Timber Creek	Fannin	1968	2			
Titus County (Lake Bob Sandlin)	Camp, Franklin, Titus	1968 - 69, 1974 - 75, 1977 - 78	150	13	5	
Toledo Bend	Newton, Panola, Sabine, Shelby	1961 - 68	139	20	7	
Upper Navasota (Lake Limestone)	Leon, Limestone, Robertson	1974 - 77	52	22	4	
Waco Lake	McLennan	1959, 1963 - 65, 1984 - 85	115	13	2	
Wallisville Lake	Chambers, Liberty	1965 - 73, 1979, 1981, 1985 - 86	171	32	9	11
Water's Bluff	Smith, Upshur	1985 - 86	32			1
Lake Whitney	Bosque, Hill, Johnson	1947 - 52, 1956 - 60, 1971 - 72, 1976, 1984	101	29	14	3
Total:			**5035**	**748**	**252**	**133**

Note: The data within this table is primarily abstracted from Guy (1990). The data in this reference only encompasses work up to and including the year 1986.

Table 2: A Synopsis of Previous Reservoir Archeological Investigations in Eastern and Central Texas, Aggregated by Region.

Northeast Region

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Bayou Loco (Nacogdoches)	Nacogdoches	1972, 1975 - 76	16	4	2	1
Big Pine	Lamar, Red River	1971 - 72, 1974 - 75	116	8	2	2
Big Sandy	Upshur, Wood	1980, 1985	129	12		
Blackburn Crossing (Lake Palestine)	Anderson, Cherokee, Henderson, Smith	1957, 1969 - 70, 1975	133		12	
Bois D'Arc	Fannin	1968	13			
Caddo	Harrison, Marion	1920, 1931, 1950s, 1957, 1968, 1974, 1977, 1983	60	1	2	
Cedar Creek	Henderson, Kaufman	1961, 1963 - 64	33	1	1	
Cooper	Delta, Hopkins	1951, 1953, 1955, 1959, 1964, 1970, 1972 - 76, 1986	160	32	17	
Cypress Springs	Franklin	1968 - 69	17			
Ferrels Bridge (Lake O' the Pines)	Camp, Harrison, Marion, Morris, Upshur	1951, 1957 - 60, 1974	75	25	11	
Flat Creek	Henderson	1959	1			
Iron Bridge (Lake Tawakoni)	Hunt, Rains, Van Zandt	1957, 1958, 1960	22		3	
Lake Fork	Hopkins, Rains, Wood	1975 - 76, 1978 - 79	130	67	11	
Marshall (Little Cypress)	Harrison, Upshur	1981, 1986	18			
McGee Bend (Lake Sam Rayburn)	Angelina, Jasper, Nacogdoches, Sabine, San Augustine	1948, 1956 - 58, 1960 - 62	81	11	10	
Mineola	Rains, Van Zandt, Wood	1971	91			
Pat Mayse	Lamar	1965, 1967	23	5	4	

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Ponta	Cherokee, Nacogdoches, Rusk	1968	10			
Tennessee Colony	Anderson, Freestone, Henderson, Navarro	1971 - 72, 1974 - 77	326	14		
Texarkana (Lake Wright Patman)	Bowie, Cass	1949, 1952, 1963, 1970	190		4	
Timber Creek	Fannin	1968	2			
Titus County (Lake Bob Sandlin)	Camp, Franklin, Titus	1968 - 69, 1974 - 75, 1977 - 78	150	13	5	
Water's Bluff	Smith, Upshur	1985 - 86	32			1
Subtotal:			**1828**	**193**	**84**	**4**

Southeast Region

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Addicks	Harris	1947, 1964, 1982 - 86	76 (1982 - 86 only)			36
Barker	Fort Bend, Harris	1983 - 1985	75	6	3	33
B. A. Steinhagen	Jasper, Tyler	1947 - 48	7			
Big Cow Creek	Jasper, Newton	1975 - 76	7			
Cleveland	San Jacinto	1985	4			
Honea (Lake Conroe)	Montgomery, Walker	1965, 1967	34		4	
Lake Creek	Montgomery	1985 - 86	46			
Lake Livingston	Polk, San Jacinto, Trinity, Walker	1961 - 66, 1968 - 69	160	3	6	
Rockland	Angelina, Polk, Trinity, Tyler	1954	10			
Toledo Bend	Newton, Panola, Sabine, Shelby	1961 - 68	139	20	7	
Wallisville Lake	Chambers, Liberty	1965 - 73, 1979, 1981, 1985 - 86	171	32	9	11
Subtotal:			**729**	**61**	**33**	**80**

North Central Region

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Aquilla	Hill	1972 - 1975, 1977 - 80, 1982 - 83	131	43	19	
Aubrey (Lake Ray Roberts)	Cooke, Denton, Grayson	1972 - 73, 1980 - 83, 1985 - 86	381	60	13	31
Bardwell	Ellis	1963, 1965	15	6	1	1
Benbrook	Tarrant	1948	0			
Bosque	Bosque	1986	146			
Brushy Creek	Fannin, Grayson	1960	10			
Denison Dam (Lake Texoma)	Cooke, Grayson	1972	158	11		
Forney (Lake Ray Hubbard)	Collin, Dallas, Kaufman, Rockwall	1940s, 1950s, 1963 - 65	33	6	3	
Garza-Little Elm (Lake Lewisville)	Denton	1940s, 1950s, 1948, 1951, 1956, 1973, 1979 - 80, 1986				
Grapevine	Denton, Tarrant	1948, 1975	12	2		
Lakeview (Joe Pool Lake)	Dallas, Ellis, Tarrant	1977 - 81, 1984 - 86	42	23	19	14
Lake Lavon	Collin	1940s, 1948, 1950 - 51, 1959 - 60, 1964, 1969, 1973 - 74	34	9	5	
Navarro Mills	Hill, Navarro	1959, 1961	19		1	
Waco Lake	McLennan	1959, 1963 - 65, 1984 - 85	115	13	2	
Lake Whitney	Bosque, Hill, Johnson	1947 - 52, 1956 - 60, 1971 - 72, 1976, 1984	101	29	14	3
Subtotal:			**1197**	**202**	**77**	**49**

South Central Region

Reservoir	County	Years Investigated	Recorded Sites	Sites Tested	Sites Excavated	Sites NHRP - Eligible or Potentially Eligible
Bedias	Grimes, Madison, Walker	1985 - 86	11			
Millican	Brazos, Grimes, Leon, Madison	1971, 1973, 1981 - 82	188			
Richland Creek	Freestone, Navarro	1979 - 84	1001	270	53	
Somerville	Burleson, Lee, Washington	1961, 1963 - 64	29		1	
Upper Navasota (Lake Limestone)	Leon, Limestone, Robertson	1974 - 77	52	22	4	
Subtotal:			**1281**	**292**	**58**	

Table 3: Comparison of Recorded Archeological and Cultural Sites for Counties Containing Proposed Reservoir Sites.

County	Historic Cemeteries	Sawmills	Military Sites	Archeological Sites	State Archeological Landmarks	National Register of Historic Places-Listed Sites	Potential Total of National Register of Historic Places-Eligible Sites
Anderson	367	83	2	240	11	25	48
Austin	315	0	2	94	5	7	19
Cameron	176	0	9	203	195	22	41
Cherokee	134	409	0	444	2	6	89
Clay	25	0	0	11	1	2	2
De Witt	62	0	0	283	1	59	57
Delta	31	5	0	283	0	0	57
Falls	77	0	0	80	1	2	16
Fannin	331	10	0	74	1	8	15
Franklin	75	9	0	144	0	2	28
Freestone	226	1	0	617	4	1	123
Garza	4	0	0	694	2	7	139
Gonzales	74	0	3	221	5	9	44
Grimes	151	43	0	431	2	6	86
Haskell	15	0	0	37	0	0	7
Hopkins	70	12	0	251	1	1	50
Jackson	51	0	1	230	1	2	46
Lamar	100	12	1	317	3	40	64
Live Oak	15	0	1	333	2	3	67
Madison	96	3	1	31	0	1	6
Palo Pinto	40	0	0	384	4	6	77
Red River	102	109	0	309	2	6	62
Shackelford	9	0	2	78	5	5	16
Smith	367	85	1	333	22	29	67
Throckmorton	11	0	1	27	1	1	5
Titus	57	0	0	901	12	1	180
Walker	61	126	1	200	15	4	40
TOTAL	**3042**	**907**	**25**	**7250**	**298**	**255**	**1451**

(Source: Texas Historical Commission On-Line Archeological Sites Atlas, November, 2006)
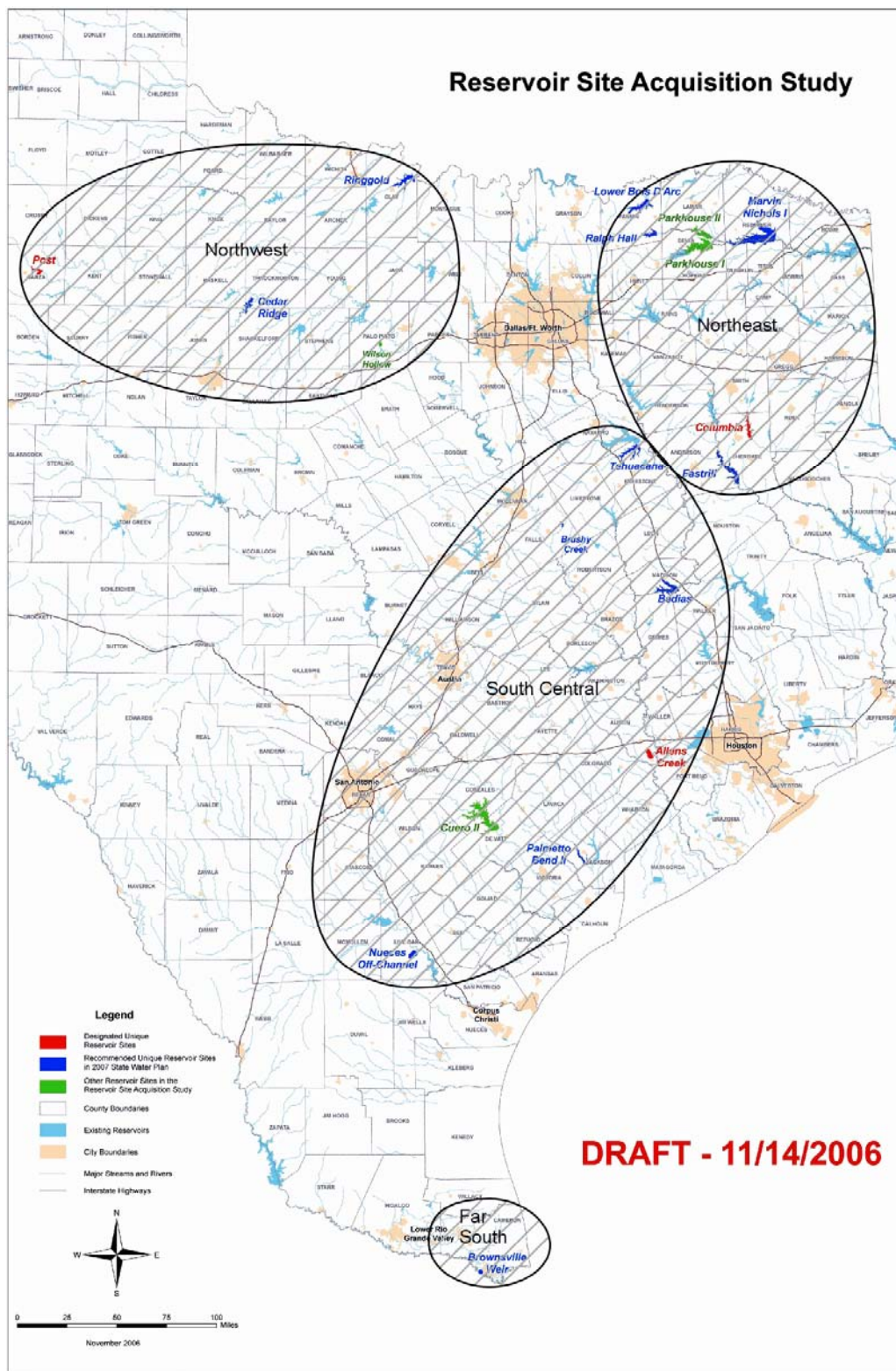
Figure 2: Location of Regional Groups Used in Study, Aggregated on the Basis of Physiography and Characteristics of Historic Properties.

Table 4: Comparison of Recorded Archeological and Cultural Sites for Counties Containing Proposed Reservoir Sites, Aggregated by Regional Group.

County	Historic Cemeteries	Sawmills	Military Sites	Archeological Sites	State Archeological Landmarks	National Register of Historic Places-Listed Sites	Potential Total of National Register of Historic Places-Eligible Sites
Northwest							
Clay	25	0	0	11	1	2	2
Garza	4	0	0	694	2	7	139
Haskell	15	0	0	37	0	0	7
Palo Pinto	40	0	0	384	4	6	77
Shackelford	9	0	2	78	5	5	16
Throckmorton	11	0	1	27	1	1	5
Group Subtotal	**104**	**0**	**3**	**1231**	**13**	**21**	**246**
Northeast							
Anderson	367	83	2	240	11	25	48
Cherokee	134	409	0	444	2	6	89
Delta	31	5	0	283	0	0	57
Fannin	331	10	0	74	1	8	15
Franklin	75	9	0	144	0	2	28
Hopkins	70	12	0	251	1	1	50
Lamar	100	12	1	317	3	40	64
Red River	102	109	0	309	2	6	62
Smith	367	85	1	333	22	29	67
Titus	57	0	0	901	12	1	180
Group Subtotal	**1634**	**734**	**4**	**3296**	**54**	**118**	**660**
South Central							
Austin	315	0	2	94	5	7	19
De Witt	62	0	0	283	1	59	57
Falls	77	0	0	80	1	2	16
Freestone	226	1	0	617	4	1	123
Gonzales	74	0	3	221	5	9	44
Grimes	151	43	0	431	2	6	86
Jackson	51	0	1	230	1	2	46
Live Oak	15	0	1	333	2	3	67
Madison	96	3	1	31	0	1	6

County	Historic Cemeteries	Sawmills	Military Sites	Archeological Sites	State Archeological Landmarks	National Register of Historic Places-Listed Sites	Potential Total of National Register of Historic Places-Eligible Sites
Walker	61	126	1	200	15	4	40
Group Subtotal	**1128**	**173**	**9**	**2520**	**36**	**94**	**504**
Far South							
Cameron	176	0	9	203	195	22	41
Group Subtotal	**176**	**0**	**9**	**203**	**195**	**22**	**41**
TOTAL	**3042**	**907**	**25**	**7250**	**298**	**255**	**1451**

(Source: Texas Historical Commission On-Line Archeological Sites Atlas, November, 2006)

Regional Groups include the Following Proposed Reservoir Sites:

Northwest:	Cedar Ridge, Post, Ringgold, and Wilson Hollow.
Northeast:	Columbia, Fastrill, Lower Bois D'Arc, Marvin Nichols I, Parkhouse I, Parkhouse II, and Ralph Hall.
South Central:	Allens Creek, Bedias, Brushy Creek, Cuero II, Nueces Off-Channel, Palmetto Bend II, and Tehuacana.
Far South:	Brownsville Weir.

Table 5: Comparison of Sensitive Cultural Resources for Counties Containing Proposed Reservoir Sites, Aggregated by Regional Group.

County	Historic Cemeteries	Sawmills	Military Sites	Potential Total of National Register of Historic Places-Eligible Sites	Total Sensitive Sites	Regional Avg. (Total Sites / Counties in Region)	Variance from Regional Avg.	Study Area Avg. (Total Sites / Counties)	Variance from Study Area Avg.
Northwest									
Clay	25	0	0	2	27		-31.8		-173.9
Garza	4	0	0	139	143		+84.2		-57.9
Haskell	15	0	0	7	22		-36.8		-178.9
Palo Pinto	40	0	0	77	117		+58.2		-83.9
Shackelford	9	0	2	16	27		-31.8		-173.9
Throckmorton	11	0	1	5	17		-41.8		-183.9
Group Subtotal	**104**	**0**	**3**	**246**	**353**	**58.8**			**-151.1**
Northeast									
Anderson	367	83	2	48	500		+196.8		+299.1

B-27

County	Historic Cemeteries	Sawmills	Military Sites	Potential Total of National Register of Historic Places-Eligible Sites	Total Sensitive Sites	Regional Avg. (Total Sites / Counties in Region)	Variance from Regional Avg.	Study Area Avg. (Total Sites / Counties)	Variance from Study Area Avg.
Cherokee	134	409	0	89	632		+328.8		+431.1
Delta	31	5	0	57	93		-210.2		-107.9
Fannin	331	10	0	15	356		+52.8		-144.9
Franklin	75	9	0	28	112		-191.2		-88.9
Hopkins	70	12	0	50	132		-171.2		-68.9
Lamar	100	12	1	64	177		-126.2		-23.9
Red River	102	109	0	62	273		-30.2		+72.1
Smith	367	85	1	67	520		+216.8		+319.1
Titus	57	0	0	180	237		-66.2		+36.1
Group Subtotal	**1634**	**734**	**4**	**660**	**3032**	**303.2**			**+102.3**
South Central									
Austin	315	0	2	19	336		+154.6		+135.1
De Witt	62	0	0	57	119		-62.4		-81.9
Falls	77	0	0	16	93		-88.4		-107.9
Freestone	226	1	0	123	350		+168.6		+149.1
Gonzales	74	0	3	44	121		-60.4		-79.9
Grimes	151	43	0	86	280		+98.6		+79.1
Jackson	51	0	1	46	98		-83.4		-102.9
Live Oak	15	0	1	67	83		-98.4		-117.9
Madison	96	3	1	6	106		-75.4		-94.9
Walker	61	126	1	40	228		+46.6		+27.1
Group Subtotal	**1128**	**173**	**9**	**504**	**1814**	**181.4**			**-19.5**
Far South									
Cameron	176	0	9	41	226		0		+25.1
Group Subtotal	**176**	**0**	**9**	**41**		**226**			**+25.1**
TOTAL	**3042**	**907**	**25**	**1451**	**5425**			**200.9**	

Appendix C
Report on the Creation of a Land Cover /
Land Use Database for
Select Proposed Reservoir Sites
In Texas

Report on

The Creation of a Land Cover / Land Use Database for Select Proposed Reservoir Sites in Texas

Texas Parks & Wildlife GIS Lab

November 16, 2006

Statement of Need

Texas Water Development Board is tasked with evaluating proposed reservoir sites. Land cover information is needed to evaluate sites with respect to possible wetland impacts and other mitigation needs. Land cover information allows efficient evaluation of relative costs and risks associated with reservoir development on a particular site. The most recent ground verified land cover / vegetation database for Texas is The Vegetation Types of Texas – Including Cropland, McMahan, et.al. 1984, PWD Bulletin 7000-120. The most recent unverified database is the 1992 National Land Cover Dataset (USGS). These dataset are unsuitable for site evaluation due to age, lack of resolution, and / or unverified accuracy and a new database needs to be developed.

Proposed Methodology

All proposed reservoir sites will be mapped using a modified version of the Texas Land Classification System (Appendix B). This classification system is an expansion of the National Land Cover Database (NLCD) Classification System (Appendix A) and is a standard land cover / land use classification system for Texas. The modified version will use all classes considered necessary to quickly evaluate potential reservoir sites as to relative risk of impacts to wetlands and other land resources subject to mitigation. The classification system is a generalization and is intended to allow rapid mapping to a level of detail considered sufficient for planning level evaluation of reservoir sites. The classes included in the system are (using NLCD / Texas Land Classification nomenclature):

Land Cover Type	Definition
1.1 Open Water	All areas of open water, generally with less than 25 percent cover of vegetation or soil.
2.0 Developed	Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50-100 % of total cover
4.111 Deciduous Forest	Areas dominated by trees where 75% or more of the canopy cover can be determined to be trees which loose all their leaves for a specific season of the year.
4.112 Evergreen Forest	Areas dominated by trees where 50% or more of the canopy cover can be determined to be trees which maintain their leaves / needles all year. All mixed Pine / Oak forests in this class. Includes Pine plantations and other evergreen dominated silvaculture operations.
4.1121 Broad-leaf Evergreen Forest	Areas dominated by evergreen trees that have well-defined leaf blades and are relatively wide in shape. Example species include: *Quercus virginicus, Quercus fusiformis*.
4.12 Shrubland	Areas where trees have less than 25% canopy cover and the existing vegetation is dominated by plants that have persistent woody stems, a relatively low growth habit (generally less than 4 m), and which generally produce several basal shoots instead of a single shoot. Includes true shrubs, trees that are small or stunted because of environmental conditions, desert scrub, and chaparral. In the eastern US, includes former cropland or pasture lands which are now covered by brush to the extent that they are no longer identifiable or usable as cropland or pasture. Clear-cut areas will exhibit a stage of shrub cover during the regrowth cycle. Some common species which would be classified as shrub land are mountain mahogany, sagebrush, and scrub oaks.
4.21 Natural Herbaceous	Areas dominated by native or naturalized grasses, forbs, ferns and weeds. They can be managed, maintained, or improved for ecological purposes such as weed/brush control or soil erosion. Includes vegetated vacant lots and areas where it cannot be determined whether the vegetation was planted or cultivated such as in areas of dispersed grazing by

Land Cover Type	Definition
	feral or domesticated animals. Includes landscapes dominated by grass-like plants such as bunch grasses, palouse grass, palmetto prairie areas, and tundra vegetation, as well as true prairie grasses.
4.22 Planted / Cultivated Herbaceous	Areas of herbaceous vegetation planted and/or cultivated by humans for agronomic purposes in developed settings. The majority of vegetation in these areas is planted and/or maintained for the production of food, feed, fiber, pasture, or seed. Temporarily flooded are included in this category. Does not include harvested areas of naturally occurring plants such as wild rice and cattails.
4.31111 Seasonally Flooded Forest	Tree dominated areas on which surface water or soil saturation is present for extended periods during the growing season, but is absent by the end of the growing season in most years. Example species include: *Quercus laurifolia, Fraxinus pennsylvanica, Nyssa sp., Acer rubrum, Liquidambar styraciflua, Ulmus americana*
4.3112 Swamp	Tree dominated areas on which surface water persists throughout the growing season, except during drought years. Example species include: *Nyssa aquatica, Taxodium distichum*.
4.312 Shrub Wetland	Wetlands with greater 25% shrub cover and less than 25% tree cover. Usually fresh water inundation, includes seasonal and greater flooding regimes. Example species include: *Arundinaria gigantea, Baccharis salicifolia, Salix Sp., Cephalanthus occidentalis, Planera aquatica and Forestiera acuminata*
4.32 Emergent Herbaceous Wetlands	Areas dominated by wetland herbaceous vegetation which is present for most of the growing season. Includes fresh-water, brackish-water, and salt-water marshes, tidal marshes, mountain meadows, wet prairies, and open bogs.

Table 1. Reservoir Site Land Cover Classification System

Land cover will be mapped using Landsat ETM+ and TM data from the most current suitable datasets available in the State of Texas imagery archive, December 1999 to March 2003 (Table 1). Imagery collected during and out of the growing season will be used. Data will be combined and an unsupervised clustering routine (Isodata) in Leica Geosystems Erdas Imagine 9.0 will be run. Data will be grouped statistically into 30 clusters and these will be assigned to one of the land cover classes. Using the national hydric soils list from the Natural Resources Conservation Service (NRCS) and the Soil Survey Geographic (SSURGO) database from the same source to develop a map of the hydric soils in the area of interest and then using this to modify the land cover classes. Only soils map units classified as Sloughs, flood plains, or salt marshes with greater than 70% hydric inclusions are included for analysis. Classes 4.111 Deciduous Forest, 4.112 Evergreen Forest and 4.1121 Broad-leaf Evergreen Forest areas that intersect the hydric soils area will be reclassified to 4.31111 Seasonally Flooded Forest. Class 4.21 Natural Herbaceous areas that intersect the hydric soil area will be reclassified to 4.32 Emergent Herbaceous Wetlands. Class 4.12 Shrubland areas will be reclassified to 4.312 Shrub Wetland. Minimum mapping unit is 1 hectare.

Row / Path	Date
25-37	1/10/2000
25-37	4/18/2001
25-38	9/6/2000
25-38	11/3/2001
25-39	1/10/2000
25-39	7/20/2000
26-37	4/25/2001
26-37	12/14/2001
26-38	2/4/2001
26-38	4/25/2001
26-39	12/16/1999
26-39	4/25/2001
26-40	2/4/2001
26-40	4/25/2001
26-42	6/12/2001
26-42	3/30/2003
27-40	7/21/2001
27-40	12/31/2002
28-36	4/4/2000
28-36	2/2/2001
28-37	4/4/2000
28-37	3/9/2002
29-37	5/29/2000
29-37	1/8/2001

Table 1

Boundary information for each potential reservoir site, provided by Texas Natural Resource Information System, will be intersected with land cover data. No buffer was applied because the small size of some sites would lead make comparison of areas difficult as relatively large percentages of total area would be outside the footprint of the reservoir sites.

Random points are selected from each class and DOQQ imagery evaluation will be conducted to get a limited amount of verification of accuracy. Points will be overlaid on 2004 National Agricultural Imagery Program DOQ mosaics displayed at 1:10,000 scale and will be evaluated as to accuracy of land cover class.

Deliverables

1. Land cover database for priority potential reservoir sites (see Appendix C). Data delivered in ESRI personal geodatabase format. UTM WGS84 Meters projection. 11x17 proof maps in both paper and Adobe Acrobat formats.

2. DOQ imagery verification report and database. Data delivered in ESRI personal geodatabase format. Geographic WGS84 Decimal Degree (change due to locations crossing UTM boundaries) projection.

Results

Overall accuracy of the classification is 91%. Errors of omission and commission were computed for each class (Table 2). Classification accuracy is grouped for all landcover classes. Class 4.31111 Seasonally Flooded Forest is mapped conservatively and may occupy a larger percentage of the landscape than mapped. Small inclusions into matrix soils or soils that had smaller percentages of hydric soil types / areas may have this class present and not be mapped.

Class	1	2	3	4	5	6	7	8	9	10	11	12	Error of Omission
1	36												**0.000**
2		9											**0.000**
3			44	2			1						**0.064**
4				9				2					**0.182**
5					12								**0.000**
6			1	1		42	2						**0.087**
7						3	42	10					**0.236**
8	1							23					**0.042**
9									24		1	1	**0.077**
10										8			**0.000**
11											15		**0.000**
12										1	1	22	**0.083**
Error of Commission	**0.027**	**0.000**	**0.022**	**0.250**	**0.000**	**0.067**	**0.067**	**0.343**	**0.000**	**0.111**	**0.118**	**0.043**	

Table 2

Appendix A – NLCD Land Cover Classification System[1]

11. Open Water—All areas of open water, generally with less than 25 percent cover of vegetation or soil.
12. Perennial Ice/Snow—All areas characterized by a perennial cover of ice and/or snow, generally greater than 25 percent of total cover.
21. Developed, Open Space—Includes areas with a mixture of some constructed materials, but mostly vegetation in the form of lawn grasses. Impervious surfaces account for less than 20 percent of total cover. These areas most commonly include large-lot single-family housing units, parks, golf courses, and vegetation planted in developed settings for recreation, erosion control, or aesthetic purposes
22. Developed, Low Intensity—Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 20–49 percent of total cover. These areas most commonly include single-family housing units.
23. Developed, Medium Intensity—Includes areas with a mixture of constructed materials and vegetation. Impervious surfaces account for 50–79 percent of the total cover. These areas most commonly include single-family housing units.
24. Developed, High Intensity—Includes highly developed areas where people reside or work in high numbers. Examples include apartment complexes, row houses, and commercial/industrial. Impervious surfaces account for 80 to 100 percent of the total cover.
31. Barren Land (Rock/Sand/Clay)—Barren areas of bedrock, desert pavement, scarps, talus, slides, volcanic material, glacial debris, sand dunes, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15 percent of total cover.
32. Unconsolidated Shore*—Unconsolidated material such as silt, sand, or gravel that is subject to inundation and redistribution due to the action of water. Characterized by substrates lacking vegetation except for pioneering plants that become established during brief periods when growing conditions are favorable. Erosion and deposition by waves and currents produce a number of landforms representing this class.
41. Deciduous Forest—Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species shed foliage simultaneously in response to seasonal change.
42. Evergreen Forest—Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. More than 75 percent of the tree species maintain their leaves all year. Canopy is never without green foliage.
43. Mixed Forest—Areas dominated by trees generally greater than 5 meters tall, and greater than 20 percent of total vegetation cover. Neither deciduous nor evergreen species are greater than 75 percent of total tree cover.
51. Dwarf Scrub—Alaska only areas dominated by shrubs less than 20 centimeters tall with shrub canopy typically greater than 20 percent of total vegetation. This type is often co-associated with grasses, sedges, herbs, and non-vascular vegetation.
52. Shrub/Scrub—Areas dominated by shrubs; less than 5 meters tall with shrub canopy typically greater than 20 percent of total vegetation. This class includes true shrubs, young trees in an early successional stage, or trees stunted from environmental conditions.
71. Grassland/Herbaceous—Areas dominated by grammanoid or herbaceous vegetation, generally greater than 80 percent of total vegetation. These areas are not subject to intensive management such as tilling, but can be utilized for grazing.
72. Sedge/Herbaceous—Alaska only areas dominated by sedges and forbs, generally greater than 80 percent of total vegetation. This type can occur with significant other grasses or other grass like plants, and includes sedge tundra, and sedge tussock tundra.
73. Lichens—Alaska only areas dominated by fruticose or foliose lichens generally greater than 80 percent of total vegetation.

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[1] Homer, C., Haung, C., Yang, L., Wylie, B., and Coan, M. Development of a 2001 Nation Land-Cover Database for the United States. Photogrammetric Engineering and Remote Sensing. Vol 70. No. 7, July 2004, pp.829-840.

74. Moss—Alaska only areas dominated by mosses, generally greater than 80 percent of total vegetation.

81. Pasture/Hay—Areas of grasses, legumes, or grass-legume mixtures planted for livestock grazing or the production of seed or hay crops, typically on a perennial cycle. Pasture/hay vegetation accounts for greater than 20 percent of total vegetation.

82. Cultivated Crops—Areas used for the production of annual crops, such as corn, soybeans, vegetables, tobacco, and cotton, and also perennial woody crops such as orchards and vineyards. Crop vegetation accounts for greater than 20 percent of total vegetation. This class also includes all land being actively tilled.

90. Woody Wetlands—Areas where forest or shrubland vegetation accounts for greater than 20 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

> **91. Palustrine Forested Wetland***—Includes all tidal and non-tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent.

> **92. Palustrine Scrub/Shrub Wetland***—Includes all tidal and non-tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Total vegetation coverage is greater than 20 percent. The species present could be true shrubs, young trees and shrubs or trees that are small or stunted due to environmental conditions.

> **93. Estuarine Forested Wetland***—Includes all tidal wetlands dominated by woody vegetation greater than or equal to 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts are equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

> **94. Estuarine Scrub/Shrub Wetland***—Includes all tidal wetlands dominated by woody vegetation less than 5 meters in height, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent. Total vegetation coverage is greater than 20 percent.

95. Emergent Herbaceous Wetlands—Areas where perennial herbaceous vegetation accounts for greater than 80 percent of vegetative cover and the soil or substrate is periodically saturated with or covered with water.

> **96. Palustrine Emergent Wetland (Persistent)***—Includes all tidal and non-tidal wetlands dominated by persistent emergent vascular plants, emergent mosses or lichens, and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is below 0.5 percent. Plants generally remain standing until the next growing season.

> **97. Estuarine Emergent Wetland***—Includes all tidal wetlands dominated by erect, rooted, herbaceous hydrophytes (excluding mosses and lichens) and all such wetlands that occur in tidal areas in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and that are present for most of the growing season in most years. Perennial plants usually dominate these wetlands.

> **98. Palustrine Aquatic Bed***—The Palustrine Aquatic Bed class includes tidal and nontidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is below 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, detached floating mats, and rooted vascular plant assemblages.

99. Estuarine Aquatic Bed*—Includes tidal wetlands and deepwater habitats in which salinity due to ocean-derived salts is equal to or greater than 0.5 percent and which are dominated by plants that grow and form a continuous cover principally on or at the surface of the water. These include algal mats, kelp beds, and rooted vascular plant assemblages.

Appendix B – Texas Land Classification System[2]

Expand the USGS MRLC classification categories to include the following new vegetative categories unique to Texas and call the new classification scheme the Texas Land Classification System. The new categories to MRLC are highlighted in blue.

VEGETATED - areas having generally 25% or more of the land or water with vegetation. Arid or semi-arid areas may have as little as 5% vegetation cover.

4.1 Woody Vegetation - land with at least 25% tree and (or) shrub canopy cover.
    4.11 Forested – trees with crowns overlapping (generally 60-100% cover)
        4.111 Deciduous Forest - area dominated by trees where 75% or more of the canopy cover can be determined to be trees which loose all their leaves for a specific season of the year.
            4.1111 Cold Deciduous Forest – area dominated by trees that shed their leaves as a strategy to avoid seasonal periods of low temperature. Example species include: *Quercus stellata , Quercus marilandica.*
        4.112 Evergreen Forest - area dominated by trees where 75% or more of the canopy cover can be determined to be trees which maintain their leaves all year.
            4.1121 Broad-leafed Evergreen Forest - area dominated by evergreen trees that have well-defined leaf blades and are relatively wide in shape. Example species include: *Quercus virginicus, Quercus fusiformis.*
            4.1122 Needle-leafed Evergreen Forest – area dominated by evergreen trees with slender elongated leaves. Example species include: *Pinus echinata, Pinus palustris, Pinus taeda, Juniperus virginiana.*
        4.113 Mixed Forest - areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the canopy cover.
    4.12 Shrubland - areas where trees have less than 25% canopy cover and the existing vegetation is dominated by plants that have persistent woody stems, a relatively low growth habit (generally less than 4 m), and which generally produce several basal shoots instead of a single shoot. Includes true shrubs, trees that are small or stunted because of environmental conditions, desert scrub, and chaparral. In the eastern US, include former cropland or pasture lands which are now covered by brush to the extent that they are no longer identifiable or usable as cropland or pasture. Clear-cut areas will exhibit a stage of shrub cover during the regrowth cycle. Some common species which would be classified as shrub land are mountain mahogany, sagebrush, and scrub oaks.
        4.121 Deciduous Shrubland - areas where 75% or more of the land cover can be determined to be shrubs which loose all their leaves for a specific season of the year.
            4.1211 Cold Deciduous Shrubland - area dominated by shrubs that shed their leaves as a strategy to avoid seasonal periods of low temperature. Example species include: *Quercus sinuata, Rubis sp., Smilax Sp.*
            4.1212 Drought Deciduous
        4.122 Evergreen Shrubland - areas where 75% or more of the land cover can be determined to be shrubs which keep their leaves year round.
            4.1221 Broad-leafed Evergreen Shrubland - area dominated by evergreen shrubs that have well-defined leaf blades and are relatively wide in shape. Example species include: *Quercus havardii, Quercus fusiformis.*
            4.1222 Needle-leafed Evergreen Shrubland – area dominated by evergreen shrubs with slender elongated leaves. Example species include: *Juniperus ashei, Juniperus virginiana.*
        4.123 Mixed Shrubland - areas dominated by shrubs where neither deciduous nor evergreen species represent more than 75% of the land cover.
        4.124 Desert Scrub - land areas predominantly in arid and semi-arid portions of the southwestern U.S. Existing vegetation is sparse and often covers only 5-25% of the land. Example species include sagebrush, creosote, saltbush, greasewood, and cacti.

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[2] Interagency LULC Working Group, GIS Managers Committee, Texas Geographic Information Council. Texas Land Classification System. October 1999.

4.13 Planted/Cultivated Woody (Orchards/Vineyards/Groves) – areas containing plantings of evenly spaced trees, shrubs, bushes, or other cultivated climbing plants usually supported and arranged evenly in rows. Includes orchards, groves, vineyards, cranberry bogs, berry vines, and hops. Includes tree plantations planted for the production of fruit, nuts, Christmas tree farms, and commercial tree nurseries. Exclude pine plantations and other lumber or pulp wood plantings, which will be classified as Forest.

    4.131 Irrigated Planted/Cultivated Woody - orchards, groves, or vineyards where a visible irrigation system is in place to supply water

    4.132 Citrus - trees or shrubs cultivated in orchards or groves that bear edible fruit such as orange, lemon, lime, grapefruit, and pineapple.

    4.133 Non-managed Citrus - orchards or groves containing fruit bearing trees or shrubs which are no longer maintained or harvested by humans.

    Evidence of non-managed citrus includes the growth of non citrus shrubs, trees, and grasses within an orchard or grove.

4.14 Woodland – Open stands of trees with crowns not usually touching (25- 59% cover).

    4.141 Deciduous Woodland - area dominated by trees where 75% or more of the canopy cover can be determined to be trees which loose all their leaves for a specific season of the year.

        4.1411 Cold Deciduous Woodland – area dominated by trees that shed their leaves as a strategy to avoid seasonal periods of low temperature. Example species include: *Quercus stellata, Quercus marilandica, Juglans nigra, Quercus alba.*

    4.142 Evergreen Woodland - area dominated by trees where 75% or more of the canopy cover can be determined to be trees which maintain their leaves all year.

        4.1421 Broad-leafed Evergreen Woodland - area dominated by evergreen trees that have well-defined leaf blades and are relatively wide in shape. Example species include: *Quercus virginicus, Quercus fusiformis.*

        4.1422 Needle-leafed Evergreen Woodland - area dominated by evergreen trees with slender elongated leaves. Example species include: *Pinus palustris, Pinus taeda, Juniperus virginiana.*

    4.143 Mixed Woodland - areas dominated by trees where neither deciduous nor evergreen species represent more than 75% of the canopy cover.

4.2 Herbaceous Vegetation - areas dominated by non-woody plants such as grasses, forbs, ferns and weeds, either native, naturalized, or planted. Trees must account for less than 25% canopy cover while herbaceous plants dominate all existing vegetation.

    4.21 Natural Herbaceous - areas dominated by native or naturalized grasses, forbs, ferns and weeds. It can be managed, maintained, or improved for ecological purposes such as weed/brush control or soil erosion. Includes vegetated vacant lots and areas where it cannot be determined whether the vegetation was planted or cultivated such as in areas of dispersed grazing by feral or domesticated animals. Includes landscapes dominated by grass-like plants such as bunch grasses, palouse grass, palmetto prairie areas, and tundra vegetation, as well as true prairie grasses.

    4.211 Natural Grasslands - natural areas dominated by true grasses. Includes undisturbed tall-grass and short-grass prairie in the Great Plains of the U.S.

        4.2111 Short Grasslands – natural areas dominated by Graminoid vegetation usually less than 0.5 meters tall when inflorescences are fully developed. Example species include: *Bouteloua eriopoda, Bouteloua gracilis, Buchloe dactyloides.*

        4.2112 Medium – Tall Grasslands – natural areas dominated by graminoid vegetation usually more than 0.5 meters tall when inflorescences are fully developed. Example species include: *Paspalum sp., Schizachyrium scoparium, Andropogon gerardii, Panicum virgatum.*

        4.212 Natural Forb – natural areas dominated by broad-leaved herbaceous plants. Example species include: *Giant Ragweed, Bigelowia nuttallii.*

4.22 Planted/Cultivated Herbaceous - areas of herbaceous vegetation planted and/or cultivated by humans for agronomic purposes in developed settings. The majority of vegetation in these areas is planted and/or maintained for the production of food, feed, fiber, pasture, or seed. Temporarily flooded are included in this category. Do not include harvested areas of naturally occurring plants such as wild rice and cattails.

4.221 Fallow/Bare Fields - areas within planted or cultivated regions that have been tilled or plowed and do not exhibit any visible vegetation cover.

4.222 Small Grains - areas used for the production of grain crops such as wheat, oats, barley, graham, and rice. Category is difficult to distinguish
from cultivated grasses grown for hay and pasture. Indicators of small grains may be a less than 10% slope, annual plowing and seeding, distinctive field patterns and sizes, different timing of green-up and harvest, different harvesting practices, a very "even" texture and tone, or regional variations discovered during field checks.

4.2221 Irrigated Small Grains - areas used for the production of small grain crops where a visible irrigation system is in place to supply water including the flooding of entire fields. Category includes rice fields. Presence of irrigation system does not guarantee that the field is irrigated. The specific small grain crops that follow while difficult to classify compared to specific row crops were included for sake of completion.

4.2222 Non-Irrigated Small Grains – Denotes fields without any visible sign of irrigation system.

4.223 Row Crops - areas used for the production of crops or plants such as corn, soybeans, vegetables, tobacco, flowers and cotton. Fields which exhibit characteristics similar to row crops, but that do not have any other distinguishing features for a more specific category may be included.

4.224 Specialty Crops - includes vegetables such as potatoes, tomatoes and fruits such as cantaloupe, and watermelon.

4.225 Cultivated Grasses - areas of herbaceous vegetation, including perennial grasses, legumes, or grass-legume mixtures that are planted by humans and used for erosion control, for seed or hay crops, for grazing animals, or for landscaping purposes

4.2251 Irrigated

4.22511 Pasture/Hay - areas of cultivated perennial grasses and/or legumes (e.g., alfalfa) used for grazing livestock or for seed or hay crops. Pasturelands can have a wide range of cultivation levels. It can be managed by seeding, fertilizing, application of herbicides, plowing, mowing, or baling. Pastureland has often been cleared of trees and shrubs, is generally on steeper slopes than cropland, and is intended to graze animals at a higher density than open rangeland, and is often fenced and divided into smaller parcels than rangeland or cropland. Hay fields may be more mottled than small grain fields as they are not plowed annually and may be harvested and baled two or three times a year in some locations.

4.22512 Turf - areas growing grasses such as St. Augustine for yards.

4.2252 Non-irrigated Cultivated Grasses

4.22521 Pasture

4.22522 Turf

4.226 Other cultivated

4.3 Vegetated Wetland - areas where the water table is at, near, or above the land surface for a significant part of most years and vegetation indicative of this covers more than 25% of the land surface. Wetlands can include marshes, swamps situated on the shallow margins of bays, lakes, ponds, streams, or reservoirs; wet meadows or perched bogs in high mountain valleys, or seasonally wet or flooded low spots or basins. Do not include agricultural land, which is flooded for cultivation purposes.

4.31 Woody Wetland - areas dominated by woody vegetation. Includes seasonally flooded bottomland, mangrove swamps, shrub swamps, and wooded swamps including those around bogs. Wooded swamps and southern flood plains contain primarily cypress, tupelo, oaks, and red maple. Central and northern flood plains are dominated by cottonwoods, ash, alder, and willow. Flood plains of the Southwest may be dominated by mesquite, salt cedar, seepwillow, and arrowweed. Northern bogs typically contain tamarack or larch, black spruce, and heath shrubs. Shrub swamp vegetation includes alder, willow, and buttonbush.

4.311 Forested Wetland – area with tree canopy greater than 25%, surface water present or saturated soils present for variable periods, which may or may not have detectable seasonality.

4.3111 Riparian Forest – tree dominated wetlands along river or stream courses.

4.31111 Seasonally flooded - tree dominated area on which surface water or soil saturation is present for extended periods during the growing season, but is absent by the end of the growing season in most years. Example species include: *Quercus*

laurifolia, Fraxinus pennsylvanica, Nyssa sp., Acer rubrum, Liquidambar styraciflua, Ulmus americana

4.31112 Temporarily Flooded – tree dominated area on which surface water is present for brief periods during the growing season. Example species include: *Quercus virginiana, Celtis laevigata, Carya illinoinensis, Ulmus crassifolia, and Platanus occidentalis.*

4.3112 Swamp – tree dominated area on which surface water persists throughout the growing season, except during drought years. Example species include: *Nyssa aquatica, Taxodium distichum.*

4.312 Shrub Wetland – wetland with shrub canopy cover greater than 25%.

4.3121 Tidal – shrub dominated wetlands with less than 25% tree canopy cover, tidal (usually saline to some extent) water covers land surface, usually on a daily cycle. Example species include: *Tamarix Sp., Baccharis halimifolia, Avicennia germinans.*

4.3122 Non-Tidal – wetlands with greater 25% shrub cover and less than 25% tree cover. Usually fresh water inundation, includes seasonal and greater flooding regimes. Example species include: *Arundinaria gigantea, Baccharis salicifolia, Salix Sp.*

4.32 Emergent Herbaceous Wetlands - areas dominated by wetland herbaceous vegetation which is present for most of the growing season. Includes fresh-water, brackish-water, and salt-water marshes, tidal marshes, mountain meadows, wet prairies, and open bogs.

4.321 Marsh – Herbaceous fresh water wetlands, dominated by rooted vascular emergent herbaceous vegetation. Example species include: *Typha sp., Juncus effusus, Rhynchospora sp., Scirpus americanus, Colocasia esculenta, Ludwigia Sp., Sagitaria Sp.*

4.3211 Prairie Pothole – off channel, isolated wetlands. Usually depressions in the landscape. Common in the panhandle region of Texas.

4.322 Tidal Marsh - wetland areas dominated by saline herbaceous vegetation, water depth and/or inundation usually changing on a daily cycle. Example species include: *Spartina patens, Spartina alternaflora, Scirpus pungens, Juncus roemerianus, and Phragmites australis.*

Appendix C – Reservoir List

Bedias
Brownsville Weir
Brushy Creek
Cedar Ridge
Cuero 2
Fastrill 274
George Parkhouse 1
George Parkhouse 2
Lower Bois D'Arc
Marvin Nichols 1
Nueces Off Channel
Palmetto Bend 2
Ralph Hall
Ringgold
Tehaucana
Wilson Hollow

Appendix D
Executive Administrator's
Draft Final Report Comments

February 2, 2007

Mr. James K. (Ken) Haney, PE
Executive Vice President
HDR Engineering, Inc.
4401 West Gate Blvd., Suite 400
Austin, Texas 78745

Re: Research and Planning Fund Grant Contract between the Texas Water Development Board
        (TWDB) and HDR Engineering, Inc. (HDR), Freese and Nichols, Inc. (FNI), and R.J. Brandes
        Company (RJB) for Research Project entitled "Reservoir Site Acquisition Study, Contract No.
        0604830615, Draft Final Report Comments

Dear Mr. Haney:

Staff members of the Texas Water Development Board have completed a review of the draft report
under TWDB Contract No. 0604830615. As stated in the above-referenced contract, HDR, FNI, and
RJB will consider incorporating draft report comments, shown in ATTACHMENT I, from the
EXECUTIVE ADMINISTRATOR as well as comments from others, into the final report. In addition,
HDR, FNI, and RJB will include a copy of the EXECUTIVE ADMINISTRATOR's draft report
comments in the Final Report.

The Board looks forward to receiving one (1) electronic copy of the entire Final Report in Portable
Document Format (PDF) and nine (9) bound double-sided copies. HDR, FNI, and RJB shall also
submit one (1) electronic copy of any computer programs or models and an operations manual
developed under the terms of this CONTRACT.

If you have any questions concerning this contract, please contact Dr. Barney Austin, the Board's
designated Contract Manager for this study, at (512) 463-8856.

Sincerely,

William F. Mullican

William F. Mullican, III
Deputy Executive Administrator
Office of Planning

Enclosure

c: Barney Austin, TWDB

Attachment I
Draft Final Report Comments
Reservoir Site Acquisition Study

1.   This is an excellent report. All Tasks mentioned in the Scope of Work appear to have been completed. The work is well documented. However, the tabular presentation of cost estimate data for the 16 detailed reservoir evaluations could use some clarification. The tables that the following comments relate to are Tables 3.4.1-5, 3.4.2-2, 3.4.3-4, 3.4.4-4, 3.4.5-5, 3.4.6-4, 3.4.7-5, 3.4.8-5, 3.4.9-3, 3.4.10-4, 3.4.11-5, 3.4.12-5, 3.4.13-4, 3.4.14-5, and 3.4.15-6.

   a) **Typo (?) on Table 3.4.1-5, Pages 3-14 to 3-15, Cost Estimate - Bedias Creek Reservoir.** Environmental Studies and Mitigation Costs are described as "(100% Land Costs)" but no value is listed in the "Cost" column, making it unclear if these costs were included in a different category (or were actually zero).

   b) **Engineering Contingencies of 35% are included in the Conflicts category for some, but not all, of the reservoirs.** No explanation of why these costs were included in some but not other reservoir sites is included in the report. For a majority of projects (11 reservoirs out of 16), a 35% Engineering Contingencies Cost was included in Conflicts Costs. For three reservoirs (Bedias Creek, Lake Ralph Hall, and Brushy Creek), a 35% Engineering Contingencies Cost was not included in the Conflicts Costs. For one Project (Brownsville Weir) Conflict Costs were estimated to be zero. For another (Tehuacanca), an itemization of Conflict Costs was not provided so it can't be determined if a 35% Engineering Contingencies Cost was included in the Conflicts Costs.

   c) **Units used in these tables are not clearly identified.** Units listed in these tables include:
   Ac
   AC
   CY
   Ea
   EA
   EACH
   LBS
   LF
   L.S.
   LS
   SF

   No description of the meaning of these abbreviations is provided in the document. Most of these abbreviations seem evident (for example "AC" probably refers to "Acre", "LF" probably refers to "Linear Foot"), but for clarity, it would be best to use a standard set of abbreviations for these tables and provide the reader with the intended meanings.

2.	Page ES-1, 2nd paragraph, first sentence: The 2007 State Water Plan's recommended sites for designation as unique for the construction of a reservoir include sites that were not identified by the regional water planning groups. Some of the sites were recommended for designation by the TWDB and not the planning groups. Suggest revising the sentence to read as follows: "The 2007 State Water Plan recommends the Legislature consider 17 major reservoir sites identified by Regional Water Planning Groups and the TWDB for protection by designation as unique reservoir sites."

3.	Page ES-4, 1st paragraph, first bullet: "Recommended to meet needs or….." should be revised to read "Recommended as water management strategies or….".

4.	Suggest including as an appendix the list of all 150 projects that were screened and the results of that screening.

5.	Page ES-6 and ES7, Recommendation for designation of 4 additional sites should be qualified by stating that there are other viable sites, these were just the sites that fell out of the screening for which we had study funds available to update the information.

6.	Page ES-7, paragraph ES.3.1 – same as comment 2 above

7.	Page ES-9, paragraph ES.3.5 – TPWD's list of stream segments are classified as "ecological significant" by the TPWD and should not be references as "recommended for designation as ecologically significant" since the statute provides for designation of river or stream segments of "unique ecological value" and not "ecological significance". Recommend substituting "identified as ecologically significant by the Texas Parks and Wildlife Department (TPWD)" in place of "recommended for designation as ecologically significant by the ….".

8.	Pages ES-11 and ES-12 and 2nd bullet on page ES-13 –Muenster Reservoir is already constructed and therefore should not be recommended for potential acquisition.

9.	Page ES-14, last bullet – TWC Section 16.051(g)(2) does not exist, so it can not be expanded. Also, the recommendation suggests including additional entities in the TWC that could not obtain land or easements that would effectively prevent the construction of a reservoir site. However, the majority of the entities listed are already included in TWC, Section 16.051(g) as they are political subdivisions of the state.

10.	Appendix B should be revised to remove the header "TWDB Internal Draft, Not for Distribution"

Appendix E
Excerpts from Matrix Screening Tool

Reservoir Site Protection Study
Results of Matrix Screening Process

Rank*	Reservoir
1	Allens Creek
2	Columbia
3	Bedias
4	Ralph Hall
5	Lower Bois D'Arc
6	Palmetto Bend II
6	Nueces Off-Channel
8	Tehuacana
9	Marvin Nichols I
10	Brownsville Weir
11	Fastrill
11	Post
13	Ringgold
13	Cedar Ridge
13	Brushy Creek
16	Wilson Hollow
17	Parkhouse II
18	Parkhouse I
18	Cuero II
20	Little River
20	Shaws Bend
22	Lower East Fork
22	Millican
24	Waters Bluff
24	Cuero I
26	Italy
27	Whitsett
28	Little River Off-Channel
29	Carl Estes
30	Lake Creek
30	Cleveland
32	Humble
33	South Fork
34	Keechi Creek
35	Bonham C of E
35	Marvin Nichols II
35	La Grange
35	Goliad
35	Cibolo (Recharge)
40	Bon Weir
40	Cibolo w/ Pump Over
42	Navasota
42	R & M
42	Sabinal (Recharge)
45	Bosque
45	Cotulla
45	Fowlerton
48	Ponta
48	Roanoke
48	Fox Crossing
48	Turkey Peak
52	Long King

Rank*	Reservoir
53	Voth
53	Caney
53	Cibolo
56	Little Cypress
56	Big Sandy
56	Tenaha
59	Black Cypress
59	Prairie Creek
59	Boyd
59	South Bend
59	Cloptin Crossing
64	Rockland
64	Bee Mountain
64	Blanco (Recharge)
67	Kilgore
67	Baylor Creek
67	Dilworth
67	Guadalupe Dam 7
67	Frio (Recharge)
72	Big Pine
72	Hightower
72	Paluxy
72	Upper Pecan Bayou
72	Tom Nunn Hill
77	Tennessee Colony
77	Matagorda
77	Gonzales
80	Liberty Hill
80	Highway 322
82	Carthage
82	Lockhart
82	Confluence
85	Crowell
85	Cochino Bayou
85	Caimanche
85	Kingsville
89	Stephenville
90	Liberty Capers Ridge
90	Applewhite
92	Upper Little Cypress
92	Oak Knoll
92	Qihi
95	Hurricane Bayou
96	Big Cow Creek
96	Pedernales
96	Ecleto w/ Pump Over
99	Lower Keechi
100	Pecan Bayou
100	Nelson
100	Mustang
100	Woodsboro
104	Turkey Creek

Rank*	Reservoir
104	Inspiration Point
104	Caldwell
104	Crystal City
108	Rabbit
108	Mill Creek
108	San Saba
111	Big Elkhart
112	Dozier
112	Barkman Creek
112	Gail
112	Ingram
112	Smyth Crossing
117	Shamrock
117	Stateline
117	Alice
120	Beaver Creek
120	Henderson
120	Indian Creek (Recharge)
123	Harmon
123	Seymour
123	Ecleto
123	Batesville
123	Garcitas
128	Saul's
129	Blanco
130	Lower McClellan Creek
130	Elm
130	Little Cow Creek
130	Kincaid
134	Mulberrry Creek
134	Buck
134	Eight Mile
134	Upper Keechi
134	Mason
139	Socagee
140	Brice
140	Groesbeck Creek
140	Beeville
143	Sweetwater Creek
143	Upper Washita
145	Alpine
146	Lelia Lake
147	South Pease
148	Cedar Creek
149	Bayside
150	Middle Pease
151	Sabinal
152	Montell
153	Concan

* Repeated rank indicates identical composite score.

Reservoir Site Protection Study
Screening Criteria Weighting Worksheet

Criteria	Weight*
Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	5
Least Distance to Major Demand Center	2
Water Supply Needs within 50 Miles	2
Firm Yield	5
Unit Cost of Water (Raw @ Reservoir)	4
Water Quality Concerns	1
Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2
Yield / Surface Area	1
System Operations Opportunity	2
Ecologically Significant Stream Segment (# Criteria)	3
Special Considerations (Permitted or Designated Unique)	3

* Weights are integers from 1 to 5. Greater weight indicates greater relative importance in matrix screening process.

Reservoir Site Protection Study
Compiled Data for Reservoir Sites*

Reservoir	River Basin	Region	Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	Firm Yield (acft/yr)	Unit Cost of Water - Raw @ Reservoir ($/acft/yr)	Special Considerations (Permitted or Unique)	Ecologically Significant Stream Segment (# Criteria)	Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2060 Water Supply Needs within 50 Miles (acft/yr)	Least Distance to Major Demand Center (miles)	System Operations Opportunity	Water Quality Concerns (treatment)	Yield / Surface Area	Rank
Barkman Creek	Red	D	No	10,800	---	No	No Impact	No Impact	31,163	168	No	No	6.8	112
Beaver Creek	Red	B	No	21,240	---	No	No Impact	No Impact	19,813	138	No	Yes	1.8	120
Big Pine	Red	D	No	32,256	$142	No	No Impact	Inundating (1)	84,815	123	No	No	6.3	72
Bonham C of E	Red	C	No	38,961	$246	No	Inundating (3)	Just Upstream (4)	1,402,653	62	Yes	No	7.4	35
Brice	Red	O & A	No	19,620	---	No	Inundating (2)	No Impact	16,871	263	No	Yes	3.4	140
Buck	Red	A	No	7,380	---	No	No Impact	No Impact	11,291	231	No	Yes	3.6	134
Crowell	Red	B	No	125,550	---	No	Inundating (1)	No Impact	11,965	190	No	Yes	8.5	85
Dozier	Red	A	No	16,020	---	No	No Impact	No Impact	194	248	No	Yes	4.6	112
Elm	Red	A	No	11,700	---	No	No Impact	No Impact	0	239	No	Yes	4.3	130
Groesbeck Creek	Red	B	No	11,160	---	No	No Impact	No Impact	11,965	195	No	Yes	2.0	140
Lelia Lake	Red	A	No	2,329	$1,103	No	Inundating (1)	No Impact	919	262	Yes	No	3.3	146
Liberty Hill	Red	D	No	30,240	$239	No	No Impact	Just Upstream (2)	39,341	148	Yes	No	4.3	80
Lower Bois D'Arc	Red	C	Yes	123,000	$91	No	Inundating (3)	Inundating (4)	728,028	80	Yes	No	7.5	5
Lower McClellan Creek	Red	A	No	7,020	---	No	Inundating (1)	No Impact	19,125	272	No	No	3.9	130
Middle Pease	Red	B	No	3,780	---	No	Indirect (1)	No Impact	2,429	231	No	Yes	2.8	150
Mulberry Creek	Red	B	No	9,630	---	No	Indirect (2)	No Impact	35,091	269	No	Yes	4.7	134
Pecan Bayou	Red	D	No	1,679	$660	No	No Impact	No Impact	48,833	126	Yes	No	15.0	100
Ringgold	Red	B	Yes	24,300	$503	No	No Impact	No Impact	313,933	96	Yes	No	1.6	13
Saul's	Red	O	No	5,580	---	No	No Impact	No Impact	33,953	260	No	Yes	8.8	128
Shamrock	Red	A	No	16,290	---	No	No Impact	No Impact	0	247	No	Yes	4.2	117
South Pease	Red	B	No	4,050	---	No	No Impact	No Impact	20,016	236	No	Yes	3.5	147
Sweetwater Creek	Red	A	No	7,830	$326	No	Inundating (2)	No Impact	0	258	No	Yes	3.1	143
Upper Washita	Red	A	No	4,410	---	No	No Impact	No Impact	0	268	No	No	2.0	143
Marvin Nichols I	Sulphur	D	Yes	612,300	$58	No	Indirect (2)	Inundating (1)	103,879	124	Yes	No	9.0	9
Marvin Nichols II	Sulphur	D	No	280,100	$89	No	Indirect (2)	Inundating (1)	103,879	125	Yes	No	7.8	35
Parkhouse I	Sulphur	D	No	135,600	$121	No	No Impact	Upstream (1)	561,591	93	Yes	No	4.6	18
Parkhouse II	Sulphur	D	No	148,700	$101	No	No Impact	Upstream (1)	473,850	94	Yes	No	12.1	17
Ralph Hall	Sulphur	C	Yes	32,940	$377	No	No Impact	No Impact	419136	72	Yes	No	4.3	4
Black Cypress	Cypress	D	No	176,770	$103	No	Inundating (3)	Inundating (1)	84,277	143	Yes	No	8.1	59
Little Cypress	Cypress	D	No	144,900	$150	No	Inundating (3)	Inundating (2)	96,441	143	Yes	No	9.2	56
Upper Little Cypress	Cypress	D	No	71,700	---	No	Inundating (3)	Upstream (2)	104,168	123	Yes	No	2.9	92
Big Cow Creek	Sabine	I	No	61,700	---	No	Indirect (2)	Just Upstream (2)	77,442	117	No	No	13.4	96
Big Sandy	Sabine	D	No	46,600	$132	No	No Impact	Inundating (2)	220,114	104	No	No	10.6	56
Bon Weir	Sabine	I	No	440,000	$57	No	Inundating (2)	Just Upstream (2)	52,698	125	Yes	No	12.7	40
Carl Estes	Sabine	D	No	95,630	$298	No	Indirect (3)	Inundating (2)	1,344,004	77	Yes	No	3.8	29
Carthage	Sabine	D & I	No	537,000	$68	No	Inundating (3)	Inundating (1)	138,671	152	No	No	13.0	82
Eight Mile	Sabine	D	No	42,030	$753	No	Indirect (3)	Just Upstream (1)	99,345	153	No	No	5.0	134
Highway 322	Sabine	I	No	22,000	$356	No	No Impact	Upstream (1)	138,651	130	Yes	No	4.9	80
Kilgore	Sabine	D	No	4,950	$193	No	No Impact	No Impact	138,904	117	No	No	6.1	67
Little Cow Creek	Sabine	I	No	---	---	No	No Impact	No Impact	41,926	131	No	No	---	130
Mill Creek	Sabine	I	No	12,000	$653	No	No Impact	Upstream (1)	138,671	131	Yes	No	5.8	108
Prairie Creek	Sabine	D	No	17,215	$248	No	No Impact	No Impact	138,904	117	No	No	7.6	59
Rabbit	Sabine	D	No	3,500	---	No	No Impact	No Impact	138,904	117	No	No	6.7	108
Socagee	Sabine	D	No	39,131	$1,015	No	No Impact	Just Upstream (1)	66,584	169	No	No	4.3	139
Stateline	Sabine	D	No	280,000	---	No	Inundating (3)	Inundating (1)	85,669	173	No	No	11.6	117
Tenaha	Sabine	D	No	180,000	$109	No	No Impact	Inundating (2)	84,704	166	No	No	5.1	56
Waters Bluff	Sabine	D	No	324,000	$112	No	No Impact	Inundating (2)	175,989	113	Yes	No	8.9	24
Cedar Creek	Neches	I	No	12,060	---	No	Indirect (4)	Just Upstream (1)	101,810	107	No	No	4.7	148
Cochino Bayou	Neches	I	No	123,300	---	No	Inundating (1)	Just Upstream (2)	101,810	110	No	No	4.9	85
Columbia	Neches	I	Yes	75,700	$197	Yes	Indirect (2)	Just Upstream (1)	148,660	120	Yes	No	6.6	2
Fastrill	Neches	I	Yes	137,843	$134	No	Inundating (3)	Inundating (1)	136,476	127	Yes	No	5.5	11
Henderson	Neches	I	No	2,016	---	No	No Impact	No Impact	125,045	129	No	No	2.7	120
Ponta	Neches	I	No	84,442	$309	No	Inundating (2)	Inundating (1)	118,192	131	Yes	No	7.7	48
Rockland	Neches	I	No	614,430	$103	No	Inundating (4)	Inundating (2)	62,100	102	Yes	No	6.2	64
Voth	Neches	I	No	312,120	$112	No	Inundating (4)	Inundating (2)	104,261	83	Yes	No	14.3	53
Bedias	Trinity	G & H	Yes	90,700	$121	No	No Impact	Just Upstream (6)	284,552	85	No	No	4.3	3
Big Elkhart	Trinity	I	No	12,320	---	No	Indirect (3)	No Impact	186,988	118	No	No	5.8	111
Boyd	Trinity	C	No	4,792	---	No	No Impact	No Impact	1,845,256	43	Yes	No	0.3	59

Reservoir Site Protection Study
Compiled Data for Reservoir Sites*

Reservoir	River Basin	Region	Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	Firm Yield (acft/yr)	Unit Cost of Water - Raw @ Reservoir ($/acft/yr)	Special Considerations (Permitted or Unique)	Ecologically Significant Stream Segment (# Criteria)	Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2060 Water Supply Needs within 50 Miles (acft/yr)	Least Distance to Major Demand Center (miles)	System Operations Opportunity	Water Quality Concerns (treatment)	Yield / Surface Area	Rank
Caney	Trinity	H	No	15,700	$316	No	No Impact	No Impact	268,850	85	No	No	7.9	53
Gail	Trinity	I	No	12,379	$669	No	No Impact	No Impact	269,629	101	No	No	3.8	112
Harmon	Trinity	H	No	10,100	$1,495	No	Inundating (3)	No Impact	685,336	77	No	No	9.2	123
Hurricane Bayou	Trinity	I	No	17,900	$377	No	Indirect (3)	No Impact	153,930	112	No	No	3.9	95
Italy	Trinity	C	No	44,800	$244	No	No Impact	No Impact	1,977,636	42	No	No	3.5	26
Liberty Capers Ridge	Trinity	H	No	193,500	$600	No	Inundating (3)	Inundating (1)	919,830	45	No	No	2.4	90
Long King	Trinity	H	No	20,200	$211	No	No Impact	Just Upstream (5)	643,545	73	No	No	6.3	52
Lower Keechi	Trinity	H	No	25,662	$639	No	Indirect (3)	No Impact	269,757	103	No	No	6.4	99
Mustang	Trinity	I	No	15,694	$469	No	No Impact	No Impact	269,629	100	No	No	2.8	100
Nelson	Trinity	H	No	7,964	---	No	Inundating (2)	No Impact	683,890	79	No	No	2.5	100
Roanoke	Trinity	C	No	20,370	$22,083	No	No Impact	No Impact	1,932,957	23	Yes	No	2.0	48
Tehuacana	Trinity	C	Yes	56,800	$368	No	Indirect (1)	Just Upstream (5)	890,895	79	Yes	No	3.8	8
Tennessee Colony	Trinity	C & I	No	405,800	$420	No	Inundating (4)	Inundating (5)	148,669	92	Yes	No	2.8	77
Upper Keechi	Trinity	C	No	14,865	$1,036	No	Indirect (2)	No Impact	226,717	103	No	No	4.5	134
Cleveland	San Jacinto	H	No	65,900	$252	No	Inundating (3)	No Impact	695,946	47	Yes	No	2.0	30
Humble	San Jacinto	H	No	165,600	$5,417	No	No Impact	Inundating (5)	1,064,231	20	Yes	No	4.6	32
Lake Creek	San Jacinto	H	No	67,200	$418	No	Inundating (2)	No Impact	1,032,783	51	Yes	No	3.5	30
Lower East Fork	San Jacinto	H	No	121,500	---	No	Inundating (3)	No Impact	1,049,017	24	Yes	No	7.5	22
Allens Creek	Brazos	H	Yes	99,650	$136	Yes	Indirect (2)	No Impact	1,090,415	47	Yes	No	14.2	1
Bee Mountain	Brazos	G	No	42,451	$890	No	Inundating (2)	No Impact	1,242,416	61	Yes	Yes	1.3	64
Bosque	Brazos	G	No	17,900	$313	No	No Impact	No Impact	640,228	77	No	No	4.0	45
Brushy Creek	Brazos	G	Yes	2,000	$257	Yes	No Impact	No Impact	246,820	83	No	No	2.9	13
Caldwell	Brazos	G	No	10,200	$1,628	No	No Impact	No Impact	680,413	70	No	No	1.3	104
Cedar Ridge	Brazos	G	Yes	28,920	$224	No	No Impact	No Impact	17,240	146	Yes	No	4.7	13
Hightower	Brazos	G	No	61,318	$643	No	Inundating (3)	No Impact	1,466,573	71	Yes	Yes	1.7	72
Inspiration Point	Brazos	G	No	24,174	$1,305	No	Inundating (3)	No Impact	771,356	72	Yes	Yes	0.9	104
Keechi Creek	Brazos	G	No	6,120	$190	No	Indirect (3)	No Impact	760,543	77	Yes	No	3.6	34
Little River	Brazos	G	No	129,000	$241	No	Inundating (2)	No Impact	548,218	57	Yes	No	3.6	20
Little River Off-Channel	Brazos	G	No	32,110	$138	No	Indirect (2)	No Impact	544,114	68	No	No	7.4	28
Millican	Brazos	G & H	No	212,500	$263	No	No Impact	Inundating (2)	671,515	71	Yes	No	2.5	22
Navasota	Brazos	G	No	38,080	$913	No	No Impact	No Impact	282,447	99	Yes	No	2.6	42
Oak Knoll	Brazos	G	No	---	---	No	No Impact	No Impact	161,305	104	Yes	No	---	92
Paluxy	Brazos	G	No	16,300	$371	No	Inundating (1)	No Impact	649,644	69	No	No	4.2	72
Post	Brazos	O	Yes	10,800	$229	Yes	Indirect (2)	No Impact	36,427	253	Yes	Yes	4.7	11
Seymour	Brazos	G	No	88,650	$547	No	Inundating (2)	No Impact	13,441	180	No	Yes	1.3	123
South Bend	Brazos	G	No	44,940	$411	No	No Impact	No Impact	92,732	105	Yes	Yes	1.5	59
South Fork	Brazos	G	No	48,600	$1,679	No	No Impact	No Impact	543,379	23	Yes	No	6.6	33
Stephenville	Brazos	G	No	6,000	---	No	No Impact	No Impact	482,121	87	No	No	2.8	89
Turkey Creek	Brazos	G	No	18,749	$1,575	No	Inundating (3)	No Impact	760,811	77	Yes	Yes	0.8	104
Turkey Peak	Brazos	G	No	8,648	$393	No	No Impact	No Impact	511,124	79	Yes	No	13.4	48
Wilson Hollow	Brazos	G	Yes	6,590	$901	No	No Impact	No Impact	511,124	79	Yes	No	13.0	16
Baylor Creek	Colorado	K	No	---	---	No	No Impact	No Impact	1065188	66	Yes	No	---	67
Fox Crossing	Colorado	F & K	No	72,500	$450	No	No Impact	No Impact	17786	84	Yes	No	1.2	48
La Grange	Colorado	K	No	52,000	$380	No	Inundating (2)	No Impact	1125013	59	Yes	No	2.7	35
Mason	Colorado	F	No	19,000	$1,293	No	Inundating (1)	No Impact	13549	92	No	No	0.9	134
Matagorda	Colorado	K	No	---	---	No	No Impact	No Impact	446521	76	Yes	No	---	77
Pedernales	Colorado	K	No	19,000	$566	No	Inundating (3)	No Impact	709455	49	No	No	0.7	96
San Saba	Colorado	F & K	No	27,400	$405	No	Indirect (4)	No Impact	18355	92	No	No	3.8	108
Shaws Bend	Colorado	K	No	51,576	$247	No	Inundating (1)	No Impact	693,090	77	Yes	No	4.2	20
Upper Pecan Bayou	Colorado	F & G	No	5,900	$202	No	No Impact	No Impact	18372	151	Yes	No	1.1	72
Palmetto Bend II	Lavaca	P	Yes	23,000	$437	Yes	Indirect (2)	No Impact	79,857	93	Yes	No	2.8	6
Garcitas	Lavaca-Guadalupe	L & P	No	20,700	$465	No	Inundating (4)	No Impact	79,857	87	No	No	4.3	123
Blanco (Recharge)	Guadalupe	L	Yes	2,458	$2,529	No	Inundating (2)	No Impact	809,971	25	No	No	1.7	64
Cloptin Crossing	Guadalupe	L	No	32,458	$511	No	Inundating (2)	No Impact	817,325	30	No	No	5.4	59
Confluence	Guadalupe	L	No	78,300	$591	No	Inundating (4)	No Impact	123,003	62	Yes	No	2.6	82
Cuero I	Guadalupe	L	No	152,606	$203	No	Indirect (4)	No Impact	118,150	74	Yes	No	3.7	24
Cuero II	Guadalupe	L	No	80,836	$268	No	No Impact	No Impact	346,140	71	Yes	No	3.0	18
Dilworth	Guadalupe	L	No	19,705	$482	No	No Impact	No Impact	489,821	58	No	No	1.3	67

Appendix E.xls   Page 4 of 5   February 2007

Reservoir Site Protection Study
## Compiled Data for Reservoir Sites*

Reservoir	River Basin	Region	Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP)	Firm Yield (acft/yr)	Unit Cost of Water - Raw @ Reservoir ($/acft/yr)	Special Considerations (Permitted or Unique)	Ecologically Significant Stream Segment (# Criteria)	Terrestrial Impacts, Bottomland Hardwood Preservation (Priority)	2060 Water Supply Needs within 50 Miles (acft/yr)	Least Distance to Major Demand Center (miles)	System Operations Opportunity	Water Quality Concerns (treatment)	Yield / Surface Area	Rank
Gonzales	Guadalupe	L	No	69,897	$281	No	Inundating (5)	No Impact	708,195	58	No	No	3.3	77
Guadalupe Dam 7	Guadalupe	L	No	30,890	$512	No	Inundating (3)	No Impact	666,395	28	Yes	No	2.4	67
Ingram	Guadalupe	J	No	7,470	$1,963	No	Inundating (1)	No Impact	279,895	64	No	No	5.9	112
Lockhart	Guadalupe	L	No	5,627	$632	No	No Impact (5)	No Impact	816,166	26	No	No	1.9	82
Applewhite	San Antonio	L	No	4,032	$1,539	No	No Impact	No Impact	376,403	15	Yes	No	1.6	90
Cibolo	San Antonio	L	No	33,200	$582	No	No Impact	No Impact	386,135	38	No	No	2.0	53
Cibolo (Recharge)	San Antonio	L	Yes	1,818	$744	No	No Impact	No Impact	655,193	14	No	No	3.8	35
Cibolo w/ Pump Over	San Antonio	L	No	69,925	$351	No	No Impact	No Impact	386,135	38	No	No	4.2	40
Ecleto	San Antonio	L	No	4,800	$1,482	No	No Impact	No Impact	379,724	44	No	No	1.1	123
Ecleto w/ Pump Over	San Antonio	L	No	13,400	$1,370	No	No Impact	No Impact	379,724	44	No	No	3.1	96
Goliad	San Antonio	L	No	99,687	$193	No	Indirect (4)	No Impact	70,910	64	No	No	3.6	35
Bayside	San Antonio-Nueces	L	No	4,500	$1,119	No	Inundating (2)	No Impact	57,801	27	No	No	0.5	149
Beeville	San Antonio-Nueces	L & N	No	3,600	$1,196	No	No Impact	No Impact	70,910	55	No	No	0.4	140
Blanco	San Antonio-Nueces	L	No	4,500	$933	No	Indirect (1)	No Impact	57,646	45	No	No	0.8	129
Woodsboro	San Antonio-Nueces	L & N	No	9,900	$365	No	Indirect (2)	No Impact	57,801	29	No	No	1.0	100
Batesville	Nueces	N	No	1	---	No	No Impact	No Impact	20,944	77	No	No	---	123
Caimanche	Nueces	N	No	17,190	$394	No	No Impact	No Impact	110,892	102	No	No	1.9	85
Concan	Nueces	J & L	No	660	$14,576	No	Inundating (5)	No Impact	15,888	74	No	No	0.2	153
Cotulla	Nueces	L	No	57,080	$271	No	No Impact	No Impact	118,170	91	No	No	1.8	45
Crystal City	Nueces	N	No	18,270	$1,493	No	No Impact	No Impact	110,892	94	No	No	2.9	104
Fowlerton	Nueces	N	No	25,650	$289	No	No Impact	No Impact	341,601	69	No	No	3.3	45
Frio (Recharge)	Nueces	L	Yes	4,873	$716	No	Inundating (1)	No Impact	15,888	74	No	No	4.4	67
Indian Creek (Recharge)	Nueces	L	Yes	4,655	$2,183	No	Inundating (3)	No Impact	15,888	90	No	No	1.3	120
Kincaid	Nueces	N	No	1	---	No	No Impact	No Impact	13,666	79	No	No	---	130
Montell	Nueces	J & L	No	2,125	$8,980	No	Inundating (4)	No Impact	15,888	93	No	No	0.3	152
Nueces Off-Channel	Nueces	N	Yes	31,800	$398	No	No Impact	No Impact	159,640	56	Yes	No	6.8	6
Qihi	Nueces	N	No	1,084	---	No	No Impact	No Impact	284,254	48	No	No	1.2	92
R & M	Nueces	N	No	91,800	$345	No	Inundating (3)	No Impact	50,329	22	Yes	No	2.5	42
Sabinal	Nueces	L	No	812	$10,429	No	Inundating (4)	No Impact	248,898	63	No	No	0.3	151
Sabinal (Recharge)	Nueces	L	Yes	2,887	$364	No	Inundating (1)	No Impact	248,898	63	No	No	6.4	42
Smyth Crossing	Nueces	L	No	7,507	---	No	No Impact	No Impact	13,666	89	No	No	0.7	112
Tom Nunn Hill	Nueces	N	No	18,270	$290	No	No Impact	No Impact	13,666	89	No	No	5.2	72
Whitsett	Nueces	N	No	31,950	---	No	Indirect (1)	No Impact	379,433	68	Yes	No	5.5	27
Alice	Nueces-Rio Grande	N	No	3,330	$774	No	No Impact	No Impact	141,373	39	No	No	0.3	117
Kingsville	Nueces-Rio Grande	N	No	9,090	$476	No	No Impact	No Impact	192,462	29	No	No	1.1	85
Alpine	Rio Grande	E	No	---	---	No	No Impact	No Impact	0	196	No	No	---	145
Brownsville Weir	Rio Grande	M	Yes	20,643	$537	Yes	Inundating (4)	No Impact	223489	29	Yes	No	34.4	10

Data compiled from available references and used in matrix screeening process. Table ES-1 and Table 4.1-1 summarize current data for sites technically evaluated in the Reservoir Site Protection Study.
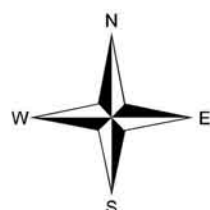
RESERVOIR SITES IDENTIFIED IN PLANS

Reservoir Site Protection Study
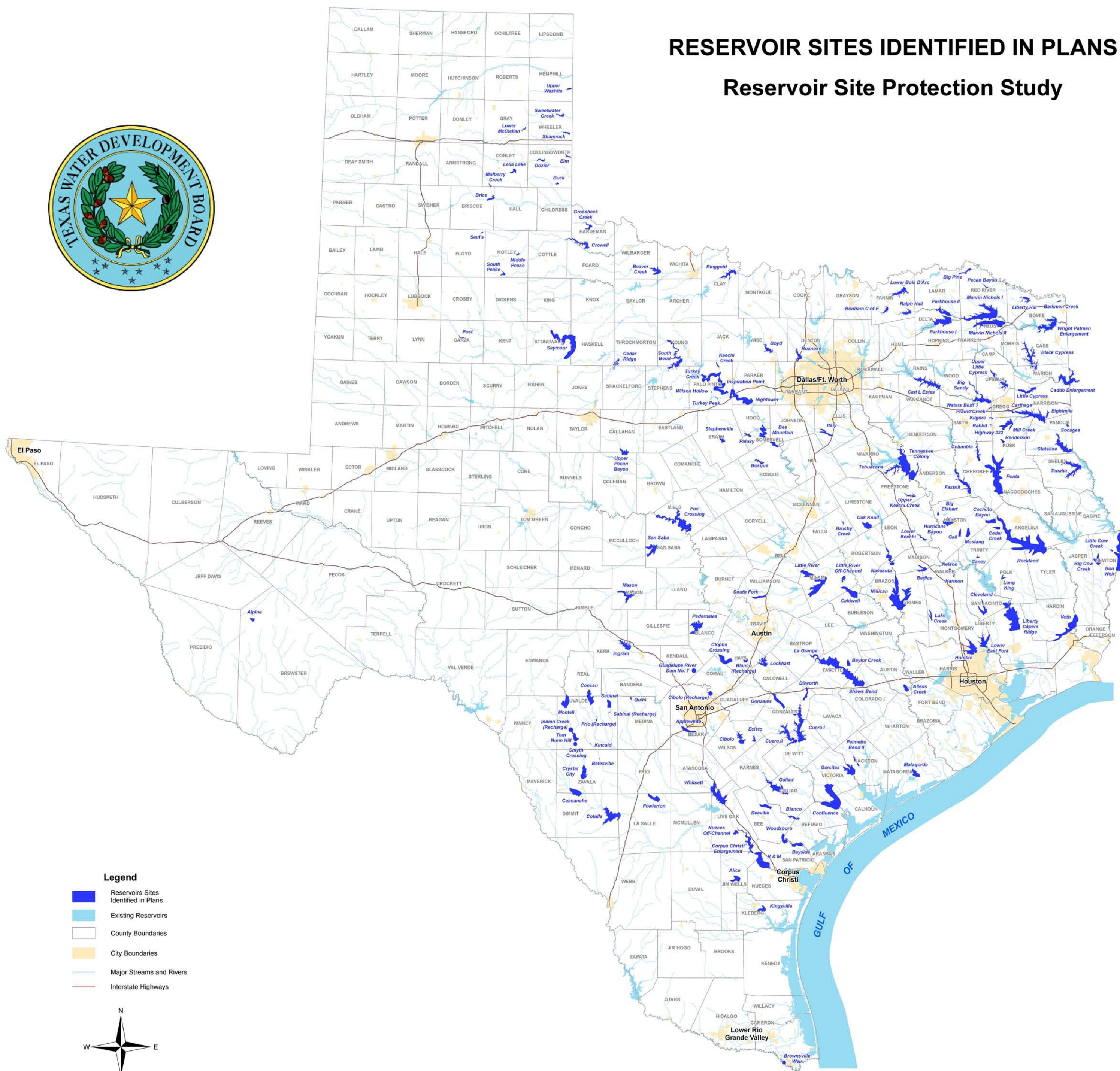
Legend

- **Reservoirs Sites Identified in Plans**
- **Existing Reservoirs**
- **County Boundaries**
- **City Boundaries**
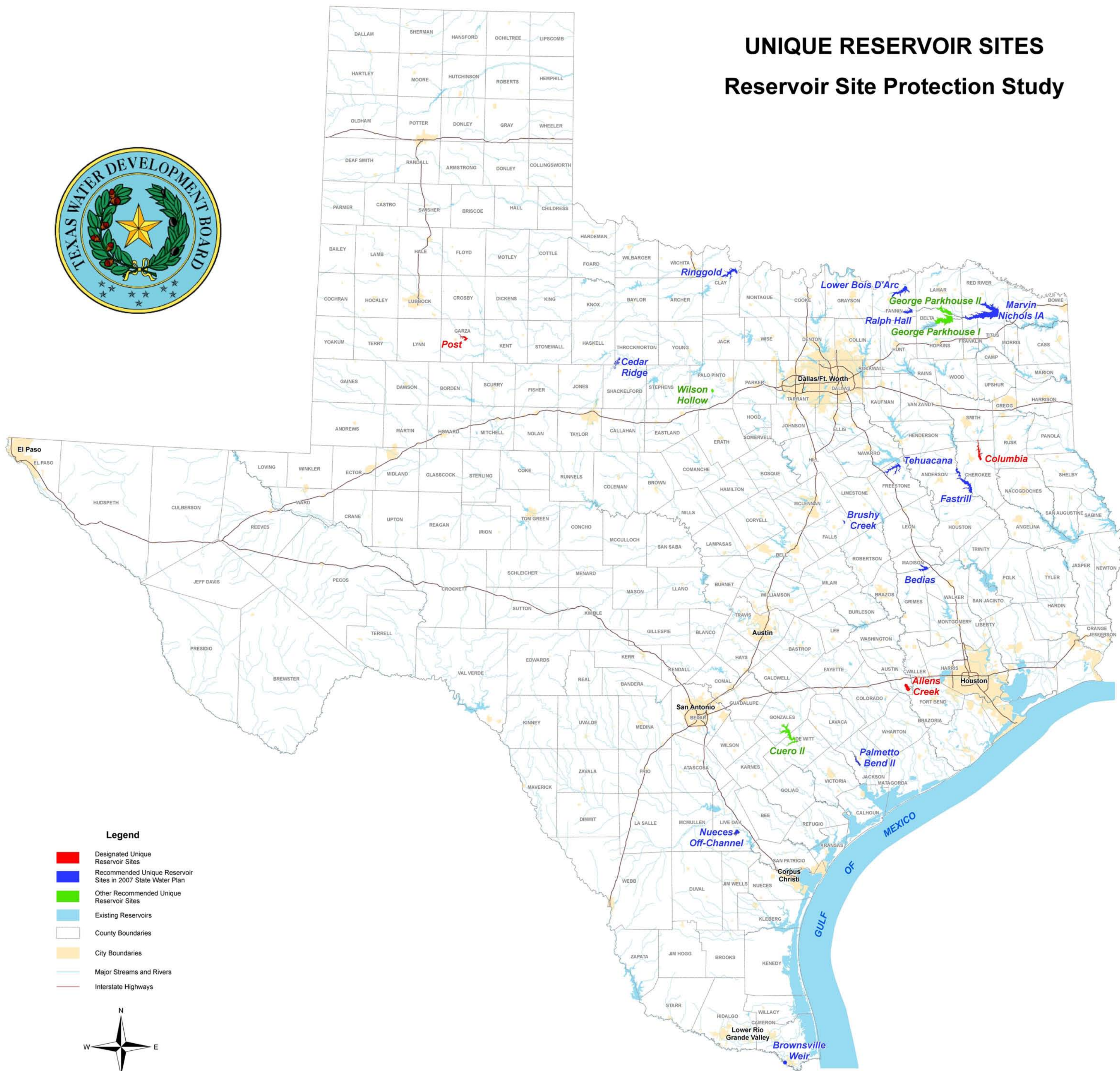- **Major Streams and Rivers**
- **Interstate Highways**

Exhibit 1

FEBRUARY 2007

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UNIQUE RESERVOIR SITES

Reservoir Site Protection Study

Ringgold

Lower Bois D'Arc

George Parkhouse II

Ralph Hall

George Parkhouse I

Marvin Nichols IA

Post

Cedar Ridge

Wilson Hollow

Dallas/Ft. Worth

Tehuacana

Columbia

Fastrill

Brushy Creek

Bedias

Austin

Allens Creek

Houston

Cuero II

Palmetto Bend II

San Antonio

Nueces Off-Channel

Corpus Christi

GULF OF MEXICO

El Paso

Lower Rio Grande Valley

Brownsville Weir

Legend

■ (red)	Designated Unique Reservoir Sites
■ (blue)	Recommended Unique Reservoir Sites in 2007 State Water Plan
■ (green)	Other Recommended Unique Reservoir Sites
■ (light blue)	Existing Reservoirs
□	County Boundaries
■ (tan)	City Boundaries
—	Major Streams and Rivers
—	Interstate Highways

N
W — E
S

0 25 50 75 100 Miles

FEBRUARY 2007

Exhibit 2

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