# Reservoir Site Protection Study

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Cover photo: south shore of Wright Patman Lake in Atlanta State Park.  Photo by Stan A. Williams/TxDOT.

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# 1 *Executive Summary*

For five 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. During this period, approximately 100 potential reservoirs have been identified or recommended in the various state water plans, and many more reservoir sites have been considered by state and federal agencies, river authorities, and other groups. Although some of these reservoirs have been constructed, many remain under consideration today. With demands for reliable surface water supplies for municipal, industrial, steam-electric power generation, and other purposes continuing to grow, reservoir projects remain important water management strategies for many areas of the state.

The 2007 State Water Plan recommends that the legislature designate 17 major and two minor reservoir sites identified by regional water planning groups and TWDB for protection as unique reservoir sites. The Texas Water Code §16.051(g) provides that the legislature may designate a site of unique value for the construction of a reservoir. It also stipulates that a state agency or political subdivision of the state "may not obtain a fee title or an easement that will significantly prevent the construction of a reservoir on a site designated by the legislature." Lack of such designation has allowed state, federal, and local governments and private entities to take actions that have significantly affected the feasibility of constructing reservoirs at some sites. A recent example of such an action is the establishment of the Neches River National Wildlife Refuge by the U.S. Fish and 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.

The most certain means of ensuring protection for unique reservoir sites is acquiring 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.

This research project examines the most promising reservoir sites in terms of their feasibility in providing cost-effective ways to satisfy future water supply needs. To determine the most appropriate reservoir sites for state protection and/or acquisition, this study develops and applies technical resources and matrix screening processes. It also includes landcover classification for potential reservoirs because reservoirs must be considered in the context of compensatory ecological resource protection and preservation to mitigate the loss of these valuable resources.

Major tasks accomplished in this research project are listed as follows and summarized in Figure 1-1:

- Research and data compilation for about 150 potential reservoir projects
- Adoption of screening criteria and application of a matrix screening process, resulting in the selection of 16 reservoir sites for technical evaluation
- Application of geographic information system (GIS) techniques for definition and mapping of reservoir sites, including elevation-area-capacity relationships, potential conflicts, and landcover classification
- Assessment of reservoir firm yield available under drought of record conditions subject to senior water rights and provisions for environmental flow needs

- Estimation of costs associated with dams and appurtenant structures, major relocations, and acquisition of reservoir and mitigation lands
- Recommendation of reservoir sites for protection and/or acquisition

Although the primary objective of this study is to select reservoir sites most appropriate for protection, it 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.

The 80th Texas Legislature designated all 19 reservoir sites recommended in the 2007 State Water Plan as sites of unique value (Senate Bill 3, Section 4.01). This report, available in draft form in February 2007, was available for reference during committee deliberations.

## 1.1 RESERVOIR SITE SCREENING PROCESS

In the course of this study, we have 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 acre-feet.) To date, reservoirs have been constructed at approximately 70 of these sites. For the remaining 150 reservoir sites, we have conducted extensive 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 1-2 shows the locations of the reservoir sites considered in the matrix screening process.

TWDB and the consultants developed 11 screening criteria and the relative weightings of these criteria for the reservoir site screening process. These criteria are listed as follows in the order of relative importance based on an assigned

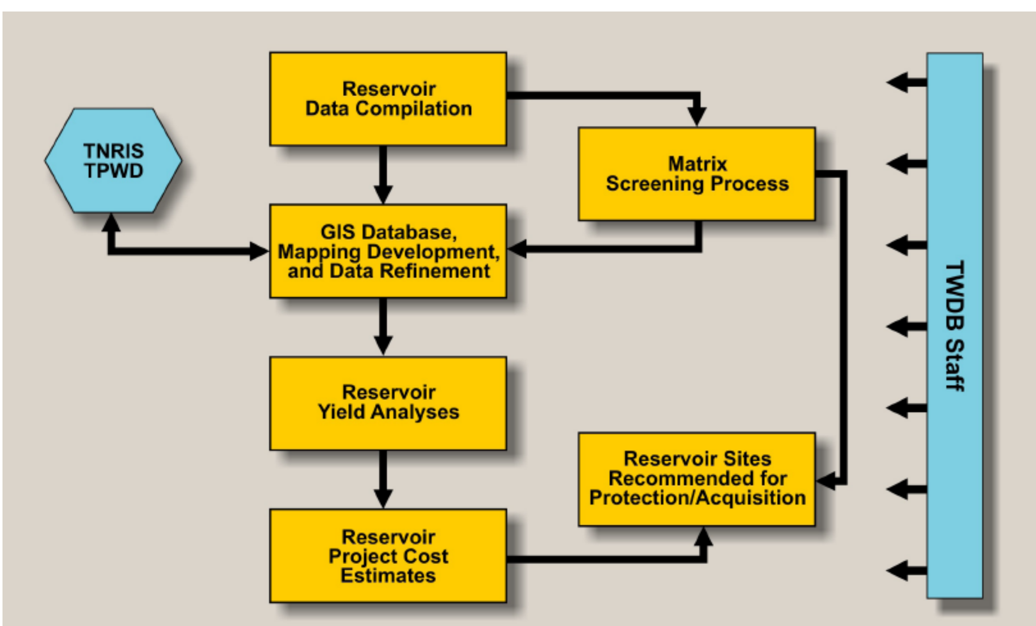


Figure 1-1. Reservoir site protection study tasks.
TNRIS=Texas Natural Resources Information System (a division of the Texas Water Development Board)
TPWD=Texas Parks and Wildlife Department

integer weighting from five (most important) to one (least important):

1. Recommended water management strategy or unique reservoir site in the 2007 State Water Plan (5)
2. Firm yield (5)
3. Unit cost of water (4)
4. Special considerations (3)
5. Ecologically significant stream segment (3)
6. Terrestrial impacts (2)
7. Water supply needs within 50 miles (2)
8. Least distance to a major demand center (2)
9. System operations opportunity (2)
10. Water quality concerns (1)
11. Yield per unit surface area (1)

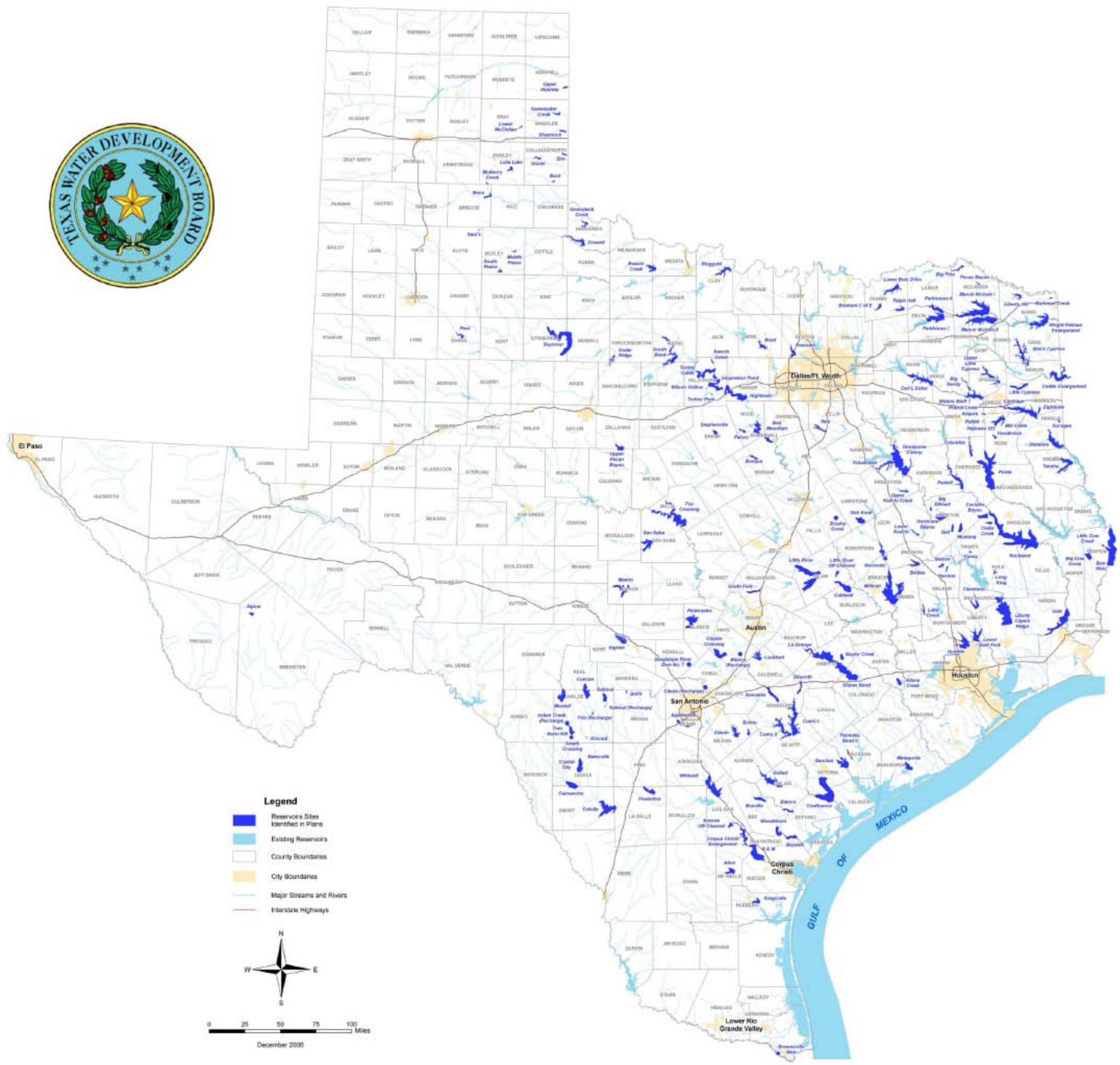


Figure 1-2. Reservoir sites identified in plans.

The 19 top-ranked sites for protection or acquisition are shown in Figure 1-3 and listed in alphabetical order as follows:

- Allens Creek
- Bedias
- Brownsville Weir
- Brushy Creek
- Cedar Ridge (Breckenridge)
- Columbia (Eastex)

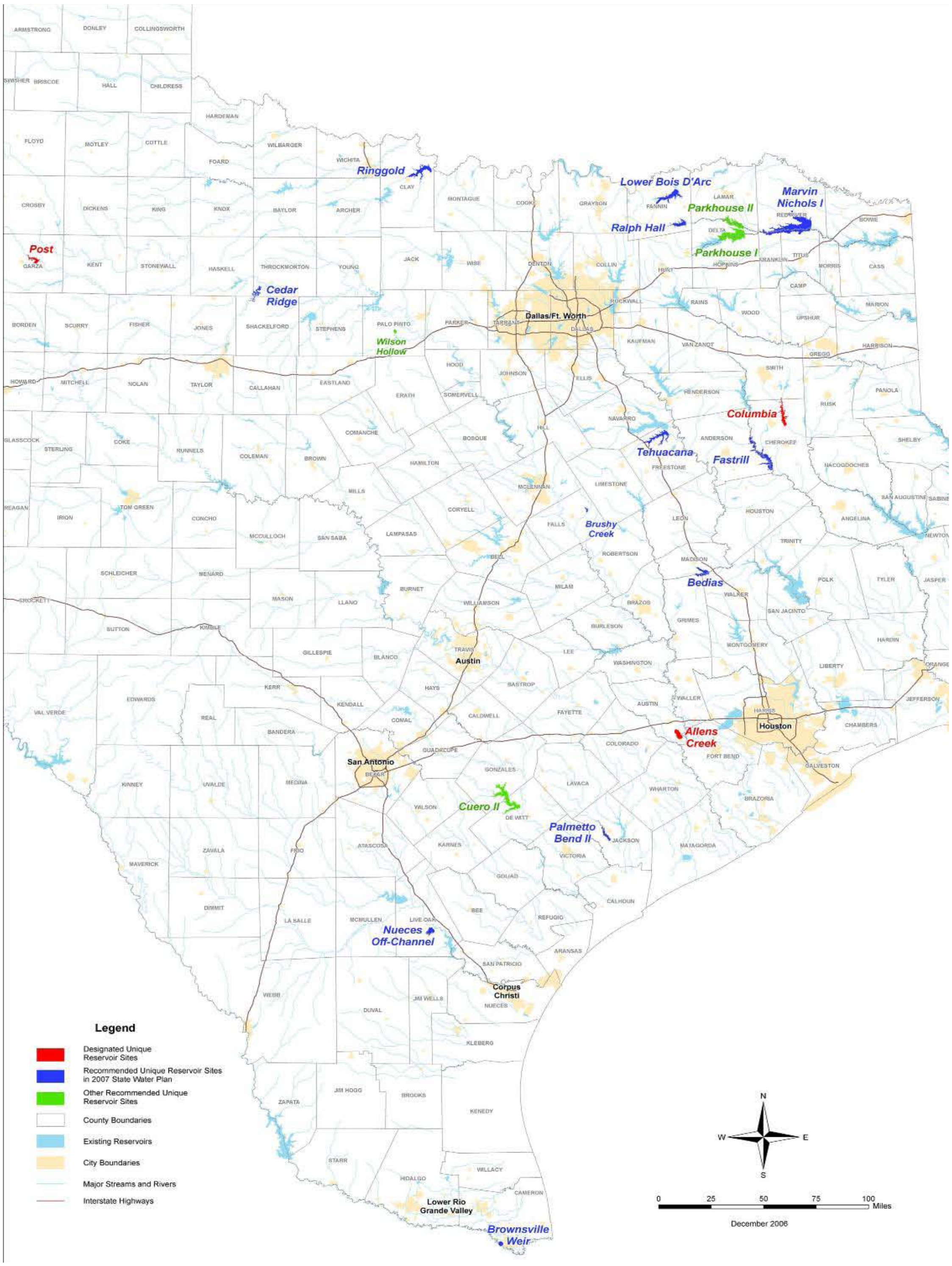


Figure 1-3. Designated and recommended unique reservoir sites.

- 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

In legislative sessions prior to the 80th session, the Texas Legislature designated three reservoir sites (Allens Creek, Columbia, and Post) as unique. Of the top-ranked sites identified by this study, 12 were recommended unique reservoir sites in the 2007 State Water Plan. 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.

Table 1-1 shows the reservoirs recom-

Table 1-1. Recommended reservoir sites.

| Reservoir Sites | Unique Reservoir Site 2007 SWP/ 80th Texas Legislature | 2007 SWP Recommended Water Management Strategies | 2007 Reservoir Site Protection Study—Recommended Reservoirs | Reservoirs Previously Designated by the Texas Legislature[a] |
|---|---|---|---|---|
| Bedias | X | | X | |
| Brownsville Weir | X | X | X | |
| Brushy Creek | X | X | X | |
| Cedar Ridge | X | X | X | |
| Cuero II | | | X | |
| Fastrill | X | X | X | |
| Goldthwaite[b] | X | X | | |
| Lake 07 | X | X | | |
| Lake 08 | X | X | | |
| Little River | X | | | |
| Little River Off-Channel | X | X | | |
| Lower Bois d'Arc | X | X | X | |
| Marvin Nichols IA | X | X | X | |
| Muenster | X | | | |
| Nueces Off-Channel | X | X | X | |
| Palmetto Bend[c] | X | X | X | |
| Parkhouse I | | | X | |
| Parkhouse II | | | X | |
| Ralph Hall | X | X | X | |
| Ringgold | X | | X | |
| Tehuacana | X | | X | |
| Wheeler Branch[b] | X | X | | |
| Wilson Hollow | | | X | |
| Columbia | | X | | X |
| Allens Creek | | X | | X |
| Post | | | | X |
| **Total** | **19** | **16** | **16** | **3** |

[a]Since these reservoirs were already designated, they were not considered for this study.
[b]These are minor reservoirs and were not considered for this study.
[c]Also known as Texana Stage II.
SWP=State Water Plan

Table 1-2. Comparison of reservoir sites recommended for protection.

| Reservoir Site | River Basin | Region | Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP[a]) | Firm Yield (acft/yr[b]) | 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 | 41,437 | $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 | Inundating (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 |

[a]SWP=State Water Plan
[b]acft/yr=acre-feet per year

mended by the 2007 State Water Plan, reservoirs recommended for designation by this research, and reservoir sites previously designated by the legislature.

## 1.2 RESERVOIR SITES RECOMMENDED FOR PROTECTION

Technical evaluations, including project description, firm yield computation, cost estimation, and assessment of environmental considerations, 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 1-2. Observations and comparisons of these 16 reservoir sites are presented in the following paragraphs in the order of relative importance for the screening process.

### *1.2.1 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 (also known as Sandies Creek and Lindenau), Parkhouse I, and 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 Regional Water Plan. The Cuero II reservoir site is not explicitly mentioned in the 2006 Region L Regional Water Plan, though it might be considered additional storage, which is referenced in that plan as a water management strategy in need of further study and funding prior to implementation.

### *1.2.2 Firm Yield*

The largest firm yield or dependable supply during a drought of record (602,000 acre-feet per year) can be provided by the Marvin Nichols IA Reservoir site. However, depending upon the ultimate development of other sites recommended for protection in the Sulphur River Basin (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 acre-feet per year (Appendix A). The Brushy Creek Reservoir site provides the least firm yield (1,380 acre-feet per year) among the sites recommended for protection; however, it is the recommended water supply strategy for the City of Marlin.

### *1.2.3 Unit Cost of Water*

The Marvin Nichols IA site provides firm raw water supply 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 will 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.

### *1.2.4 Special Considerations*

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

*1.2.5*

***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 and Wildlife Department. The Brownsville Weir, Fastrill, and Lower Bois d'Arc Creek sites will affect recommended segments by inundation, and 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.

*1.2.6*

***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 and Wildlife Service. The Fastrill, Lower Bois d'Arc Creek, and Marvin Nichols IA sites will affect such bottomland hardwood preservation sites by inundation, and the Bedias and Tehuacana sites will be located immediately upstream of potential preservation sites. Although the Parkhouse I and II sites will be located some distance upstream of a prioritized bottomland hardwood preservation site, detailed hydrological and biological studies will likely be required to assess potential reservoir impacts. Developing the 16 reservoir sites recommended in this study will significantly affect only two of 14 Priority 1 bottomland hardwood preservation sites in Texas. Since the U.S. Fish and Wildlife Service published the prioritized bottomland hardwood preservation sites in 1985, no major reservoirs have been constructed that consequentially affect any of the Priority 1 sites.

*1.2.7*

***Water Supply Needs Within 50 Miles***

The counties within (or partially within) 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 by 2060. The Cedar Ridge and Palmetto Bend II sites have the least projected needs for potential users geographically near the reservoir sites.

*1.2.8*

***Least Distance to a 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, and the Cedar Ridge, Fastrill, and Marvin Nichols IA sites are the most distant.

*1.2.9*

***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.

*1.2.10*

***Water Quality Concerns***

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

*1.2.11*

***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.

## 1.3
## RESERVOIR SITE ACQUISITION

Table 1-3 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. The City of Marlin has purchased land for Brushy Creek Reservoir, 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. Acquiring the remaining 14 sites up to the conservation storage level will entail purchasing about 244,000 acres at an estimated capital cost of about $428 million for land only. This capital cost equates to an annual cost of about $28.4 million, assuming a 40-year debt service period and an annual interest rate of 6 percent.

Additional acreage for project facilities and land 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 16 reservoir sites recommended for protection and/or acquisition. Additional costs for title research, negotiations, land surveying, and legal proceedings are not included.

As an important part of this reservoir site study, the Texas Parks and Wildlife Department performed landcover classifications for each of the 16 reservoir sites

Table 1-3. Reservoir site acquisition costs.

| Reservoir | Conservation Pool Elevation (ft-msl)[a] | Conservation Pool Area (acres) | Land Unit Cost[b] ($/ac)[c] | Conservation Pool Land Cost[c] ($) |
|---|---|---|---|---|
| Bedias | 210 | 10,000 | $3,288 | $32,880,000 |
| Brownsville Weir | 26 | 600 / 0[d] | $0[d] | $0[d] |
| Brushy Creek | 380.5 | 697 / 0[e] | $0[e] | $0[e] |
| 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[f] | 315 | 10,000 | $1,825 | $18,250,000 |
| Post[f] | 2,420 | 2,283 | $566 | $1,292,278 |
| Allens Creek[f] | 121 | 7,003 | $0[g] | $0[g] |
| **Grand Total** | | **263,452** | | **$447,173,657** |

[a]ft-msl=feet above mean sea level
[b]Land costs in 2005 dollars.
[c]$/ac=dollars per acre
[d]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.
[e]All of the land to be inundated by Brushy Creek Reservoir has been purchased by the City of Marlin.
[f]The Texas Legislature has designated this site as being of unique value for the construction of a reservoir.
[g]All of the land to be inundated by Allens Creek Reservoir has been jointly purchased by TWDB, the City of Houston, and the Brazos River Authority.

selected for technical evaluation (Figure 1-4). 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.

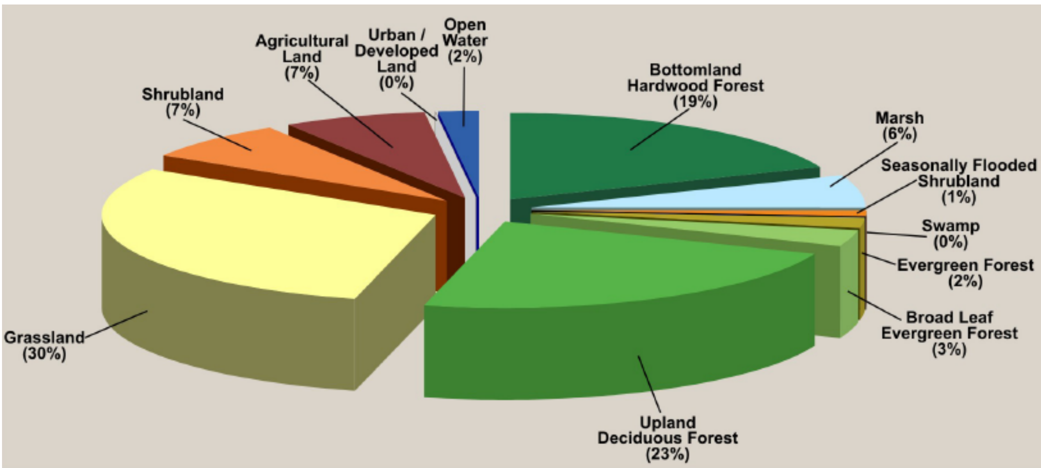

Figure 1-4. Landcover classification for 16 reservoir sites (up to conservation storage levels).

# 2 *Introduction*

For five 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. During this period, approximately 100 potential reservoirs have been identified or recommended in the various state water plans, and many more reservoir sites have been considered by state or federal agencies, river authorities, and other groups. Although some of these reservoirs have been constructed, many remain under consideration. With demands for reliable surface water supplies for municipal, industrial, steam-electric power generation, and other purposes continuing to grow, reservoir projects remain an important water management strategy for many areas of the state.

The 2007 State Water Plan recommends that the legislature designate 17 major reservoir sites identified by regional water planning groups and TWDB for protection as unique reservoir sites. The Texas Water Code §16.051(g) provides that the legislature may designate a site of unique value for the construction of a reservoir. It also stipulates that a state agency or political subdivision of the state "may not obtain a fee title or an easement that will significantly prevent the construction of a reservoir on a site designated by the legislature." Lack of such designation has allowed state, federal, and local governments and private entities to take actions that have significantly affected the feasibility of constructing reservoirs at some sites. A recent example of such an action is the designation of the Neches River National Wildlife Refuge by the U.S. Fish and 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.[1]

The most certain means of ensuring protection for unique reservoir sites is acquiring 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. This research project examines the most promising reservoir sites in terms of their feasibility in providing cost-effective water to satisfy future water supply needs. It develops and applies technical resources and matrix screening processes necessary to provide recommendations as to the most appropriate reservoir sites for state protection and/or acquisition. It also includes landcover classification because reservoirs must be considered in the context of compensatory ecological resource protection and preservation to mitigate the loss of these valuable resources.

## 2.1 AUTHORIZATION AND OBJECTIVES

The reservoir site protection study summarized in this report was authorized by TWDB through Contract No. 0604830615 effective April 17, 2006. The primary objective of the study is to select 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 for accomplishing this objective, along with the section of this report in which pertinent information can be found, are listed as follows and summarized in Figure 2-1:

1 Although several reservoirs in this report are water management strategies for the greater Dallas-Ft. Worth metropolitan area, only one reservoir is planned by the City of Dallas.

- Research and data compilation for about 150 potential reservoir projects (chapter 3)
- Adoption of screening criteria and application of a matrix screening process resulting in the selection of 16 reservoir sites for technical evaluation (chapter 3)
- Application of GIS techniques for definition and mapping of reservoir sites, including potential conflicts, elevation-area-capacity relationships, and landcover classification (chapter 5)
- Assessment of reservoir firm yield available under drought of record conditions subject to senior water rights and provisions for environmental flow needs (chapter 5)
- Estimation of costs associated with dams and appurtenant structures, major relocations, and acquisition of reservoir and mitigation lands (chapter 5)
- Recommendation of reservoir sites for protection and/or acquisition (chapter 6)

Although the primary objective of this study is to select the reservoir sites most appropriate for protection, it 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.

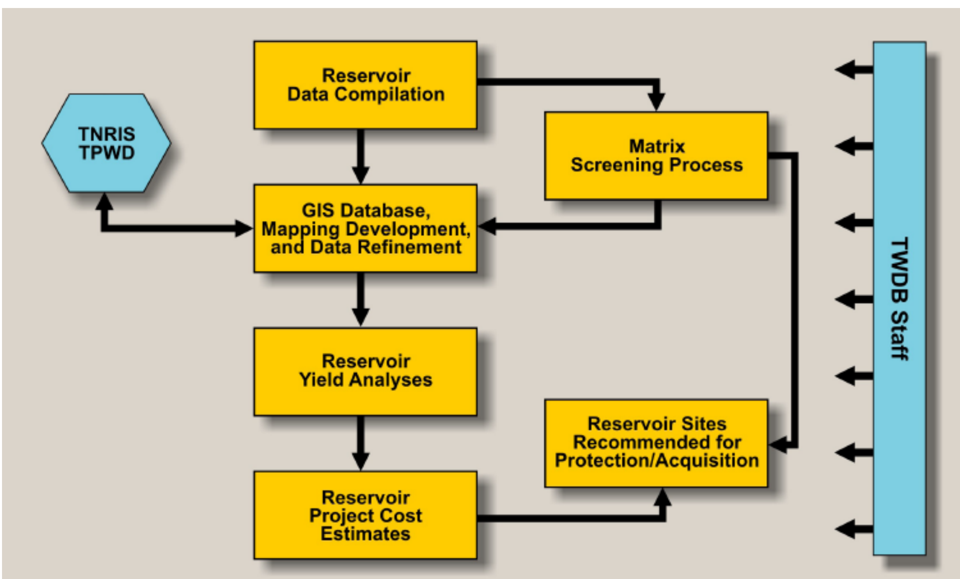


Figure 2-1. Reservoir site protection study tasks.
TNRIS=Texas Natural Resources Information System (a division of TWDB); TPWD=Texas Parks and Wildlife Department

# 3 *Reservoir Site Screening Process*

In the course of this study, we have 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. (For the purposes of this study, a major reservoir is defined to be one having a conservation storage capacity of at least 5,000 acre-feet.) To date, reservoirs have been constructed at approximately 70 of these sites. For the remaining 150 reservoir sites, we 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. A tabular summary of these reservoir sites is found in Appendix D. In addition, shape files for use in GIS applications have been compiled or created for the 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 3.2.

## 3.1 Matrix Screening Process

In cooperation with TWDB, we 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

- identifying potential screening criteria;
- selecting and refining screening criteria in cooperation with TWDB;
- assigning appropriate relative importance, or weighting, to each selected screening criterion in cooperation with TWDB;
- developing and testing a matrix screening tool;
- compiling supplemental data necessary to populate a matrix of reservoir sites and screening criteria;
- applying 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
- selecting 16 reservoir sites for technical evaluation (TWDB selected the sites).

Information and activities relevant to each of the steps in the matrix screening process are described in sections 3.2 through 3.4.

## 3.2
## Screening Criteria

Potential screening criteria to be used in this study were first considered at an initial meeting on May 1, 2006, during which TWDB articulated goals for the study and critical issues to be considered in meeting these goals. With this guidance from TWDB, the consultants developed a preliminary list of potential screening criteria and met again with TWDB to discuss the criteria on May 17, 2006. These discussions provided supplemental guidance, resulting in significantly refining the preliminary list prior to developing the matrix screening tool. On August 14, 2006, the consultants met with TWDB 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. Integrating limited refinements suggested by TWDB 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.

### *3.2.1 Criteria Discussion and Relative Weighting of Criteria*

TWDB and the consultants developed 11 screening criteria and the relative weightings of these criteria 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.

**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 a unique reservoir site has been subject to public comment and due consideration by one or more regional water planning groups representing diverse interests.

**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 capable of meeting many needs may provide an economy of scale and concentration of impacts deemed beneficial from a statewide 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.

**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. A lower unit cost indicates that a more dependable water supply is developed per dollar expended and is scored more favorably. Before calculating unit cost and using it in the matrix screening process, we updated to current dollars the project cost estimates from older plans.

**Special considerations (3)**

The Allens Creek, Columbia, and Post reservoir sites were designated as unique by the Texas Legislature pursuant to Senate Bill 1593 (76th Legislature), Senate Bill 1362 (78th Legislature), and House Bill 3096 (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 or one of its predecessor regulatory agencies. This criterion recognizes the more advanced regulatory status of these six reservoir sites as compared to others.

**Ecologically significant stream segment (3)**

The Texas Parks and Wildlife Department has identified a number of stream segments throughout the state as ecologically significant on the basis of biological and hydrologic function, riparian conservation, exceptional aquatic life uses, and/or threatened or endangered species (Figure 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. This criterion accounts for differences between inundation of and indirect impacts to stream segments.

### Terrestrial impacts (2)

The U.S. Fish and Wildlife Service issued a report (USFWS, 1985) on the Texas Bottomland Hardwood Preservation

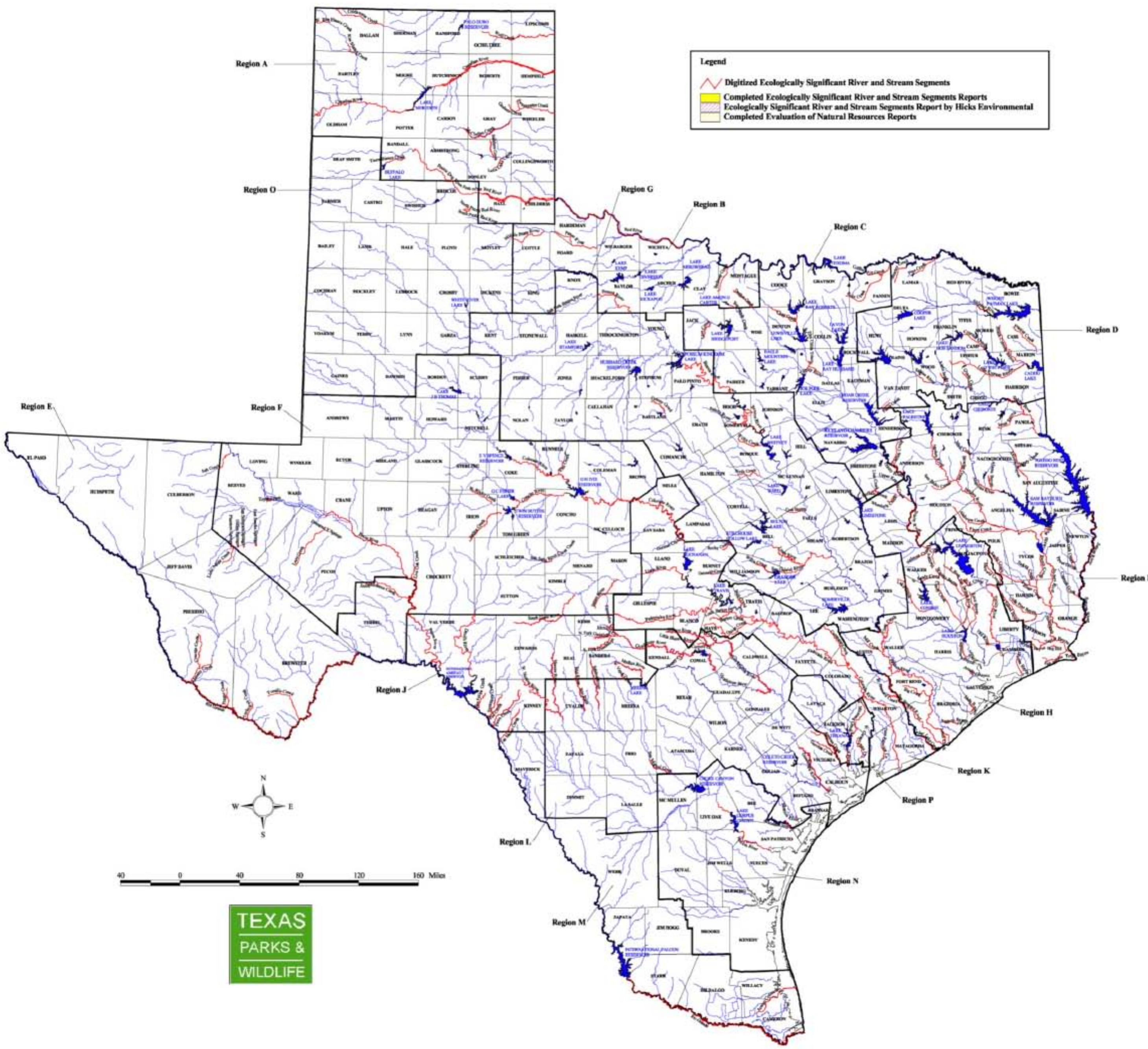


Figure 3-1. Ecologically significant river and stream segments as defined by the Texas Parks and Wildlife Department.

Program in which numerous potential preservation sites, located primarily in East Texas, were identified and prioritized for protection (Figure 3-2). The Terrestrial Impacts criterion scores more favorably reservoir sites that do

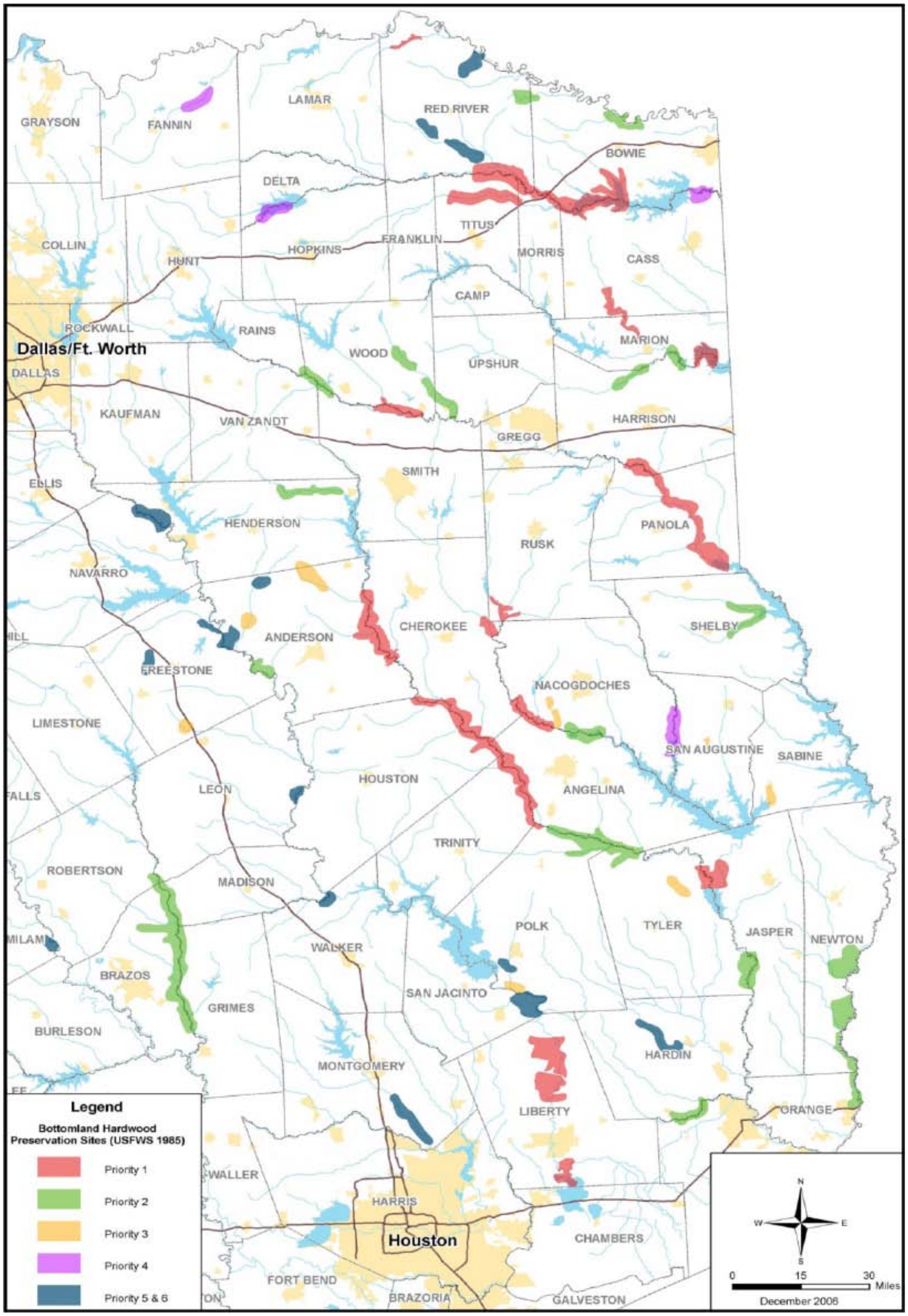


Figure 3-2. Bottomland hardwood preservation sites as recommended by the U.S. Fish and Wildlife Service.

not conflict with these prioritized bottomland hardwood preservation sites. This criterion accounts for differences between reservoir sites inundating or being located immediately upstream or some distance upstream of bottomland hardwood preservation sites. Preserving site habitat quality as reflected in the priority assigned by the U.S. Fish and Wildlife Service was part of this criterion.

**Water supply needs within 50 miles (2)**

Reservoir sites that are geographically near areas having long-term water supply needs may have advantages of lower costs for transmission facilities and fewer concerns with interbasin transfers 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 in 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.

**Least distance to a major demand center (2)**

Similar to the previous criterion, this criterion scores reservoir sites more favorably the closer they are located to one or more of the largest current population centers in Texas (Figure 3-3).

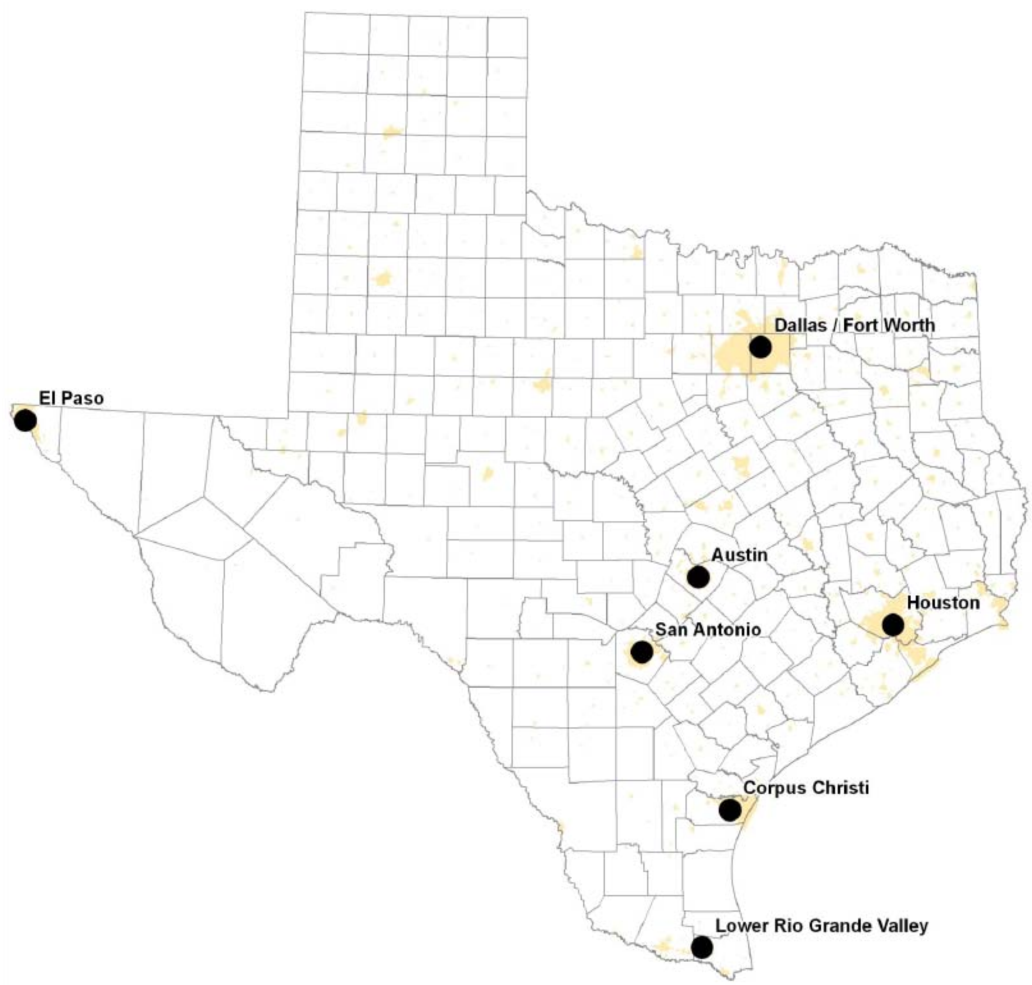


Figure 3-3. Major water demand centers.

**System operations opportunity (2)**

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

**Water quality concerns (1)**

This criterion gives preference to reservoir sites for which there are no known inflow constituents likely to significantly increase difficulty and cost of treatment to drinking water standards.

**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. Reservoir sites for which available inflow is efficiently stored and evaporation losses are minimized, thereby maximizing firm yield, are scored more favorably.

## 3.3 MATRIX SCREENING TOOL DESCRIPTION

We constructed a matrix screening tool in Microsoft Excel to provide organized storage of compiled information regarding numerous reservoir sites. We also used the matrix to create a table preferentially ranking the reservoir sites based on criteria and assigned weights discussed in the preceding section. The scoring system used within the matrix screening tool is briefly summarized in the following paragraphs.

Four of the criteria (Recommended Water Management Strategy or Unique Reservoir Site in the 2007 State Water Plan, Special Considerations, System Operations Opportunity, and Water Quality Concerns) were based on a simple yes or no entry and received a base score of 5 or 1, respectively. This base score was 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) were derived from numerical data specific to each reservoir site. Comprehensive data are not available for all reservoir sites, so we integrated techniques in the matrix screening tool to minimize potential biases resulting from missing data. The application of each of these five criteria was 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 was then multiplied by the assigned weight and added to the composite score for each reservoir site.

The Ecologically Significant Stream Segment criterion was 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 Texas Parks and Wildlife Department. We then assigned a secondary weighting factor according to whether the reservoir will 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 was 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 could range from 5 (most favorable, no impacts) to 0 (least favorable, inundation impacts in all five categories). The base score was then multiplied by the assigned weight and added to the composite score for each reservoir site.

The Terrestrial Impacts criterion was 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 the U.S. Fish and Wildlife Service. The initial score ranged 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 we assigned a secondary weighting factor according to whether the reservoir will 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 was calculated by multiplying the initial score by the secondary weighting factor and dividing by 2. Therefore, base scores for this criterion could range from 5 (most favorable, no impacts) to 0.5 (least favorable, inundation of Priority 1 preservation site). The base score was then multiplied by the assigned weight and added to the composite score for each reservoir site.

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

## 3.4 RESULTS OF MATRIX SCREENING PROCESS

During a September 21, 2006, meeting, the consultants demonstrated the application of the populated matrix screening tool to TWDB and presented a ranking of reservoir sites based on criteria and weightings previously adopted. The 19 top-ranked sites for protection or acquisition are shown in Figure 3-4 and Exhibit 2 in the Appendix 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. Three reservoir sites were designated as unique by the Texas Legislature prior to this study. Detailed information regarding the 16 remaining potential reservoir sites is presented in chapters 4 and 5.

Table 3-1 shows the reservoirs recommended by the 2007 State Water Plan, reservoirs recommended for designation by this research, and reservoir sites designated by the legislature. Senate Bill 3 from the 80th Legislative Session passed after the delivery of this draft final report.

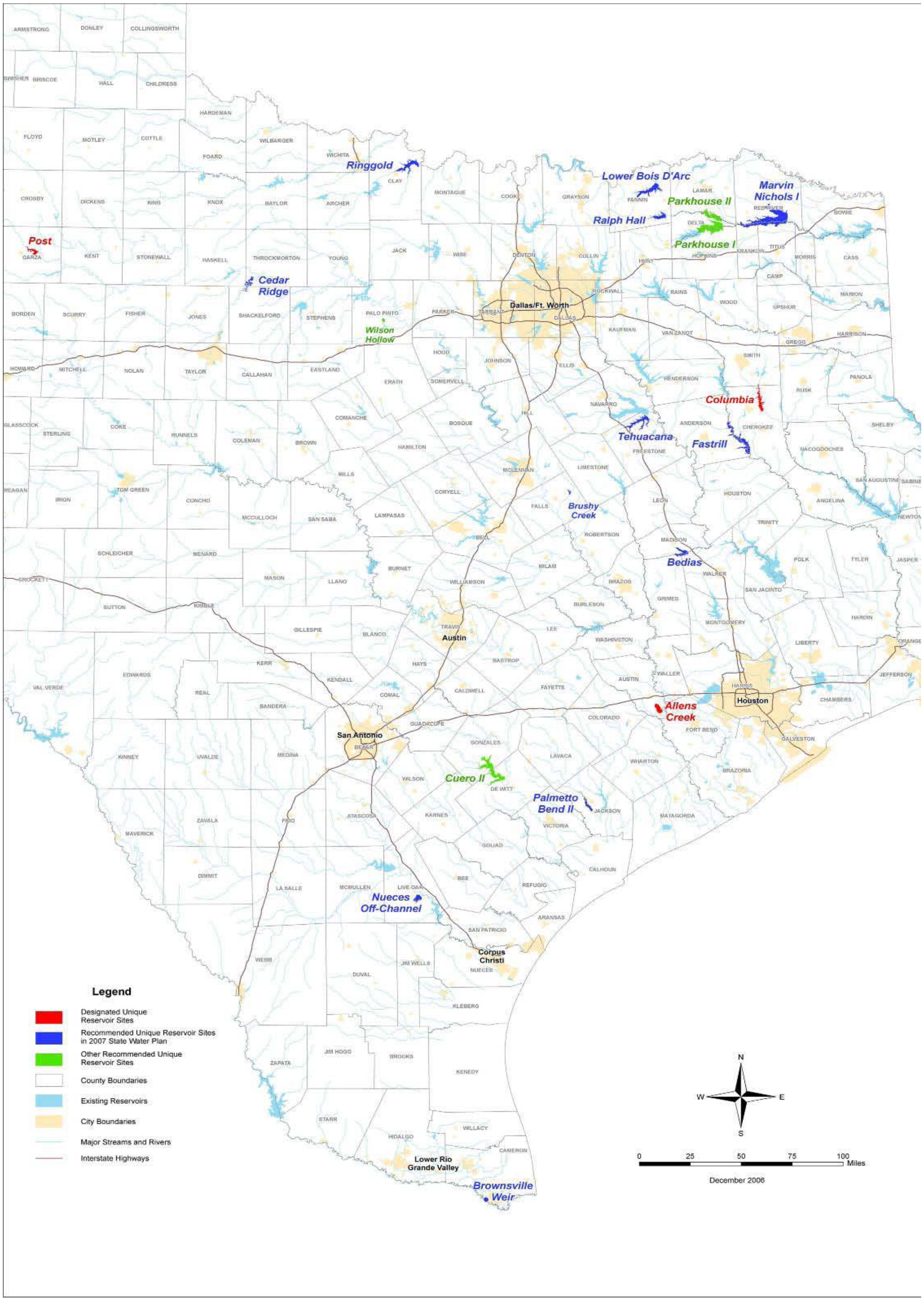


Figure 3-4. Designated and recommended unique reservoir sites.

Table 3-1. Recommended reservoir sites.

| Reservoir Sites | Unique Reservoir Site 2007 SWP/80th Texas Legislature | 2007 SWP Recommended Water Management Strategies | 2007 Reservoir Site Protection Study—Recommended Reservoirs | Reservoirs Previously Designated by the Texas Legislature[a] |
|---|---|---|---|---|
| Bedias | X | | X | |
| Brownsville Weir | X | X | X | |
| Brushy Creek | X | X | X | |
| Cedar Ridge | X | X | X | |
| Cuero II | | | X | |
| Fastrill | X | X | X | |
| Goldthwaite[b] | X | X | | |
| Lake 07 | X | X | | |
| Lake 08 | X | X | | |
| Little River | X | | | |
| Little River Off-Channel | X | X | | |
| Lower Bois d'Arc | X | X | X | |
| Marvin Nichols IA | X | X | X | |
| Muenster | X | | | |
| Nueces Off-Channel | X | X | X | |
| Palmetto Bend[c] | X | X | X | |
| Parkhouse I | | | X | |
| Parkhouse II | | | X | |
| Ralph Hall | X | X | X | |
| Ringgold | X | | X | |
| Tehuacana | X | | X | |
| Wheeler Branch[b] | X | X | | |
| Wilson Hollow | | | X | |
| Columbia | | X | | X |
| Allens Creek | | X | | X |
| Post | | | | X |
| **Total** | **19** | **16** | **16** | **3** |

[a]Since these reservoirs were already designated, they were not considered for this study.
[b]These are minor reservoirs and were not considered for this study.
[c]Also known as Texana Stage II.
SWP=State Water Plan

# 4 *Water Supply Modeling and Cost Estimates for Recommended Sites*

Applying the matrix screening process to approximately 150 potential reservoir sites resulted in identifying 19 sites that appear most suitable for protection or acquisition by the State of Texas to ensure availability for future water supplies. Three of these sites have already been designated by the Texas Legislature as being of unique value for the construction of a dam and reservoir. These three 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 these three sites have already received some degree of protection from the state, detailed study has been focused upon developing and compiling technical information about the other 16 reservoir sites that emerged from the matrix screening process. Such information is summarized by reservoir site in chapter 5. General assumptions regarding water supply modeling and cost estimates are presented in sections 4.1 and 4.2, respectively.

## 4.1 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 chapter 5.

- The latest applicable water availability model from the Texas Commission on Environmental Quality is used to simulate the operation of each reservoir (TCEQ, 2006). The water availability models were developed under the guidance of and are maintained by the Texas Commission on Environmental Quality. Each water availability model is easily modified by consultants to simulate the impact of a reservoir or other water management strategy on the water resources of the basin. The water availability model run used, known as Run 3, assumes that diversions are at their fully authorized amount and there are no return flows. It also excludes temporary water rights and uses original reservoir storage-surface area relation curves. Any necessary modifications of water availability model basic data (for example, naturalized flows and net evaporation) or uses of alternative modeling tools (for example, Corpus Christi Water Supply Model) are described in each reservoir section.
- Unless already permitted, each potential reservoir is modeled at the most junior priority date in the applicable water availability model, 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.
- Firm yields are calculated for a minimum of four reservoir conservation storage capacities, including those 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.

- Environmental flow requirements are modeled using the Consensus Criteria for Environmental Flow Needs except for those reservoirs already permitted or that have applications pending at the Texas Commission on Environmental Quality. The Consensus Criteria for Environmental Flow Needs approach uses percentages of reservoir capacity as triggers for determining the pass-through flow requirements for three stages. A reservoir must pass the median flow when storage is greater than 80 percent of the conservation storage capacity, the 25th-percentile flow when storage is greater than 50 percent of the conservation storage capacity, and the 7Q2 flow when storage is less than 50 percent of conservation storage capacity. (The 7Q2 flow is the annual lowest mean discharge for seven consecutive days with a two-year recurrence interval.) 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. We have evaluated firm yield with and without environmental flow passage requirements for the recommended conservation storage capacity only. We did this to assess the potential yield commitment to environmental flow needs.
- For off-channel reservoirs that depend on 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.

## 4.2 ASSUMPTIONS FOR COST ESTIMATES

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

- **General cost considerations**—Costs are estimated for each reservoir at its recommended conservation capacity and reported in 2005 dollars.
- **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, a division of TWDB, provided technical support with identifying potential relocations and facility conflicts, including roadways, railroads, active oil and gas wells, product transmission pipelines, power transmission lines, and state lands.
- **Other project costs**—Contingency, 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 Web site for the land market area in which the reservoir site is located (TAMU, 2005). 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.
- **Annual costs**—Debt service is calculated using a 6 percent annual interest rate over a 40-year amortization period. Annual operations and maintenance of dams and spillways

are 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/kilowatt per hour, which is consistent with Senate Bill 1 cost estimate requirements. Recent data, however, indicates that current energy costs can be higher.

- **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.

# 5 *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 Resources Information System, Texas Parks and Wildlife Department, and the Texas Water Development Board.

The Texas Natural Resources Information System, which is a division of TWDB, researched and assembled extensive geodatabases in order to map and tabulate conflicts with existing facility locations within or near each reservoir site. Such conflicts are mapped in the following subsections 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 Texas Parks and Wildlife Department 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, they 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 subsections. Summary landcover information for all 16 reservoir sites is included in chapter 6. Because landcover for each reservoir site is estimated based on approximate GIS coverages, they do not necessarily exactly match the area estimated from the elevation-area-capacity relationships.

For this study, TWDB prepared a memorandum summarizing the potential effects to archeological and cultural sites, which include historic properties, cemeteries, sawmills, and military sites (Appendix B). Resolving conflicts regarding these cultural resources within reservoir sites can be quite significant with respect to time and costs associated with excavations and recovery. In addition, 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 the reservoir sites, TWDB 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, Parkhouse I, Parkhouse II, and Ralph Hall.

## 5.1 BEDIAS RESERVOIR

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. The proposed reservoir will be located in Madison, Grimes, and Walker counties about 3.5 miles west of the U.S. Highway 75 crossing of Bedias Creek (Figure 5-1). Conveyance facilities will allow a portion of the created supply to be diverted into the West Fork of the San Jacinto River for use by the San Jacinto River Authority. The reservoir will help meet the demands of Montgomery County, which will exceed available groundwater and Lake Conroe supplies beginning in 2020. The projected needs within 50 miles of the proposed reservoir site by 2060 are 284,552 acre-feet per year. The nearest major demand center is the greater Houston area, located approximately 85 miles southeast of the project site.

Bedias Reservoir was previously studied by the U.S. Bureau of Reclamation 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 Regional Water Plan as well as the 2002 State Water Plan. In the 2006 Region H Regional 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 (TRA, 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 feet, the reservoir will have a conservation capacity of 192,700 acre-feet and will inundate 10,000 acres.

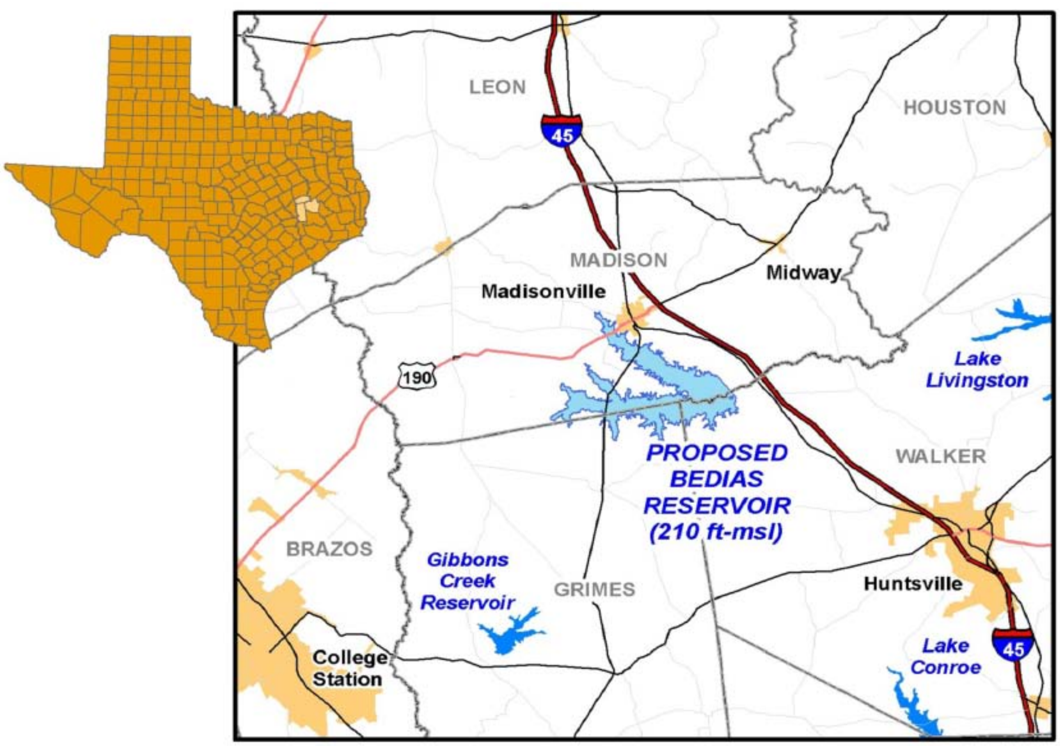


Figure 5-1. Location map of Bedias Reservoir.
ft-msl=feet above mean sea level

### 5.1.1
### *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 whether this reservoir was actually modeled as part of the planning process even though a recommended conservation pool level of 230 feet is stated in the Region H plan. Therefore, for purposes of this reservoir siting investigation, we have used the Burns and McDonnell (1989) study. Of the four potential reservoir sites investigated by that study, the Bedias 10-mile site, with a conservation pool level of 210 feet and a maximum storage capacity of 192,700 acre-feet, was recommended as the most feasible reservoir location. This site is approximately 10 miles upstream of Farm to Market road 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 and Run 3 assumptions. The water availability model simulations were performed using the Water Rights Analysis Package program. 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 water availability model. The naturalized flows and adjusted net evaporation for this primary control point were used in this study of the yield analysis of Bedias Reservoir.

Table 5-1. Elevation-area-capacity relationship for Bedias Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 160 | 0 | 0 |
| 180 | 3,750 | 52,500 |
| 200 | 7,600 | 105,500 |
| 210 | 10,000 | 192,700 |
| 220 | 18,200 | 337,000 |
| 230 | 23,000 | 541,400 |
| 235 | 26,800 | 665,700 |
| 240 | 30,500 | 808,100 |

[a]ft-msl=feet above mean sea level
[b]acft=acre feet

The Bedias Reservoir elevation-area-capacity relationship is presented in Table 5-1 and shown in Figure 5-2. The data in the table were developed in the previous U.S. Bureau of Reclamation's water supply plan, which used U.S. Geological Survey topographic maps. Figure 5-3 shows the reservoir inundation at 10-foot contours.

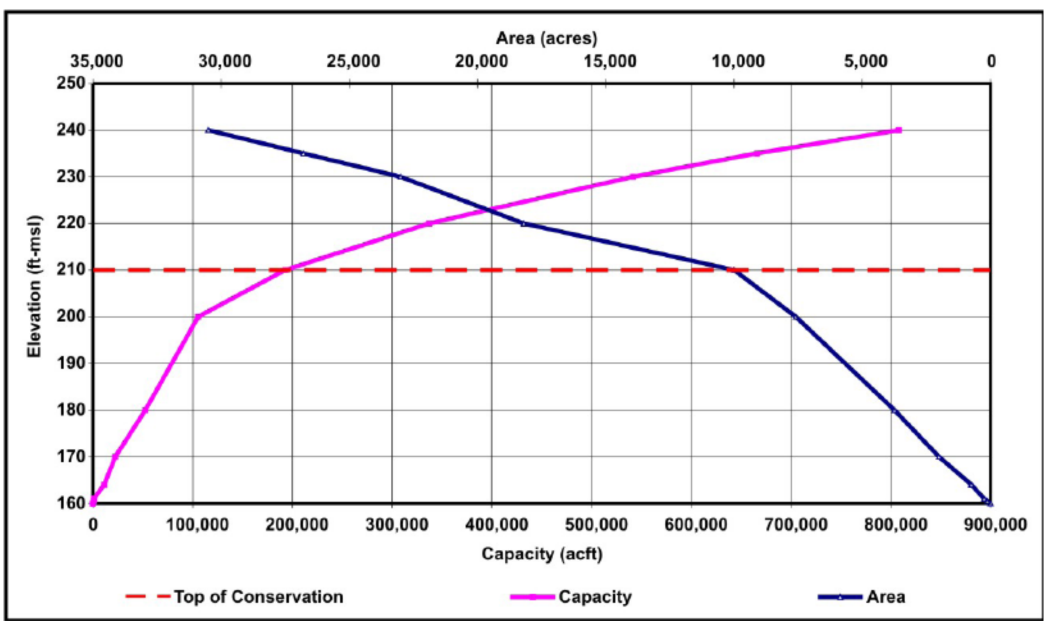


Figure 5-2. Elevation-area-capacity relationship for Bedias Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

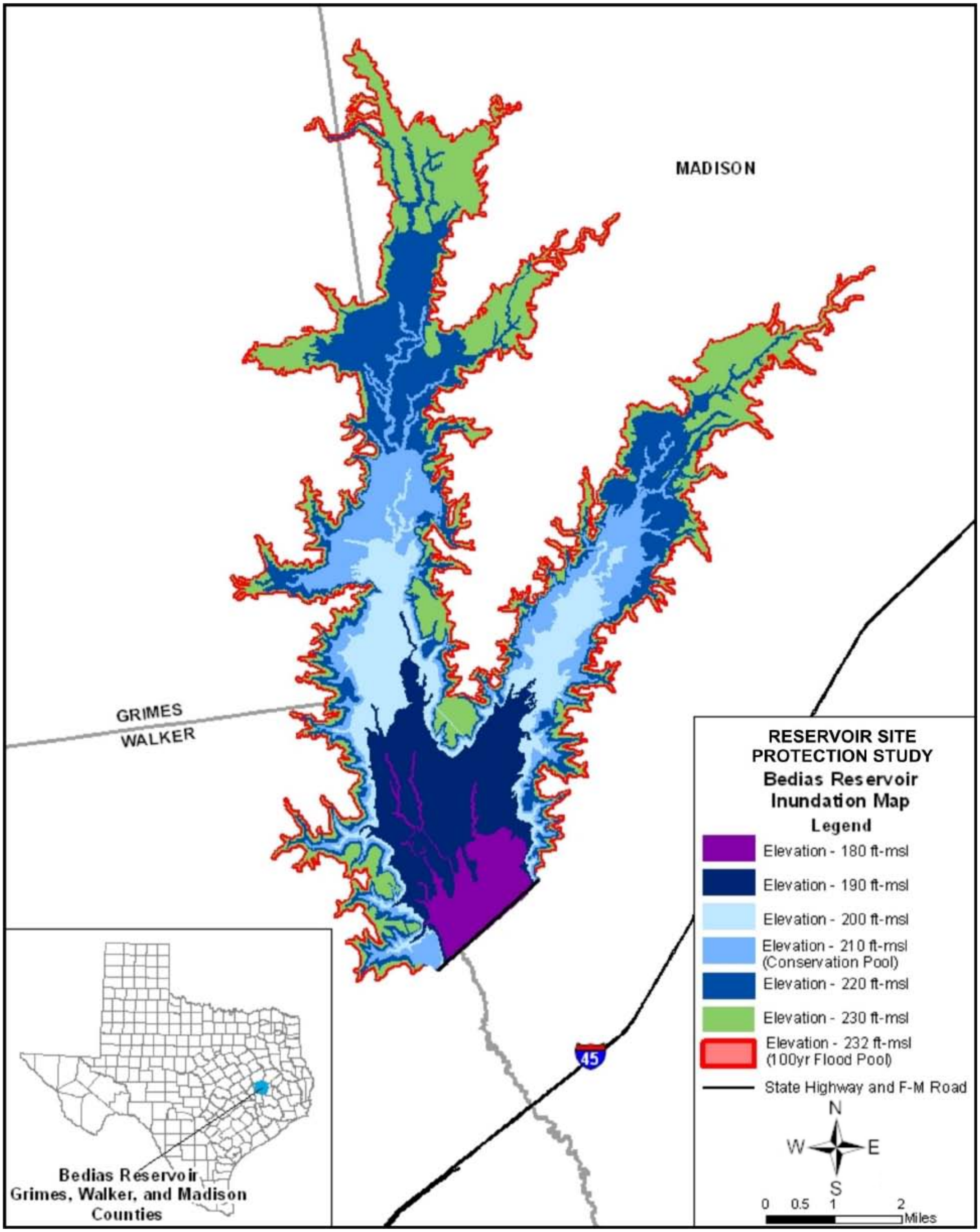


Figure 5-3. Inundation map for Bedias Reservoir.
ft-msl=feet above mean sea level

For purposes of this yield study, we assumed that Bedias Reservoir will be subject to environmental flow requirements based on the Consensus Criteria for Environmental Flow Needs. These minimum requirements are summarized in Table 5-2. The reservoir has to pass the lesser of the inflow and the values in the table, depending on storage in the reservoir. For example it must pass the median flow when storage is greater than 80 percent of the conservation storage capacity, the 25-percentile flow when storage is greater than 50 percent of the conservation storage capacity, and the 7Q2 flow when storage is less than 50 percent of the conservation storage capacity.

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

The water availability simulations were made to determine firm yield using conservation pool elevations of 200, 210, 220, 230, and 240 feet, assuming standalone reservoir operations and no minimum reserve content. Results of these simulations are summarized in Table 5-3 and Figure 5-4. At the conservation pool level of 210 feet, or 192,700 acre-feet of conservation storage capacity, the firm yield is 75,430 acre-feet per year. Meeting the Consensus Criteria for Environmental Flow Needs reduces the firm yield of the reservoir by 150 acre-feet per year. The firm annual yield determined in the Bedias Project Investigation (Burns and McDonnell, 1989) was 78,500 acre-feet per year for the same conservation pool level. At the conservation pool elevation of 210 feet, the reservoir will be full about 19 percent of the time and will be

Table 5-2. Consensus Criteria for Environmental Flow Needs for Bedias Reservoir.

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

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-3. Firm yield versus conservation storage for Bedias Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 200 | 105,500 | CCEFN[d] | 57,220 | 6/50–1/58 |
| 210* | 192,700 | CCEFN | 75,430 | 6/50–1/58 |
| | | None | 75,580 | 6/50–1/58 |
| 220 | 337,000 | CCEFN | 91,100 | 6/50–1/58 |
| 230 | 541,400 | CCEFN | 108,400 | 6/50–1/58 |
| 240 | 808,100 | CCEFN | 115,900 | 6/50–1/58 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

below 50 percent of the conservation storage capacity about 18 percent of the months simulated from January 1940 to December 1996. Figure 5-5 presents the storage trace and corresponding storage frequency curve for Bedias Reservoir as simulated with the water availability model assuming a conservation storage capacity of 192,700 acre-feet (elevation 210 feet) and an annual firm yield diversion of 75,430 acre-feet.

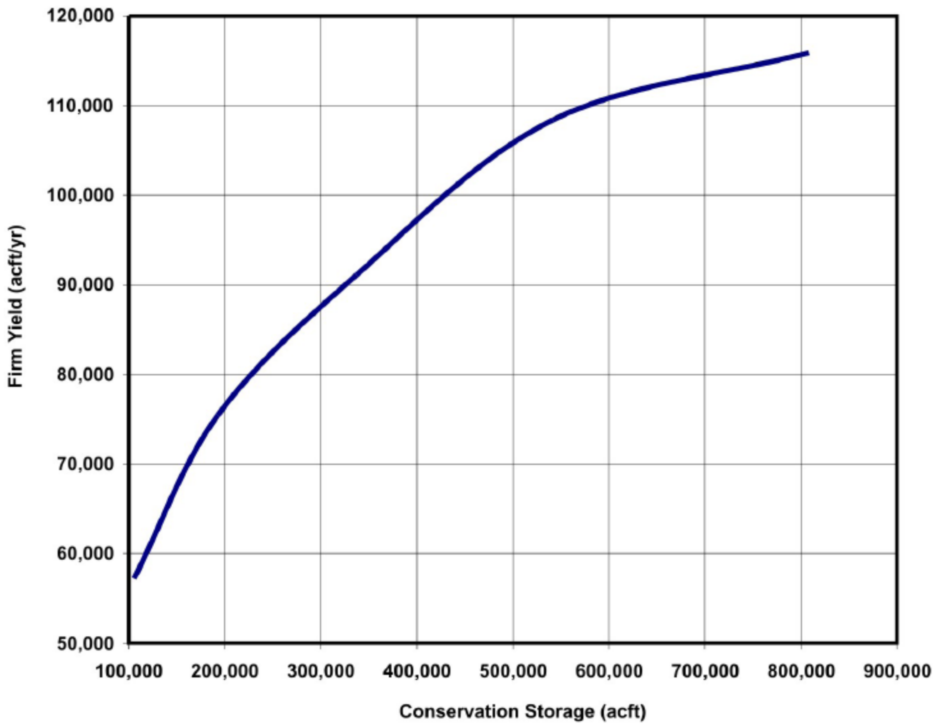


Figure 5-4. Firm yield versus conservation storage for Bedias Reservoir.
acft/yr=acre-feet per year

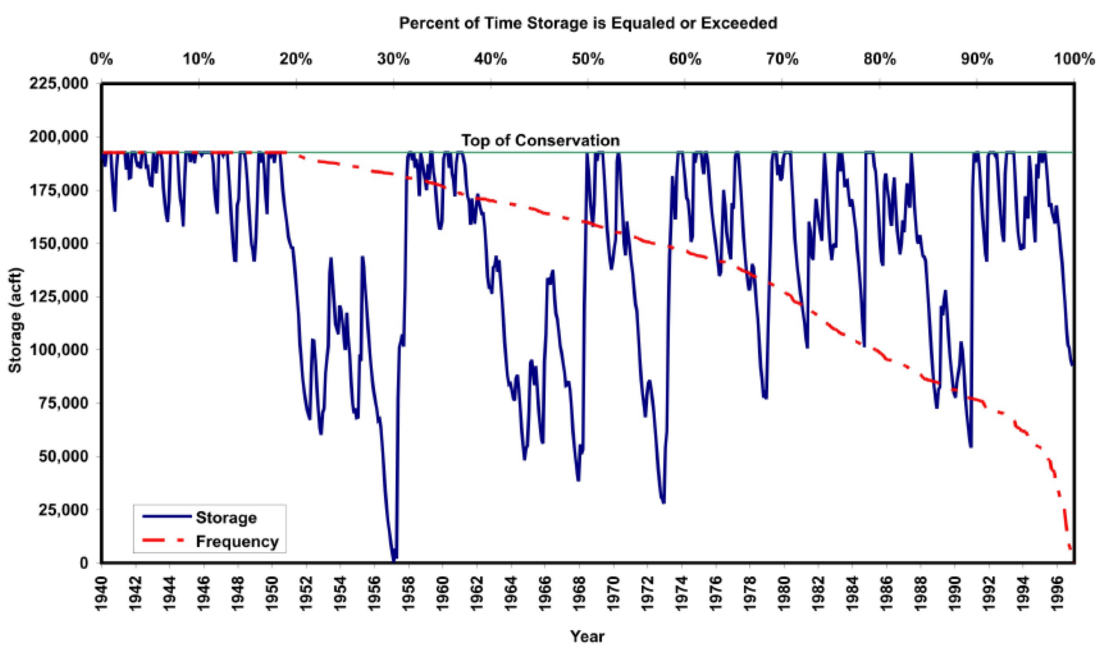


Figure 5-5. Simulated storage in Bedias Reservoir (conservation elevation=210 feet; diversion=75,430 acre-feet per year).
acft/yr=acre-feet per year

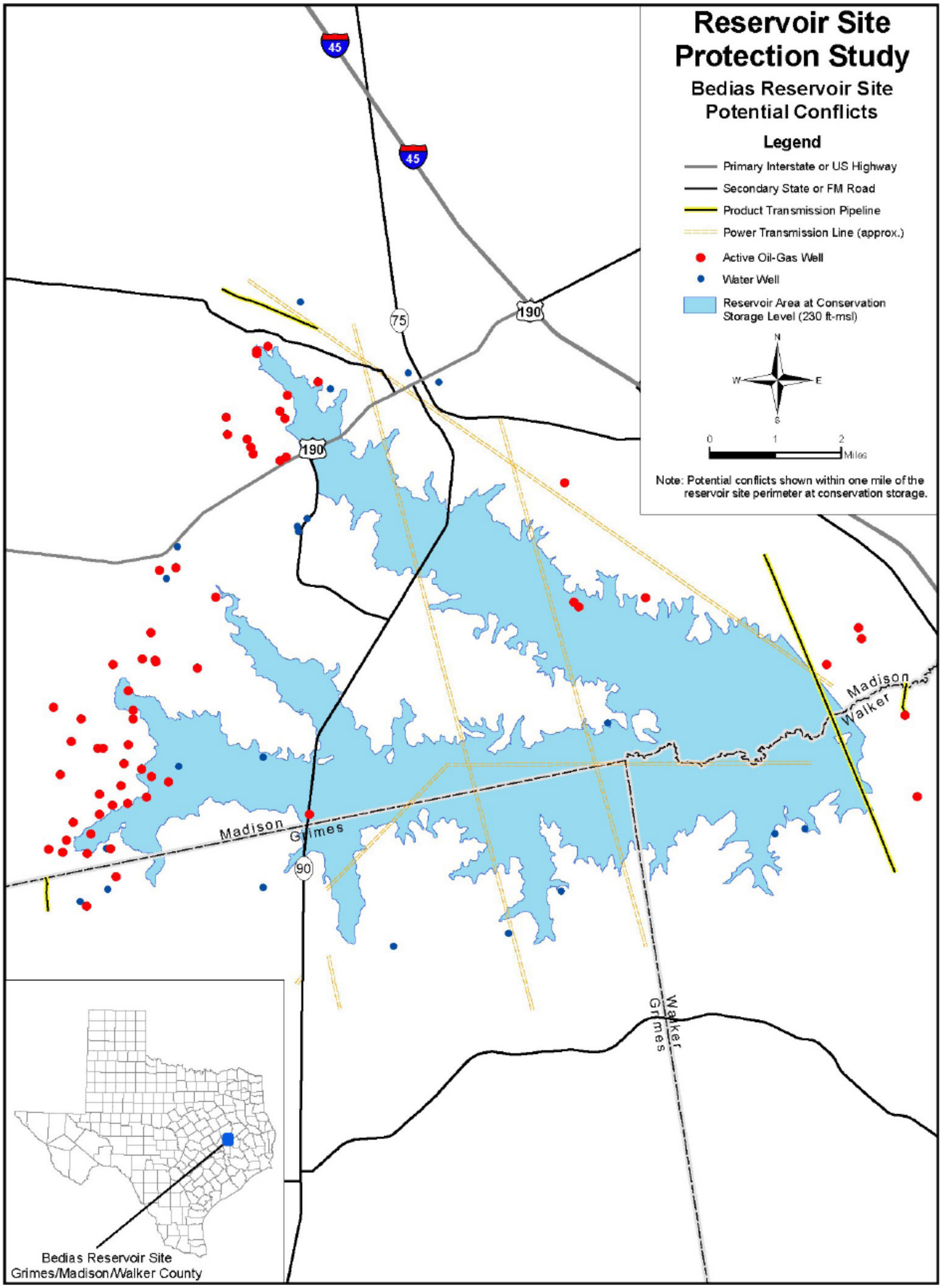


Figure 5-6. Potential major conflicts for Bedias Reservoir (map from the Texas Natural Resources Information System).
ft-msl=feet above mean sea level

### 5.1.2 *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 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 (Figure 5-6). The conflict costs represent less than 4 percent of the total construction cost of the reservoir project.

Table 5-4 summarizes the estimated capital costs for the Bedias Reservoir project, including construction, engineering, permitting, and mitigation costs. Unit costs for the dam and reservoir are

Table 5-4. Cost estimate—Bedias Reservoir at elevation 210 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Mobilization (5%)** | 1 | LS | | **$3,801,877** |
| **Embankment:** | | | | |
| Diversion & care of water | 1 | LS | $1,267,476.17 | $1,267,476 |
| Clearing and grubbing | 75 | AC | $2,000.00 | $150,000 |
| Excavation, stripping | 100,550 | CY | $2.00 | $201,100 |
| Compacted fill | 2,513,761 | CY | $2.50 | $6,284,403 |
| Drainage blanket | 226,238 | CY | $35.00 | $7,918,330 |
| Riprap | 93,009 | CY | $172.50 | $16,044,053 |
| Bedding | 35,192 | CY | $35.00 | $1,231,720 |
| Roadway | 14,737 | LF | $150.00 | $2,210,550 |
| Grassing | 25 | AC | $4,500.00 | $112,500 |
| Foundation treatment | 698,667 | CY | $2.50 | $1,746,668 |
| **Subtotal—Embankment Construction** | | | | **$37,166,799** |
| | | | | |
| **Spillway:** | | | | |
| Clearing & grubbing | 14 | AC | $4,000.00 | $56,000 |
| Care of water-construction | 1 | LS | $844,984.11 | $844,984 |
| Line drilling | 10,362 | SF | $12.84 | $133,087 |
| Perforated pipe drains | 1,398 | LF | $38.87 | $54,339 |
| Reinforced concrete | 51,810 | CY | $400.00 | $20,724,000 |
| Miscellaneous steel | 167,712 | LB | $3.21 | $538,356 |
| Tainter gates & anchorage | 872,352 | LB | $2.20 | $1,919,174 |
| Hoists & machinery | 204,864 | LB | $7.94 | $1,626,620 |
| Sluice gates & operators | 1 | LS | $60,839.00 | $60,839 |
| Bridge | 377 | LF | $1,300.00 | $490,100 |
| Crane | 1 | LS | $667,537.45 | $667,537 |
| Electrical facilities | 1 | LS | $79,428.51 | $79,429 |
| Standby power unit | 1 | LS | $55,768.95 | $55,769 |
| Power line to site | 1 | LS | $40,559.24 | $40,559 |
| Riprap | 6,912 | CY | $172.50 | $1,192,320 |
| Bedding | 2,368 | CY | $35.00 | $82,880 |
| **Subtotal—Spillway Construction** | | | | **$28,565,994** |
| | | | | |
| **Outlet Works:** | | | | |
| Excavation & backfill | 153,670 | CY | $2.50 | $384,175 |
| Line drilling | 2,480 | SF | $12.84 | $31,843 |
| Reinforced concrete | 13,344 | CY | $400.00 | $5,337,600 |
| Riprap | 2,767 | CY | $172.50 | $477,308 |
| Bedding | 922 | CY | $35.00 | $32,270 |
| Access bridge | 300 | LF | $1,300.00 | $390,000 |
| Miscellaneous steel | 114,237 | LB | $3.21 | $366,701 |

Table 5-4 (continued).

| | Quantity | Unit | Unit cost | Cost |
|---|---|---|---|---|
| Flood gates | 1 | LS | $1,233,676.80 | $1,233,677 |
| Water outlet pipe | 270 | LF | $456.29 | $123,199 |
| Water supply gates | 1 | LS | $163,926.92 | $163,927 |
| Low-flow release gates | 1 | LS | $506,990.47 | $506,990 |
| Control house | 1 | LS | $483,330.91 | $483,331 |
| Miscellaneous items | 1 | LS | $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** | 2,843 | AC | $1,000.00 | $2,843,000 |
| **Permanent Operating Facilities** | 1 | LS | $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 | 19,536 | LF | $256.06 | $5,002,306 |
| Electrical distribution & phone lines | 4,752 | LF | $16.00 | $76,032 |
| Cemeteries | 1 | EA | $506.99 | $507 |
| Dikes: Embankment | 4,255 | CY | $2.50 | $10,638 |
| Soil cement facing | 700 | CY | $65.00 | $45,500 |
| | | | | **$5,134,982** |
| **Engineering & Contingencies (35% Conflicts)** | | | | **$1,797,244** |
| **Land Purchase** | 11,495 | AC | $3,288.0 | **$37,795,560** |
| **Environmental Studies & Mitigation** | | | | **$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 year)** | | | | **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; SY=Square Yard.

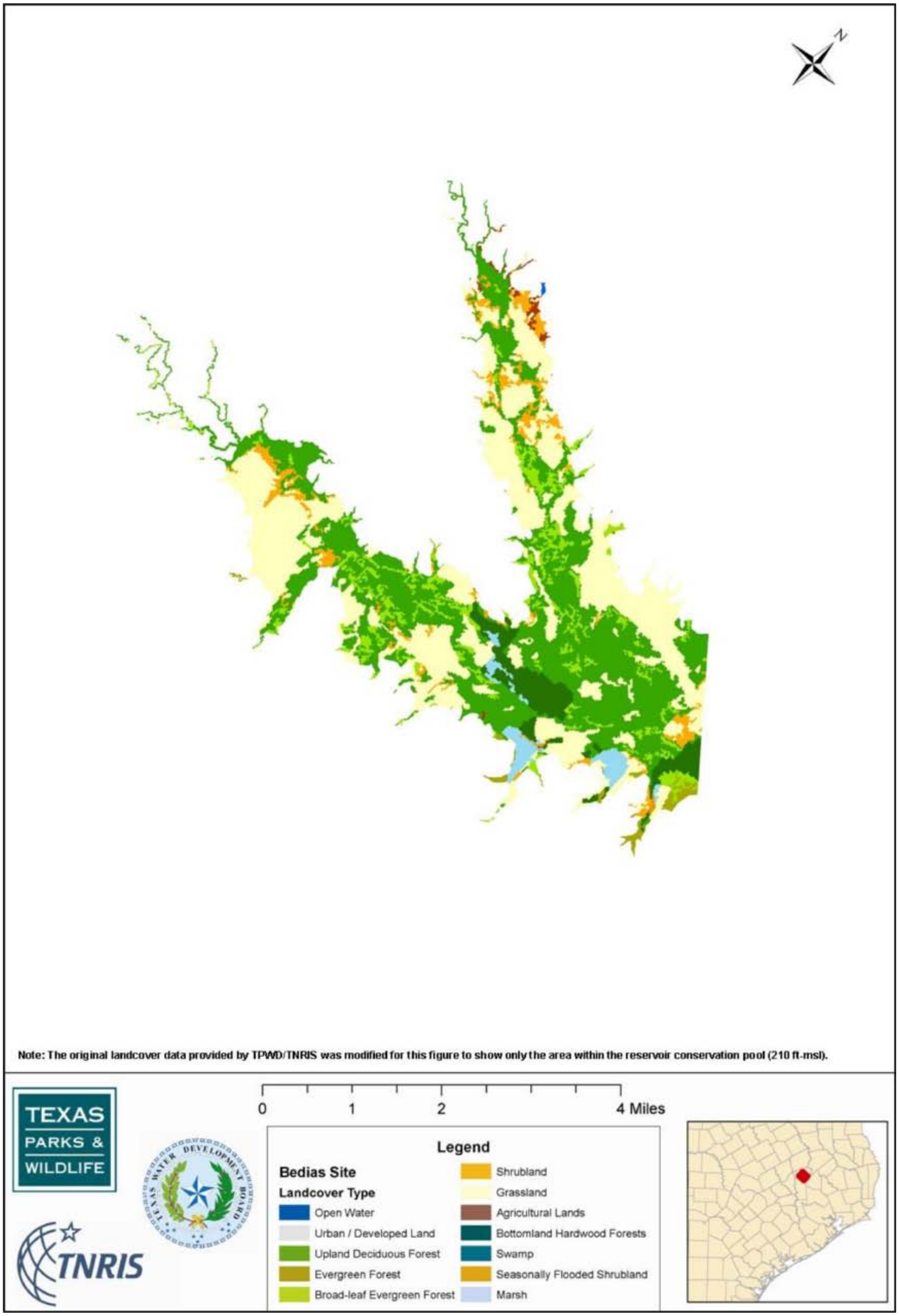


Figure 5-7. Existing landcover for Bedias Reservoir.
ft-msl=feet above mean sea level

Table 5-5. Acreage and percent landcover for Bedias Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

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 acre-feet per year, raw water from the project will cost approximately $232 per acre-foot ($0.71 per 1,000 gallons) during the debt service period.

### *5.1.3 Environmental Considerations*

Bedias Reservoir is not located on an ecologically significant stream segment as identified by the Texas Parks and Wildlife Department. 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, developing the lakeshore area will also bring congestion, noise, and some unavoidable air pollution to a previously rural area. On the other hand, residents in the area will likely welcome the additional camping, boating, and fishing activities that the reservoir will provide (Brown and Root and Turner Collie and Braden, Inc., 2001).

Bedias Reservoir will inundate 10,000 acres of land at conservation storage capacity. Figure 5-7 and Table 5-5 summarize existing landcover for the Bedias Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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.

## 5.2 BROWNSVILLE WEIR AND RESERVOIR PROJECT

The Brownsville Public Utilities Board is proposing to construct and operate the Brownsville Weir and Reservoir project on the Lower Rio Grande just below Brownsville (Figure 5-8). The project (Water Right Permit No. 5259) is designed to provide a maximum of 6,000 acre-feet of storage capacity for capturing and storing excess flows of U.S. water in the Rio Grande that will otherwise flow to the Gulf of Mexico. The Public Utilities Board will operate the project in conjunction with their existing excess flows diversion Permit No. 1838 (authorizes diversions of excess flows from the Rio Grande of 40,000 acre-feet per year). The Brownsville Weir and Reservoir will be operated as a system with the existing Amistad-Falcon Reservoir storage rights. The project will develop an additional municipal and industrial water supply for the customers of the Brownsville Public Utilities Board who are located in south and southeastern Cameron County. It is expected to provide approximately 20,000 acre-feet per year in additional dependable supply of Rio Grande water. Approximately 71 percent of the time, it should be capable of supplying the full 40,000 acre-feet per year 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 Regional Water Plans as well as the 2002 and 2007 State Water Plans. The projected water needs within 50 miles of the proposed reservoir site by 2060 are 223,489 acre-feet per year. The nearest major demand center is the Lower Rio Grande Valley, which extends north of the reservoir for approximately 60 miles.

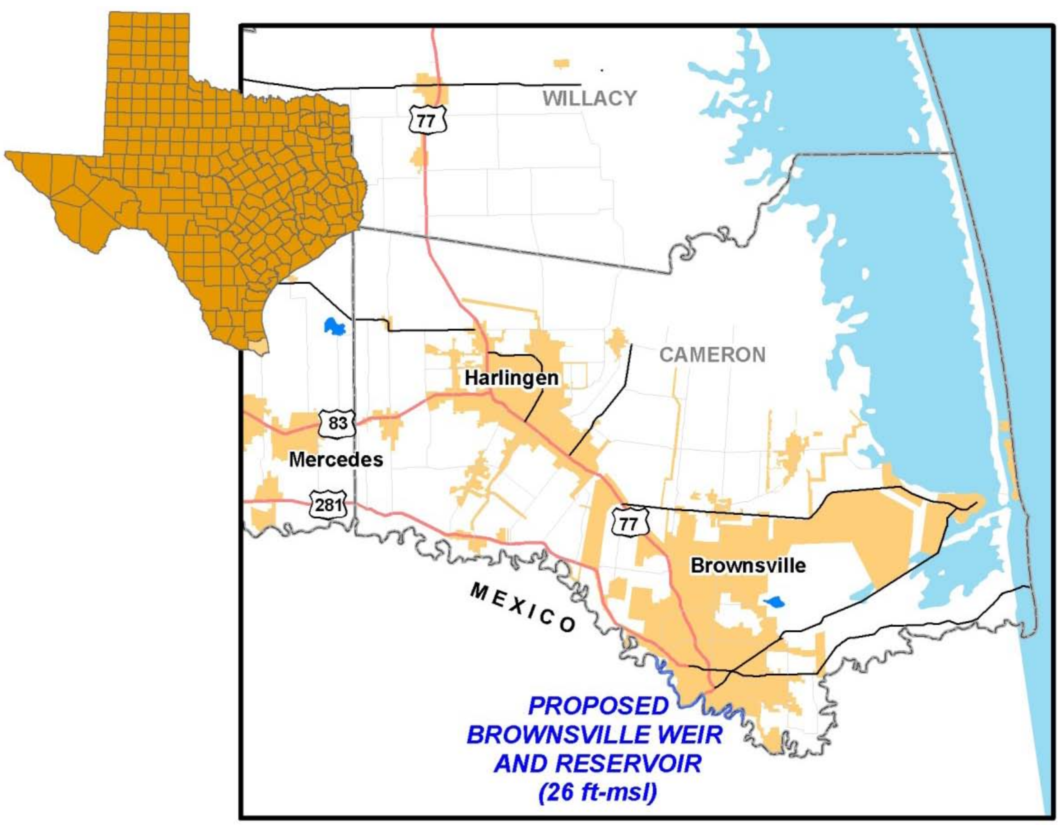


Figure 5-8. Location map of Brownsville Weir and Reservoir.
ft-msl=feet above mean sea level

The proposed Brownsville Weir and Reservoir 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 nonproject 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 an elevation of 26 feet. The elevation of the river channel flow line at the weir structure is about 1 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. Under the normal maximum water level condition, the entire reservoir will be contained within the banks of the natural channel of the river.

### *5.2.1*
### *Reservoir Yield Analysis*

As part of the water right permitting process in the 1990s, the Brownsville Public Utilities Board investigated the ability of the weir and reservoir to develop and provide an additional dependable supply of water from the Lower Rio Grande. These earlier studies provide the basis for the project yield information reported in this study. This earlier work involved a computer modeling analysis in which the operation and performance of the reservoir was simulated under actual historical hydrologic and climatic conditions. For this analysis, we assumed the historical quantities of U.S. water that flowed past the Brownsville streamflow gage were available for capture and diversion by the project. However, water released from Falcon Reservoir for authorized downstream users and water required for existing instream uses and maintenance of bay and estuarine resources were excluded from the available quantity.

Storage variations for the Brownsville Reservoir were simulated on a daily basis in response to several conditions: the historical river inflows; system releases from Falcon Reservoir; specified project and system water right diversions; releases for historical downstream U.S. users and Mexican water pass-throughs; specified releases for instream uses and bay and estuarine purposes (minimum of 25 cubic feet per second 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 the customers of the Brownsville Public Utilities Board.

Historical conditions corresponding to the period 1960 through 1997 were used for the water supply evaluation of the Brownsville Weir and Reservoir. This period encompasses a broad spectrum of river flow conditions that are reflected in the historical streamflows measured at the Brownsville gage. These include 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

Table 5-6. Elevation-area-capacity relationship for Brownsville Weir and Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| -1 | 0 | 0 |
| 10 | 84 | 460 |
| 15 | 185 | 1,390 |
| 20 | 308 | 2,830 |
| 25 | 470 | 5,220 |
| 26 | 600 | 6,000 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

selected primarily because Anzalduas Reservoir, which is located approximately 100 river miles upstream of the weir and reservoir site and provides regulation of normal flows in the Lower Rio Grande, was completed in 1960. Since that time, it has had a direct influence on normal (nonflood) river flows at the Brownsville gage.

For purposes of simulating the operation and performance of the Brownsville Reservoir in conjunction with the Brownsville Public Utilities Board's existing Amistad-Falcon water rights, we used the computer program SIMYLD-IID. This program, which is an extension of the SIMYLD-II program originally developed by TWDB, simulates the movement

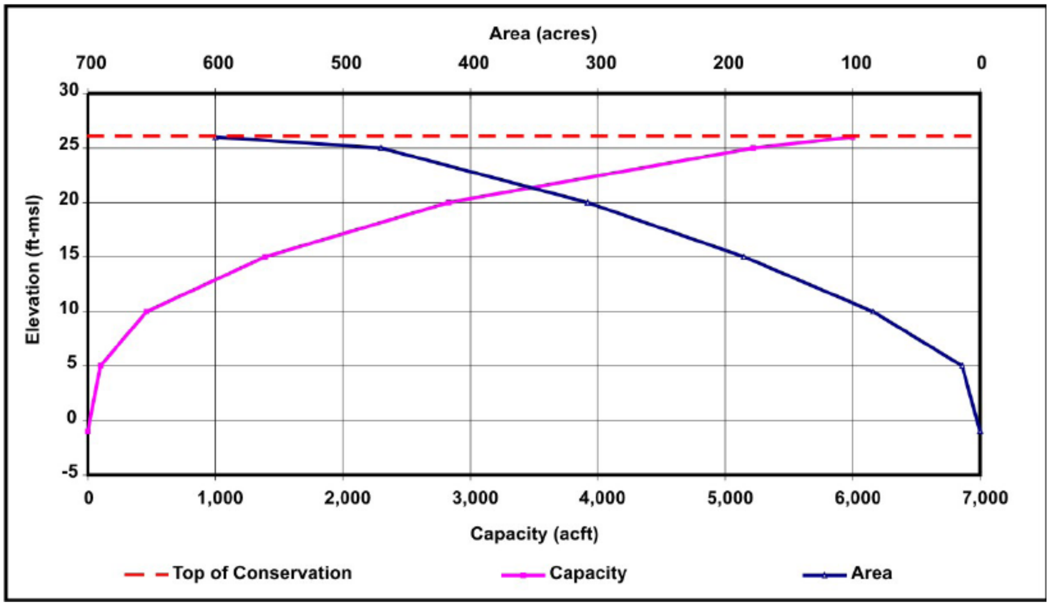


Figure 5-9. Elevation-area-capacity relationship for Brownsville Weir and Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

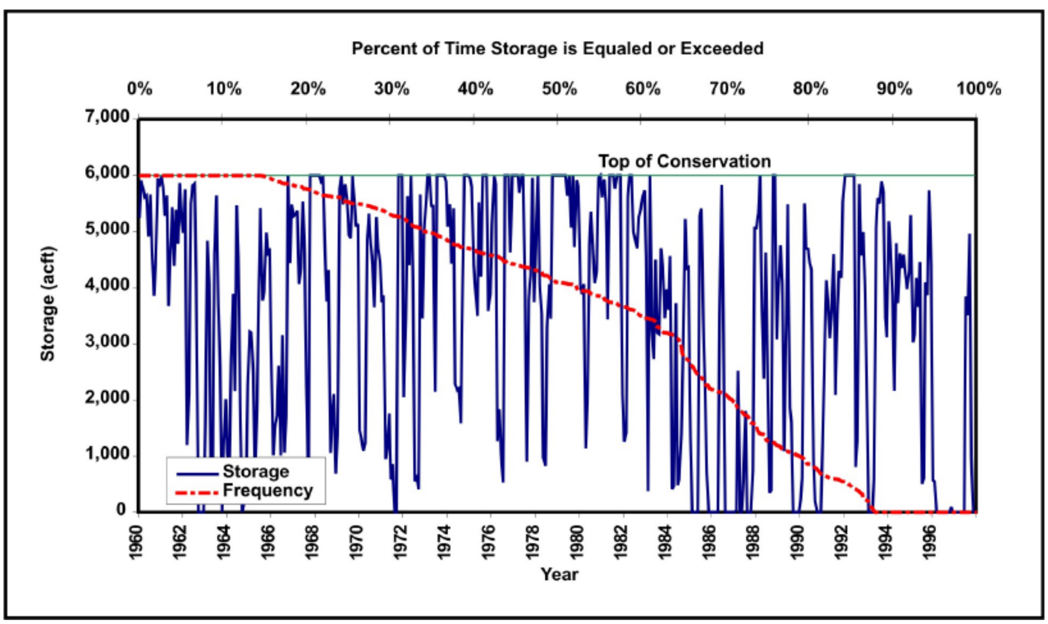


Figure 5-10. Simulated storage in Brownsville Weir and Reservoir (conservation elevation=26 feet; diversion=20,643 acre-feet per year).
acft=acre-feet

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 Brownsville Reservoir. Table 5-6 and Figure 5-9 present the elevation-area-capacity data for the project. The Brownsville Public Utilities Board originally developed these data 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 will not be meaningful and has not been prepared.

Results from modeling the Brownsville Weir and Reservoir indicated that in most of the years of the 1960–1997 simulation period (71 percent) the total diversion of 40,000 acre-feet per year (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 acre-feet. This amount represents the additional dependable supply of Rio Grande water available to the utility under Permit No. 1838 with the reservoir in operation. It is the amount considered to be the firm annual yield. Figure 5-10 presents a simulated storage trace and storage frequency curve for the Brownsville Reservoir based on the minimum monthly storage amounts simulated with the SIMYLD-IID daily model. Since the project is already permitted with a maximum storage capacity of 6,000 acre-feet, no analyses of yield versus storage capacity have been performed.

### *5.2.2*
### *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 will be 1 foot above mean sea level. Concrete abutments will be constructed on each end of the sill, one on the U.S. 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 feet. With the radial gates fully open at flood stage, the Rio Grande will pass through unobstructed. The length of the structure is approximately 400 feet, including the approach section. As proposed, the actual width of the gates and sill will be 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 feet below mean sea level. 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 footprint 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 5-11).

Table 5-7 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 acre-feet per

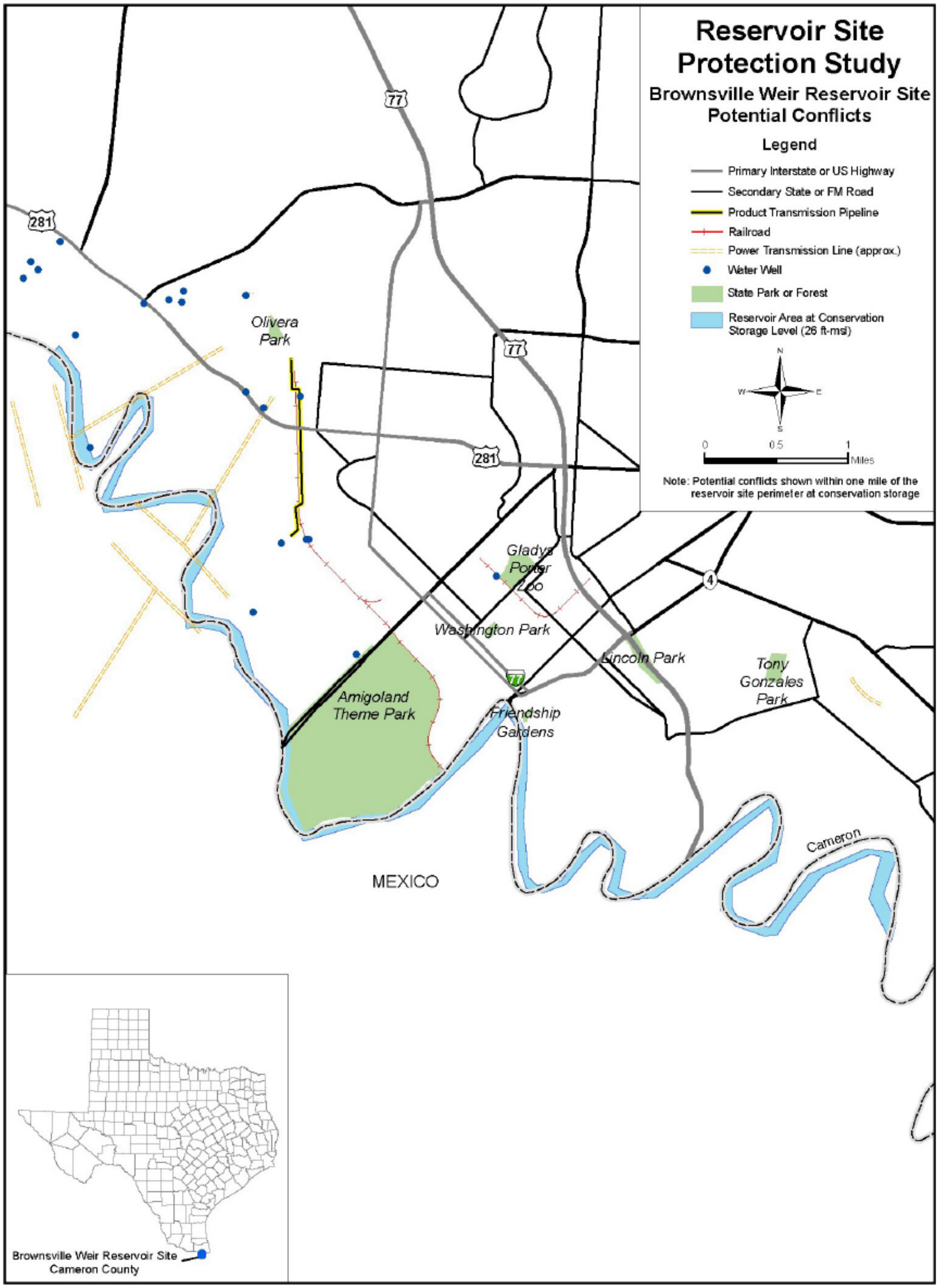


Figure 5-11. Potential major conflicts for Brownsville Weir and Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Table 5-7. Cost estimate—Brownsville Weir and Reservoir at elevation 26 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Mobilization (5%)** | 1 | LS | $1,469,358 | $1,469,358 |
| **Access Road** | | | | |
| Clearing & grubbing | 3.4 | AC | $2,000.00 | $6,800 |
| Compacted fill | 20,000 | CY | $2.50 | $50,000 |
| Flex base- 6-inch | 1,514 | CY | $120.00 | $181,680 |
| Pipe 24- inch | 140 | LF | $42.53 | $5,954 |
| Metal guard rail | 4,800 | LF | $36.45 | $174,971 |
| **Care of roads** | 8,020 | SY | $3.04 | $24,362 |
| **Diversion Channel** | | | | |
| Clearing & grubbing | 10 | AC | $2,000.00 | $20,000 |
| Dewatering system | 1 | LS | $60,753.92 | $60,754 |
| Excavation | 324,385 | CY | $2.50 | $810,963 |
| Riprap bedding | 3,364 | CY | $35.00 | $117,740 |
| Riprap | 6,726 | CY | $172.50 | $1,160,235 |
| Construction crossing | 1 | LS | $170,110.97 | $170,111 |
| Maintenance | 50,622 | SY | $1.22 | $61,510 |
| Restoration | 356,823 | CY | $1.58 | $563,638 |
| Seeding | 11 | AC | $729.05 | $8,020 |
| **Coffer Dams** | | | | |
| Random fill | 40,774 | CY | $2.50 | $101,935 |
| Riprap bedding | 700 | CY | $35.00 | $24,500 |
| Riprap | 1,867 | CY | $172.50 | $322,058 |
| Sheetpiling | 21,280 | SF | $30.38 | $646,422 |
| Flex base | 526 | CY | $120.00 | $63,120 |
| Maintenance | 1 | LS | $12,150.78 | $12,151 |
| Removal | 40,774 | LS | $3.65 | $148,631 |
| **Care of Water** | 1 | LS | $243,015.67 | $243,016 |
| **Sheet Pile Cutoff** | | | | |
| Cells sheetpiles | 52,053 | SF | $44.96 | $2,340,193 |
| Piles other | 13,000 | SF | $42.53 | $552,861 |
| **Foundation Piles** | | | | |
| Test piles | 4 | EA | $3,645.23 | $14,581 |
| Designed piles | 22,380 | LF | $36.45 | $815,804 |
| **General Excavation** | | | | |
| Clearing and grubbing | 6 | AC | $2,000.00 | $12,000 |
| Upstream | 78,400 | CY | $2.50 | $196,000 |
| Downstream | 74,100 | CY | $2.50 | $185,250 |
| Ogee & abutments | 70,460 | CY | $2.50 | $176,150 |
| **Foundation Preparation** | 65,500 | SY | $1.50 | $98,250 |
| **Impervious Fill** | 32,000 | CY | $3.00 | $96,000 |
| **Random Fill** | 108,200 | CY | $2.50 | $270,500 |
| **Stilling Basin** | | | | |
| Dewatering system | 1 | LS | $48,603.13 | $48,603 |
| Sub-drain system | 1 | LS | $36,452.35 | $36,452 |
| Sheet pile cutoff | 6,000 | SF | $42.53 | $255,166 |
| **Reinforced Concrete** | | | | |
| Counterfort walls | 7,360 | CY | $400.00 | $2,944,000 |
| Ogee crest | 5,685 | CY | $400.00 | $2,274,000 |
| Abutments | 3,200 | CY | $400.00 | $1,280,000 |
| Cutoff walls | 245 | CY | $400.00 | $98,000 |
| Piers | 5,363 | CY | $400.00 | $2,145,200 |
| Concrete. basin | 3,500 | CY | $400.00 | $1,400,000 |
| **Spillway Bridge (240’x16’ prestressed)** | 3,840 | SF | $81.25 | $312,000 |

Table 5-7 (continued).

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Spillway Radial Gates** | | | | |
| Radial gates 25'x35' | 6 | EA | $263,672.00 | $1,582,032 |
| Gate embeds | 6 | EA | $70,474.54 | $422,847 |
| Gate hoists | 6 | EA | $208,993.47 | $1,253,961 |
| Supports | | | | |
| Wire ropes | | | | |
| Electric generator | 1 | EA | $21,871.41 | $21,871 |
| Generator fuel tank | 1 | EA | $1,458.09 | $1,458 |
| Anchorages | 12 | EA | $36,452.35 | $437,428 |
| **Outlet Works Gates** | | | | |
| 3'x5' sluice gates | 4 | EA | $97,206.27 | $388,825 |
| 12"x12" sluice gate | 2 | EA | $60,753.92 | $121,508 |
| 18'x30' sluice gate | 2 | EA | $85,055.48 | $170,111 |
| **Stop Gates** | | | | |
| Stop gates plus | 1 | LS | $243,015.67 | $243,016 |
| Lifting beam | | | | |
| Lifting beam storage pad | | | | |
| **Stop Gate Monorail** | | | | |
| Rails & supports | 1 | LS | $425,277.42 | $425,277 |
| Electrical system | | | | |
| Traveling hoist | | | | |
| **Barrier & Warning System** | 1 | LS | $64,399.15 | $64,399 |
| **Site Water Service** | | | | |
| **Buried Water Service** | 10,500 | LF | $4.86 | $51,033 |
| **Site Electrical system** | | | | |
| Electrical equipment site | 1 | LA | $291,618.80 | $291,619 |
| Transformer | 1 | LA | $24,301.57 | $24,302 |
| Underground primary line | 10,500 | LF | $9.72 | $102,067 |
| **Site Computer/Telephone Service** | | | | |
| Underground line | 10,500 | | $9.72 | $102,067 |
| **Control House** | | | | |
| Concrete building | 400 | SF | $48.60 | $19,441 |
| Reservoir gage | 1 | LS | $12,150.78 | $12,151 |
| Miscellaneous instrument | 1 | LS | $12,150.78 | $12,151 |
| Septic system | 1 | LS | $5,467.85 | $5,468 |
| Steps & sidewalk | 1 | LS | $3,645.23 | $3,645 |
| Flag pole | 1 | LS | $1,215.08 | $1,215 |
| **Open Rise Piezometers** | 12 | EA | $2,673.17 | $32,078 |
| **Riprap Slope Protection** | | | | |
| Upstream channel | 2,411 | CY | $172.50 | $415,898 |
| Downstream channel | 10,750 | CY | $172.50 | $1,854,375 |
| Abutments | 1,690 | CY | $172.50 | $291,525 |
| **Surface Monuments** | 9 | EA | $6,075.39 | $54,679 |
| **Chain Link Fence-6 foot** | 2,500 | LF | $24.30 | $60,754 |
| **Barbed Wire Fence** | 5,000 | LF | $4.62 | $23,086 |
| **Concrete Parking Area** | | | | |
| 6-inch concrete paving | 550 | CY | $400.00 | $220,000 |
| Lighting | 1 | LS | $72,904.70 | $72,905 |
| Guard rail | 1,520 | LF | $36.45 | $55,408 |
| 4-foot chainlink fence | 630 | LF | $18.23 | $11,482 |
| **Seeding & Landscaping** | 11 | AC | $729.05 | $8,020 |
| | | | | |
| **Subtotal Weir Construction Costs** | | | | **$29,387,680** |

Table 5-7 (continued).

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **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 | 1 | LS | $1,215,078.33 | $1,215,078 |
| IBWC streamgage & road relocation | 1 | LS | $30,376.96 | $30,377 |
| **Subtotal Conflicts** | | | | **$1,245,455** |
| **Engineering & Contingencies (35% conflicts)** | | | | **$435,909** |
| **Total Conflicts** | | | | **$1,681,365** |
| **Land Purchase** | 86 | AC | $3,482 | **$299,452** |
| **Environmental Studies & Mitigation** | | | | **$1,394,343** |
| **Subtotal—Other Project Costs** | | | | **$3,375,159** |
| **Total Capital Costs** | | | | **$45,032,195** |
| **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 Yeld (acre-feet per year)** | | | | **20,643** |
| **Unit Cost of Water (during Amortization)** | | | | |
| per acre foot | | | | **$181** |
| per 1,000 gallons | | | | **$0.55** |

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

Table 5-8. Acreage and percent landcover for Brownsville Weir and Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

year, raw water from the project will cost approximately $181 per acre-foot ($0.55 per 1,000 gallons) during the debt service period.

### *5.2.3 Environmental Considerations*

The Brownsville Weir and Reservoir project affects two Texas Commission on Environmental Quality designated water quality segments: Rio Grande Tidal (2301) and Falcon Reservoir (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 rock weir to the Gulf of Mexico, approximately 49 miles. Segment 2302 extends from its headwater at Falcon Dam in Starr County to the Brownsville Irrigation and Drainage District weir, approximately 226 miles. Both sections are identified as ecologically significant by the Texas Parks and Wildlife Department because they contain priority bottomland habitat and extensive freshwater and estuarine wetland habitats (Bauer and others, 1991).

In addition, 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 the Brownsville Reservoir issued on September 29, 2000, contains special conditions in order to mitigate these possible impacts. Some of these conditions include

- requiring a minimum streamflow of 25 cubic feet per second 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 Texas Commission on Environmental Quality and Texas Parks and Wildlife Department, to develop a mitigation plan for the entire Brownsville Weir and Reservoir project.

The project will inundate 600 acres of land at conservation storage capacity. Table 5-8 and Figure 5-12 summarize existing landcover for the Brownsville Weir and Reservoir project site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by grassland (32 percent), agricultural land (22 percent), urban/developed land (18 percent), and open water (17 percent).

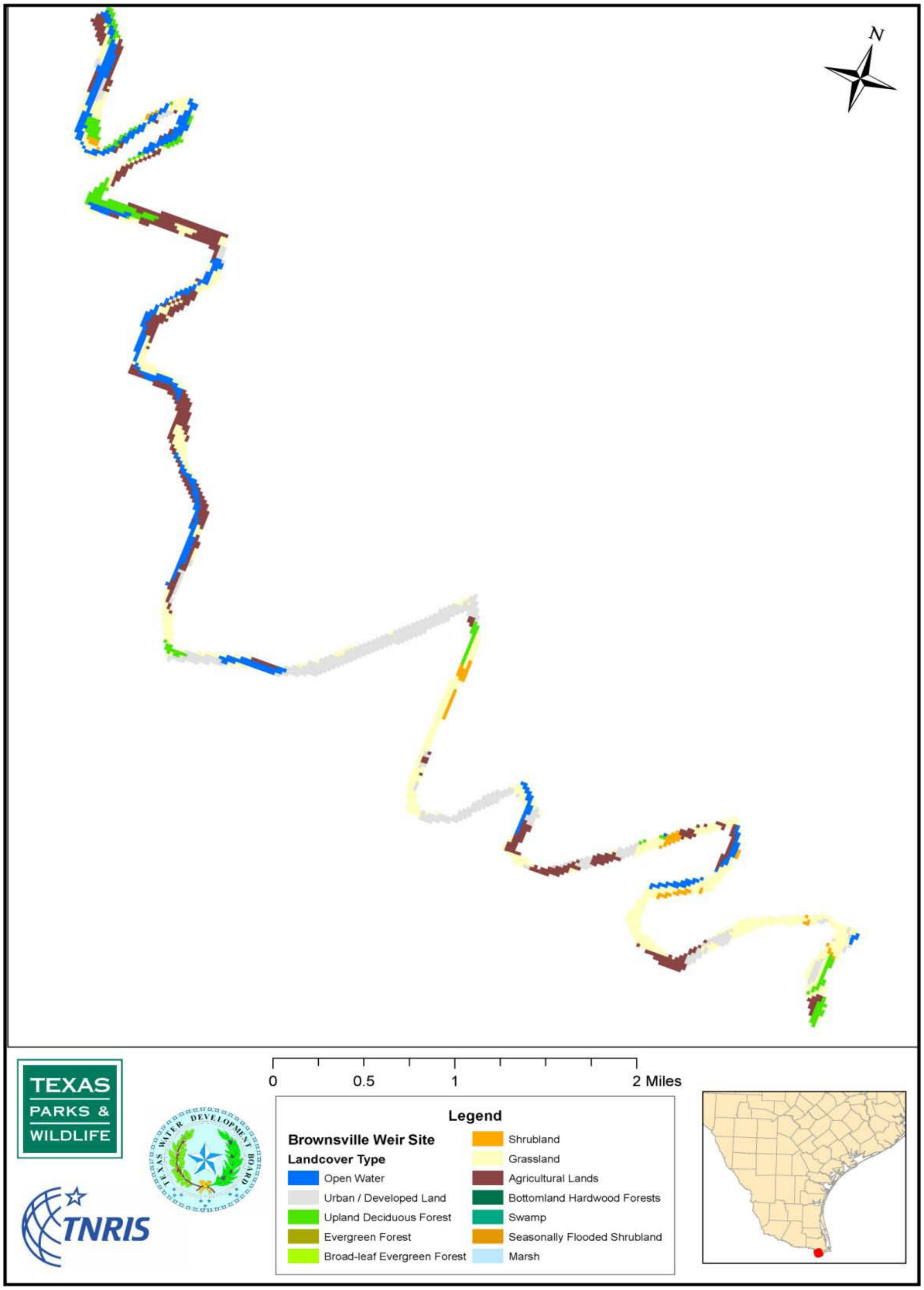


Figure 5-12. Existing landcover for Brownsville Weir and Reservoir.

## 5.3
## BRUSHY CREEK RESERVOIR

Brushy Creek Reservoir, proposed as part of the long-term plan developed by the City of Marlin and the Natural Resources Conservation Service, will serve 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. Located in Central Texas in Falls, Limestone, and McLennan counties, the Big Creek watershed encompasses 369.6 square miles. The 1984 Big Creek watershed plan includes three flood-retarding structures located in the upper reaches of Brushy Creek and a larger multipurpose dam located just above the confluence of Brushy Creek with Big Creek (USDA, 1984). This dam, when constructed, will form the Brushy Creek Reservoir (Figure 5-13) and impound runoff from a 44.3 square mile watershed. At its conservation elevation of 380.5 feet, the reservoir will have a conservation capacity of 6,560 acre-feet and inundate 697 acres.

The projected needs within 50 miles of the proposed reservoir site by 2060 are 246,820 acre-feet per year. The nearest major demand center is the Austin area, which is located approximately 85 miles southwest of the reservoir site.

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 Marlin, reduce channel erosion, sedimentation, and downstream flooding and increase the availability of prime farmland soils and acreage of open water within the watershed. The Brushy Creek Reservoir 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 Marlin in the regional planning process. All of the land required for Brushy Creek Reservoir has been purchased by the City of Marlin.

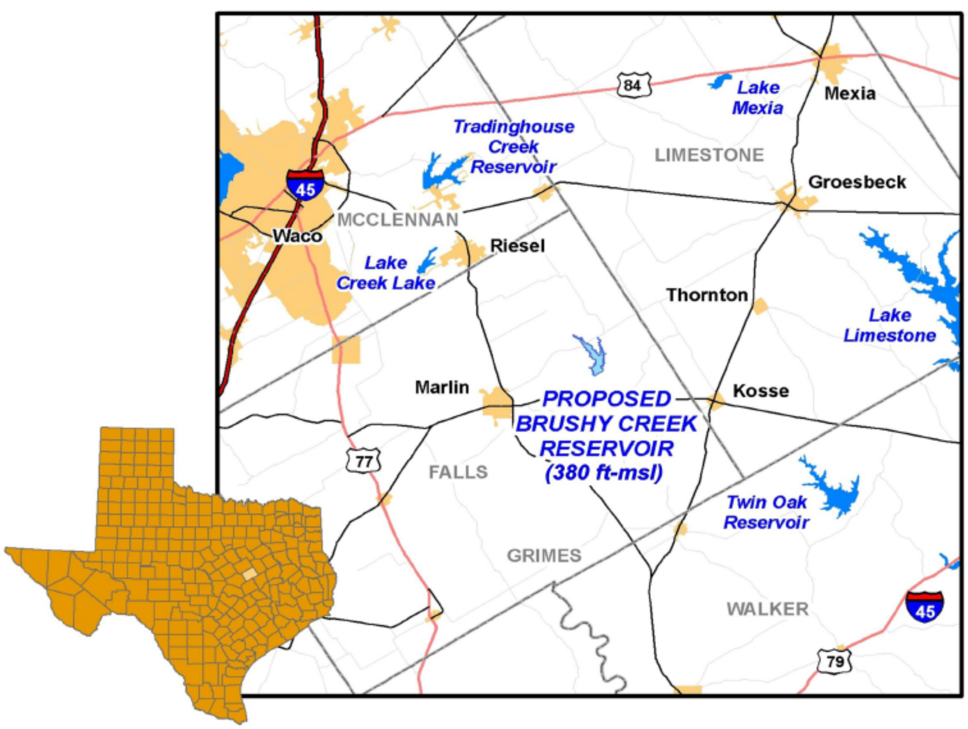


Figure 5-13. Location map of Brushy Creek Reservoir.
ft-msl=feet above mean sea level

### *5.3.1 Reservoir Yield Analysis*

We calculated the firm yield of Brushy Creek Reservoir using the Brazos River Basin water availability model with Run 3 assumptions. The monthly simulations were performed using the Water Rights Analysis Package. This existing water availability 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 5-9 and Figure 5-14. The Natural Resources Conservation Service developed this data as part of the original watershed planning study. Figure 5-15 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 cubic feet per second.

Water availability model simulations were made to determine the firm yield of the reservoir for the authorized conservation pool elevation of 380.5 feet, which corresponds to a maximum conservation storage capacity of 6,560 acre-feet. The resulting firm yield is 1,380 acre-feet per year. Environmental flow requirements reduce the firm yield of the reservoir by approximately 55 acre-feet.

Figure 5-16 presents the monthly variation in storage in Brushy Creek Reservoir and a storage frequency curve as simulated with the water availability model under firm yield conditions. At

Table 5-9. Elevation-area-capacity relationship for Brushy Creek Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 352 | 0 | 0 |
| 356 | 1 | 1 |
| 360 | 33 | 68 |
| 364 | 115 | 363 |
| 368 | 234 | 1,059 |
| 372 | 341 | 2,208 |
| 376 | 497 | 3,884 |
| 380 | 668 | 6,214 |
| 380.5 | 697 | 6,560 |
| 384 | 896 | 9,296 |
| 388 | 1,065 | 13,119 |
| 392 | 1,310 | 17,868 |
| 394 | 1,431 | 20,608 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

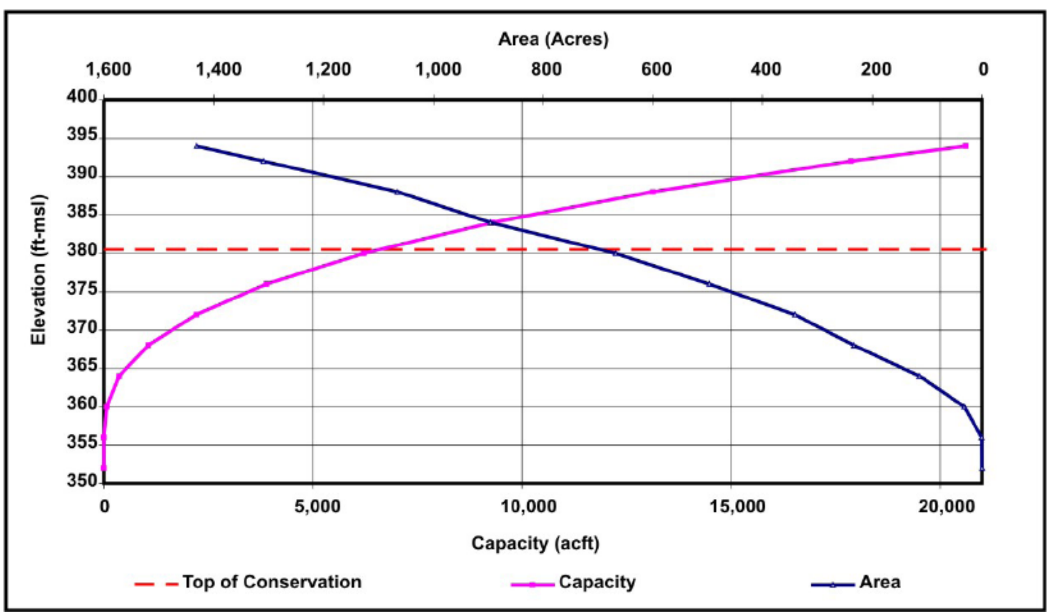


Figure 5-14. Elevation-area-capacity relationship for Brushy Creek Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

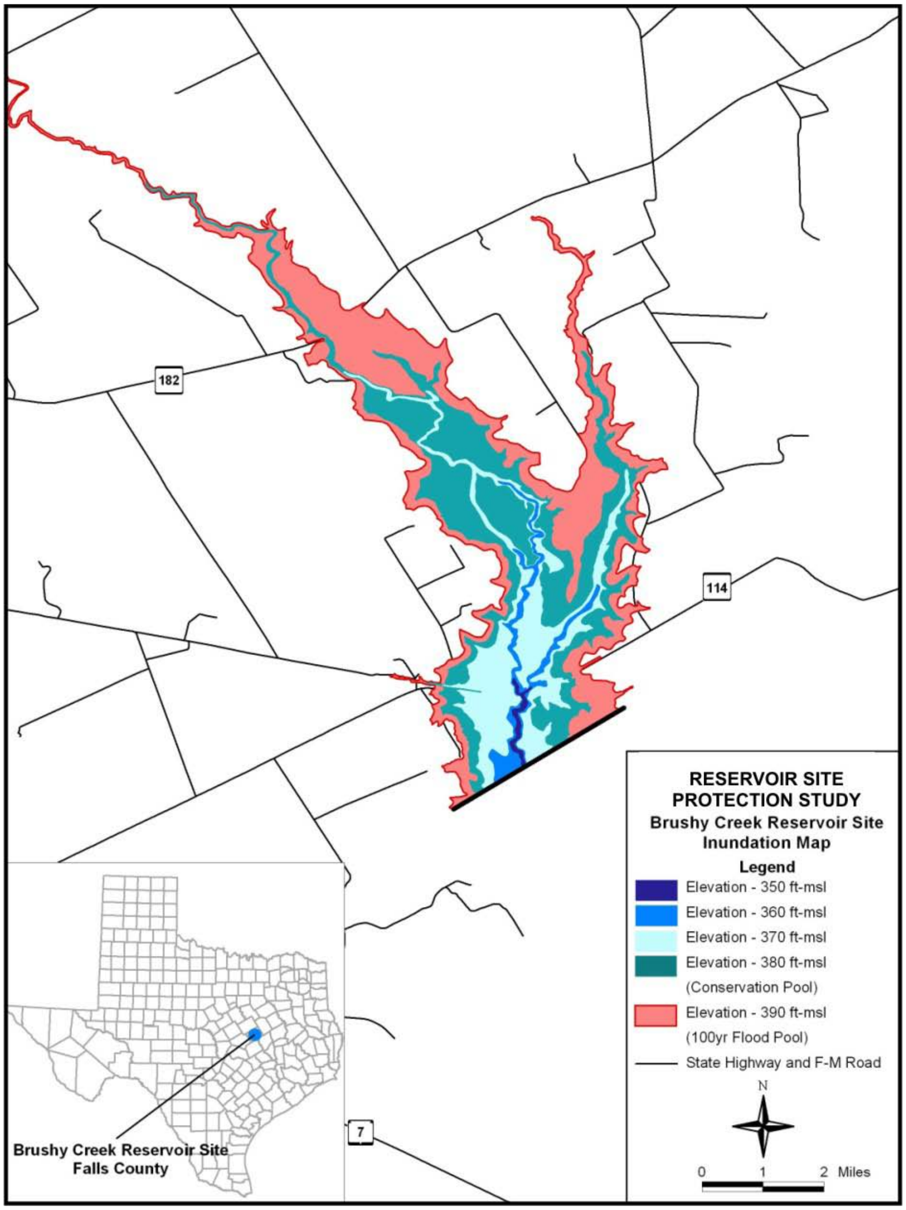


Figure 5-15. Inundation map for Brushy Creek Reservoir.
ft-msl=feet above mean sea level

the conservation pool elevation of 380.5 feet (6,560 acre-feet of storage capacity), the reservoir will be full about 25 percent of the time and below 50 percent of the conservation storage capacity about 12 percent of the time.

### *5.3.2 Reservoir Costs*

The costs for the Brushy Creek Reservoir include 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, as well as county and farm to market roads (Figure 5-17). The conflict costs represent less

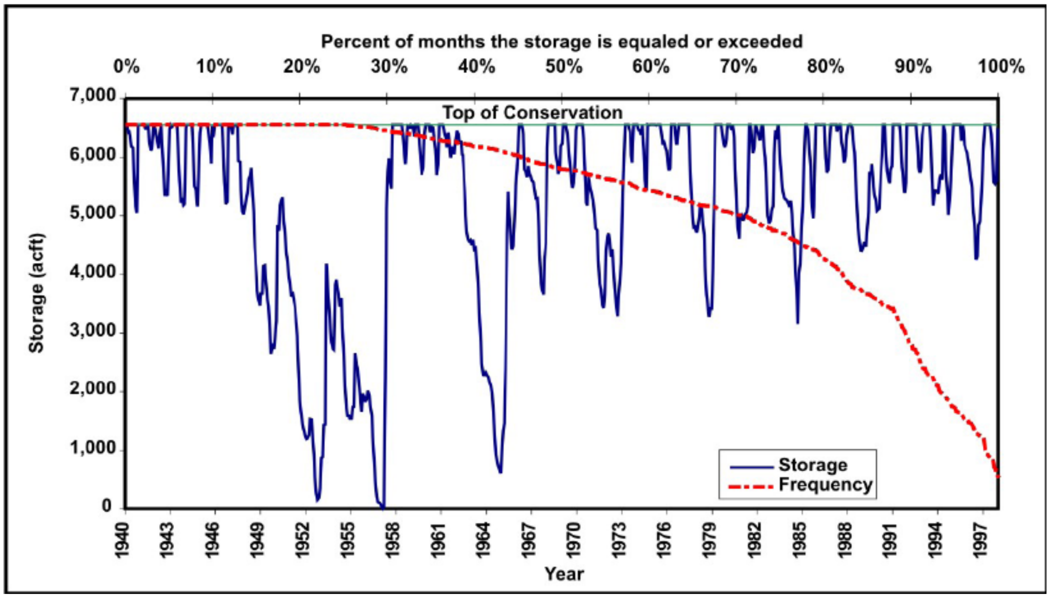


Figure 5-16. Simulated storage in Brushy Creek Reservoir (conservation elevation=380.5 feet; diversion=1,380 acre-feet per year).
acft=acre-feet

than 17 percent of the total construction cost of the reservoir project.

Table 5-10 shows the estimated capital costs for the Brushy Creek Reservoir, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, 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 1,000 gallons).

### *5.3.3 Environmental Considerations*

The Brushy Creek Reservoir site is not located on an ecologically significant stream as identified by the Texas Parks and Wildlife Department. The main impacts of this project are from dam construction and to the inundated areas. Because of the nature of the soils in the drainage area, the reservoir will experience some sediment loading. Temporary loading will occur immediately after construction of these upstream structures before all disturbed soils are revegetated. Several floodwater-retarding structures located in the upper part of the basin will, however, act to reduce the loading In addition, as the vegetation matures and sedimentation and erosion controls are maintained, the loading is expected to diminish.

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–the City of Marlin and the Natural Resources Conservation Service.

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

Brushy Creek Reservoir will inundate 697 acres of land at conservation storage capacity. Table 5-11 and Figure 5-18 summarize existing landcover for the Brushy

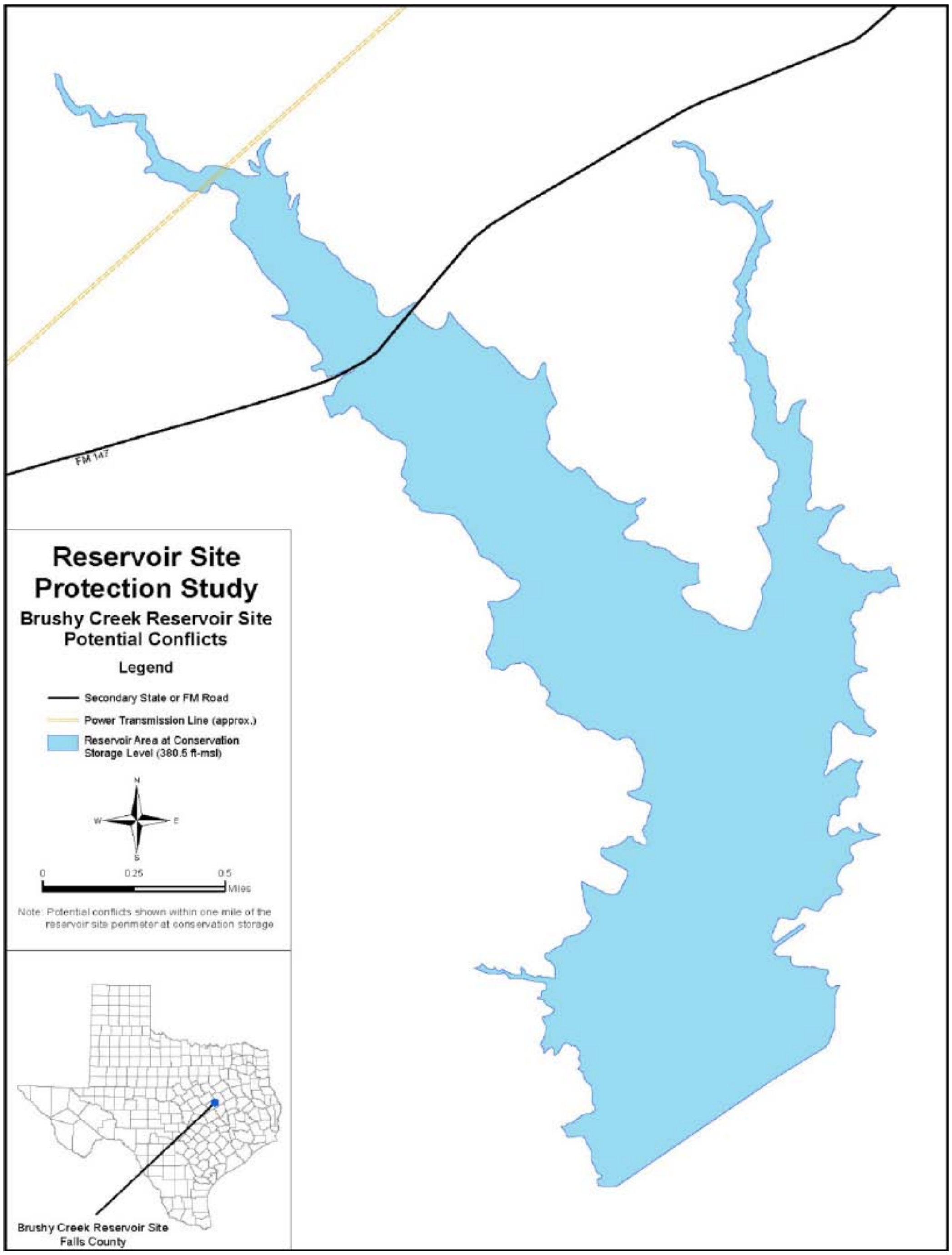


Figure 5-17. Potential major conflicts for Brushy Creek Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Creek Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by upland deciduous forest (44 percent) and agricultural land (39 percent).

Table 5-10. Cost estimate—Brushy Creek Reservoir at elevation 380.5 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Mobilization (5%)** | 1 | LS | | **$183,340** |
| **Foundation:** | | | | |
| Cutoff excavation | 61,832 | CY | $2.50 | $154,580 |
| Channel cleanout excavation & foundation preparation | 29,000 | CY | $2.50 | $72,500 |
| Compacted fill—cutoff trench | 61,832 | CY | $2.50 | $154,580 |
| **Subtotal—Foundation Construction** | | | | **$381,660** |
| **Embankment:** | | | | |
| Clearing & grubbing | 40 | AC | $2,000.00 | $80,000 |
| Compacted fill | 579,789 | CY | $2.50 | $1,449,473 |
| Riprap & bedding | 12,500 | TON | $65.00 | $812,500 |
| Topsoil & grassing | 50 | AC | $4,500.00 | $225,000 |
| Fencing | 14,190 | LF | $4.00 | $56,760 |
| **Subtotal—Embankment Construction** | | | | **$2,623,733** |
| **Emergency Spillway:** | | | | |
| Excavation—emergency spillway | 110,000 | CY | $2.50 | $275,000 |
| **Subtotal—Emergency Spillway Construction** | | | | **$275,000** |
| **Principal Spillway:** | | | | |
| Reinforced concrete | | | | |
| 7' X 7' box culvert conduit | 290 | CY | $400.00 | $116,000 |
| Anti-seep collars | 39 | CY | $400.00 | $15,600 |
| Riser | 81 | CY | $400.00 | $32,400 |
| Footing | 31 | CY | $400.00 | $12,400 |
| St. Anthony Falls basin | 490 | CY | $400.00 | $196,000 |
| Slide gate | 1 | EA | $6,000.00 | $6,000 |
| Trash rack | 1 | EA | $8,000.00 | $8,000 |
| **Subtotal—Principal Spillway Construction** | | | | **$386,400** |
| **Subtotal—Dam Construction** | | | | **$3,666,793** |
| **Clearing Reservoir** | 175 | AC | $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 kilovolt distribution line | 1 | LS | $30,000.00 | $30,000 |
| 69 kilovolt transmission line | 1 | LS | $270,000.00 | $270,000 |
| Close county roads 182 & 182A | 1 | LS | $150,000.00 | $150,000 |
| Water lines | 1 | LS | $80,000.00 | $80,000 |
| TXDOT Highway 147 | 1 | LS | $2,500,000.00 | $2,500,000 |
| **Subtotal—Conflicts** | | | | **$3,030,000** |

Table 5-10 (continued).

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Engineering & Contingencies (35% Conflicts)** | | | | **$1,060,500** |
| **Land Purchase** | 1,812 | AC | 2,009 | **$3,640,308** |
| **Environmental Studies & Mitigation** | | | | **$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 year)** | | | | **1,380** |
| **Unit Cost: City Share (52%) & NRCS[a] 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; SY=Square Yard.

Table 5-11. Acreage and percent landcover for Brushy Creek Reservoir.

| Landcover Classification | Acreage[a] | Percent |
|---|---|---|
| Upland deciduous forest | 269 | 44.3% |
| Grassland | 58 | 9.5% |
| Shrubland | 45 | 7.3% |
| Agricultural land | 235 | 38.7% |
| **Total** | **607** | **100.0%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

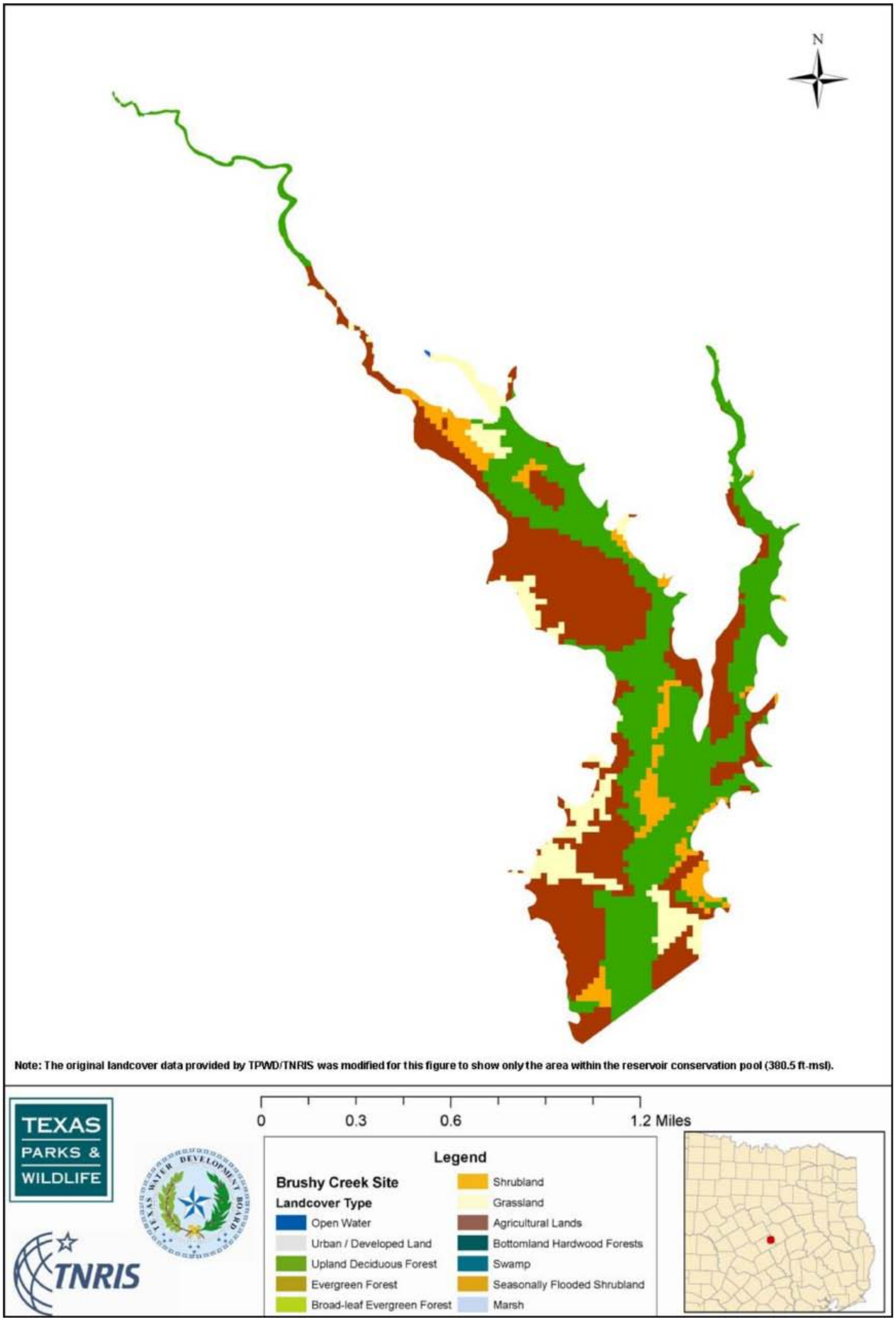


Figure 5-18. Existing landcover for Brushy Creek Reservoir.
ft-msl=feet above mean sea level

## 5.4
## CEDAR RIDGE RESERVOIR (BRECKENRIDGE RESERVOIR)

The proposed Cedar Ridge Reservoir site, also referred to in past plans as the Breckenridge or Reynolds Bend site, will be located in Throckmorton County on the Clear Fork of the Brazos River and in Haskell and Shackelford counties. This reservoir was first studied in 1971 and most recently in 2004 by HDR Engineering (HDR, 2004). The location of this reservoir site differs from the locations in previous reports; it is upstream of the confluence of Paint Creek 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 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 (Figure 5-19). The proposed reservoir will impound 310,383 acre-feet and inundate 6,190 acres at the full conservation storage level of 1,430 feet.

The 2001 Brazos G Regional Water Plan identified Cedar Ridge Reservoir as a potentially feasible project. It 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 recommends that the legislature designate Cedar Ridge Reservoir as a unique reservoir site. Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply in 2060 total 17,240 acre-feet per year 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).

### *5.4.1*
### *Reservoir Yield Analysis*

The elevation-area-capacity relationship

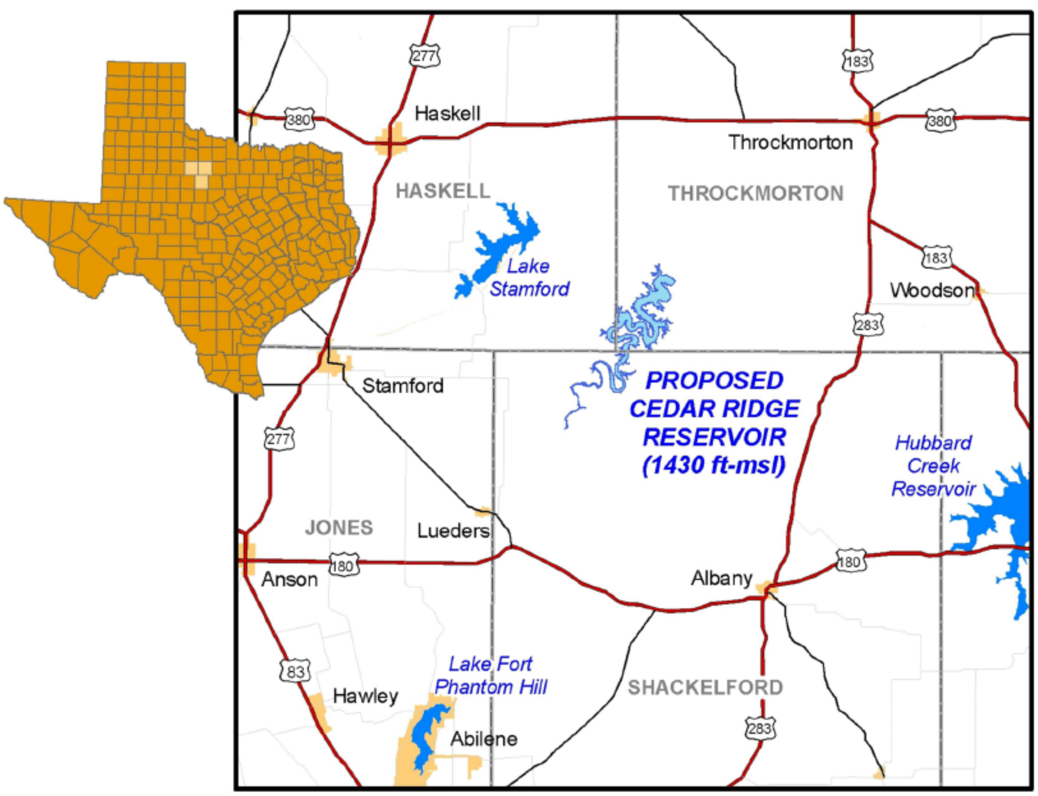


Figure 5-19. Location map of Cedar Ridge Reservoir.
ft-msl=feet above sea level

for Cedar Ridge Reservoir is presented in Table 5-12 and Figure 5-20 and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data are derived from the 1:24,000-scale (7.5-minute) quadrangle maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-21. At the conservation storage pool elevation of 1,430 feet, Cedar Ridge Reservoir will inundate 6,190 acres and have a capacity of 310,383 acre-feet.

Median and quartile (25th percentile) streamflows have been calculated for the Cedar Ridge site based on monthly naturalized flows from the Brazos water availability model. These monthly flows were then disaggregated to daily naturalized flows using historical records of the U.S. Geological Survey 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 5-13.

Table 5-12. Elevation-area-capacity relationship for Cedar Ridge Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

The Consensus Criteria for Environmental Flow Needs were used for modeling Cedar Ridge Reservoir. Pass-through flows are the monthly naturalized median flow when reservoir storage is greater than 80 percent of capacity,

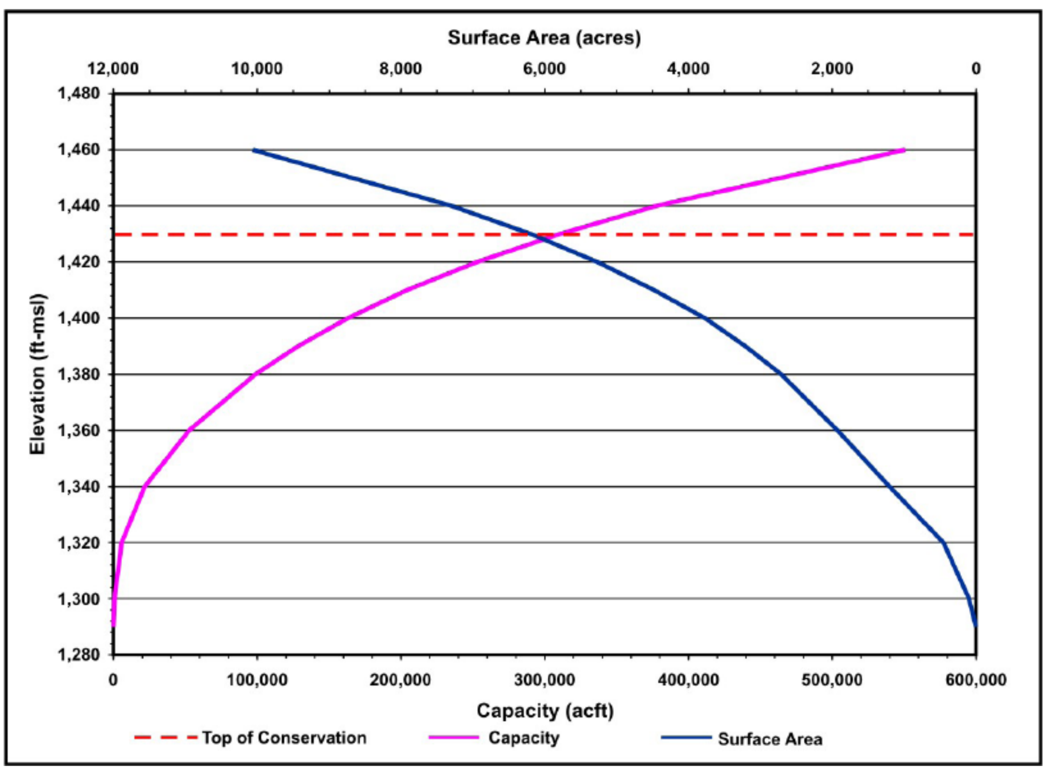


Figure 5-20. Elevation-area-capacity relationship for Cedar Ridge Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

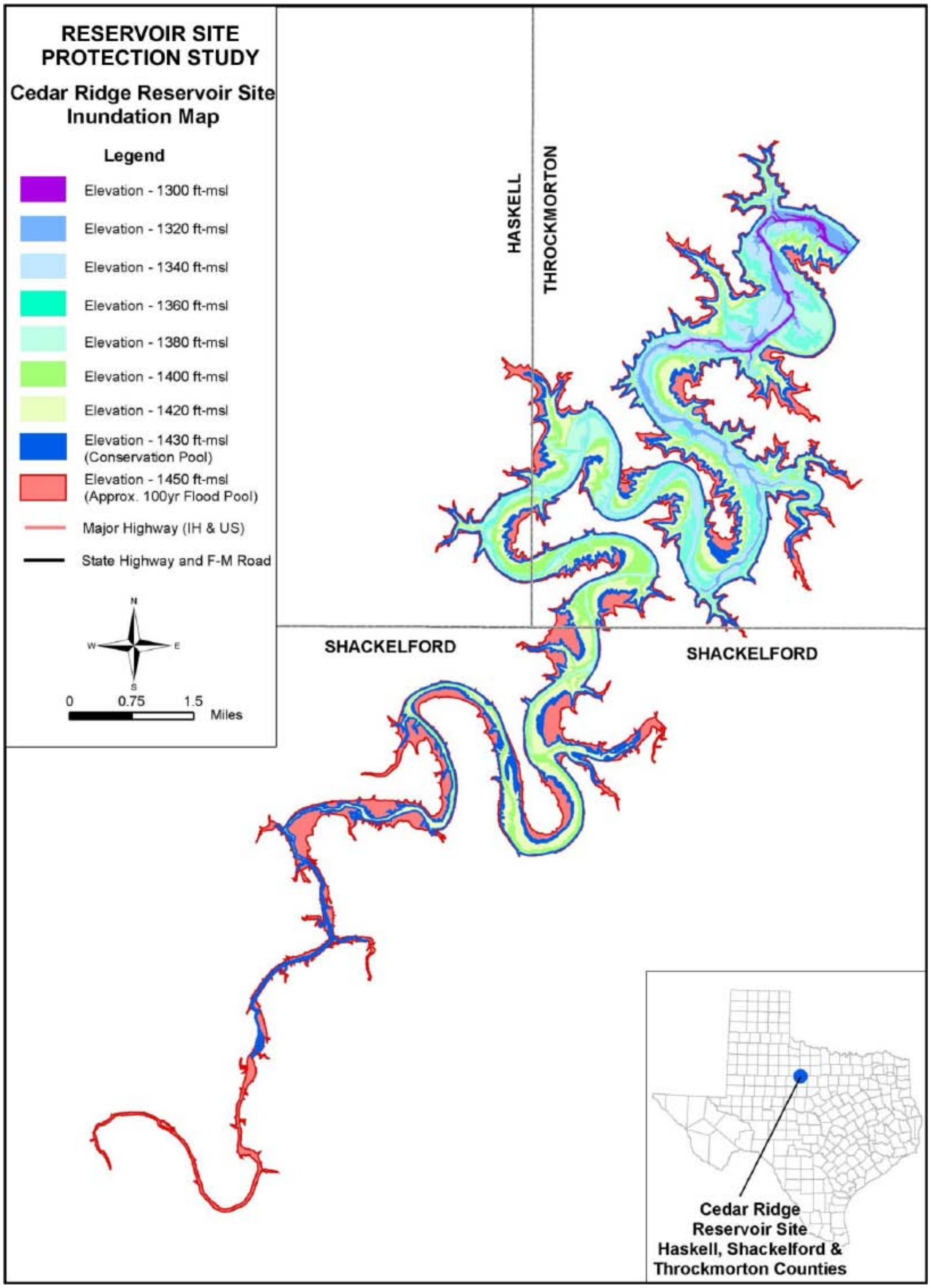


Figure 5-21. Inundation map for Cedar Ridge Reservoir.
ft-msl=feet above mean sea level

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 values used include the median and quartile flows in Table 5-13 and the 7Q2 value of 1.5 cubic feet per second published in the Texas Surface Water Quality Standards (30 Texas Administrative Code §307.10). Cedar Ridge Reservoir will be located well in

Table 5-13. Consensus Criteria for Environmental Flow Needs for Cedar Ridge Reservoir.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 1,510 | 24.6 | 829 | 13.5 | 92 | 1.5 |
| Feb | 1,664 | 30.0 | 815 | 14.7 | 83 | 1.5 |
| Mar | 2,125 | 34.6 | 1,065 | 17.3 | 92 | 1.5 |
| Apr | 2,212 | 37.2 | 760 | 12.8 | 89 | 1.5 |
| May | 3,322 | 54.0 | 772 | 12.6 | 92 | 1.5 |
| Jun | 3,192 | 53.7 | 1,000 | 16.8 | 89 | 1.5 |
| Jul | 1,311 | 21.3 | 168 | 2.7 | 92 | 1.5 |
| Aug | 799 | 13.0 | 92 | 1.5 | 92 | 1.5 |
| Sep | 1,269 | 21.3 | 89 | 1.5 | 89 | 1.5 |
| Oct | 1,482 | 24.1 | 236 | 3.8 | 92 | 1.5 |
| Nov | 1,099 | 18.5 | 246 | 4.1 | 89 | 1.5 |
| Dec | 1,024 | 16.7 | 432 | 7.0 | 92 | 1.5 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-14. Firm yield versus conservation storage for Cedar Ridge Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) |
|---|---|---|---|
| 1,410 | 204,399 | CCEFN[d] | 31,860 |
| 1,420 | 253,125 | CCEFN | 34,000 |
| 1,430* | 310,383 | CCEFN | 36,891 |
| | | None | 39,225 |
| 1,440 | 377,727 | CCEFN | 39,033 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

excess of 200 river miles from the coast, so freshwater inflow needs for bays and estuaries are not explicitly considered in this report, but are assumed to be sufficiently addressed by the Consensus Criteria for Environmental Flow Needs.

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

For the purposes of this study, Possum Kingdom Reservoir is assumed to be subordinate to Cedar Ridge Reservoir. Specific terms of such subordination, however, are the subject of negotiations between reservoir sponsors and the Brazos River Authority. In this report, estimates of Cedar Ridge Reservoir firm yield do not include passage of inflow for senior water rights associated with Possum Kingdom Reservoir.

We modeled four potential conservation storage capacities for Cedar Ridge Reservoir associated with 1,410 feet, 1,420 feet, 1,430 feet, and 1,440 feet conservation pool elevations (Table 5-14). Firm yield estimates for Cedar Ridge Reservoir for all four conservation pool elevations are also shown in Table 5-14. Current planning initiatives envision a conservation pool elevation of 1,430 feet for the reservoir, thereby yielding a firm supply of 36,891 acre-feet per year. For comparison purposes, the firm yield of the reservoir at a conservation pool elevation of 1,430 feet without an environmental flow requirement is 39,225 acre-feet per year. Figure 5-22 shows the relationship between firm yield and conservation storage capacity for Cedar Ridge Reservoir.

Cedar Ridge Reservoir was most recently studied for the 2006 Brazos G Regional Water Plan. The safe yield of Cedar Ridge Reservoir in that report is 31,910 acre-feet per year at a conservation pool elevation of 1,430 feet.

Figure 5-23 illustrates storage fluctuations through time for Cedar Ridge Reservoir subject to firm yield diversions and the Consensus Criteria for Environmental Flow Needs. The reservoir storage frequency curve indicates that the reservoir will be full approximately 4 percent of the time and more than half full about 64 percent of the time.

### 5.4.2
### Reservoir Costs

The Cedar Ridge Reservoir includes the construction of an earthen dam, principal and emergency spillways, 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 will include a Morning Glory intake, a 14-foot diameter outlet pipe, a stilling basin, and an outlet channel to convey up to 5,000 cubic feet per second. A summary cost estimate for Cedar Ridge Reservoir at an elevation of 1,430 feet is shown in Table 5-15. Dam and reservoir costs total about $62.4 million, and relocations add $18.7 million. Land, including 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 per acre-foot ($0.71 per 1,000 gallons).

The major conflicts within a 1-mile buffer of the reservoir include oil and gas wells and a power transmission line (Figure 5-24). According to the Texas Natural Resources Information System, there are 65 oil and gas wells within the conservation storage level (1,430 feet) of the reservoir. Resolving 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.

### 5.4.3
### Environmental Considerations

Cedar Ridge Reservoir will inundate a portion of the Texas Commission on Environmental Quality classified stream segment 1232. This segment is not listed by Texas Parks and Wildlife Department as an ecologically significant stream segment.

Cedar Ridge Reservoir will inundate 6,190 acres of land at conservation storage capacity. Table 5-16 and Figure 5-25 summarize existing landcover for the Cedar Ridge Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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).

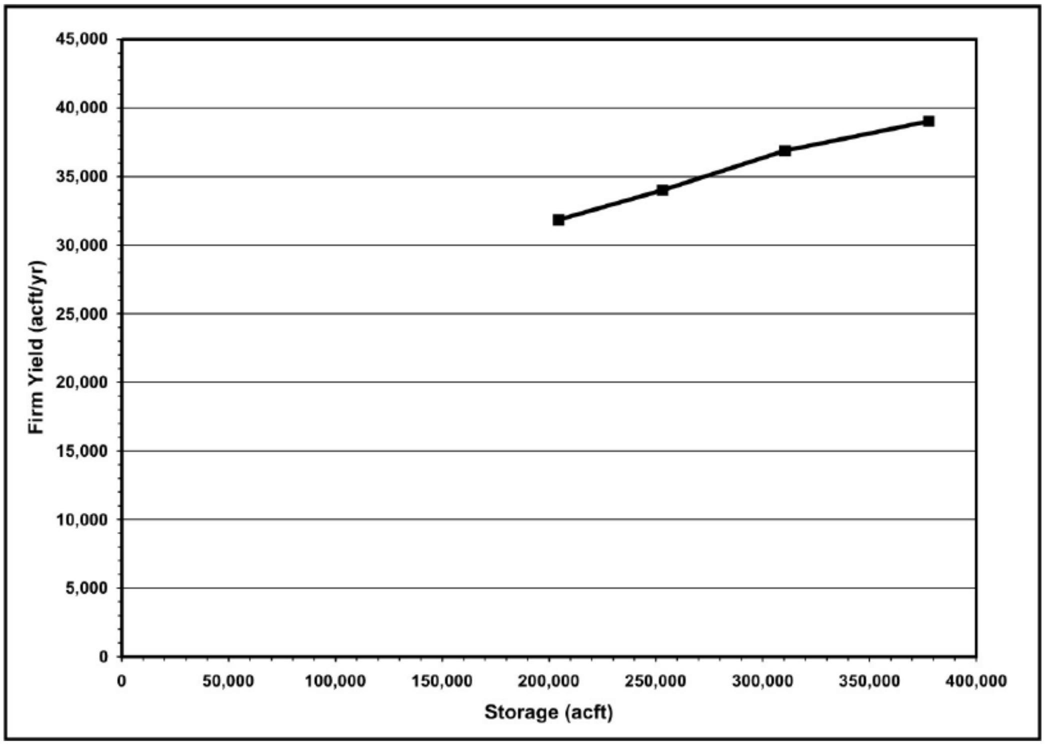


Figure 5-22. Firm yield versus conservation storage for Cedar Ridge Reservoir.
acft/yr=acre-feet per year

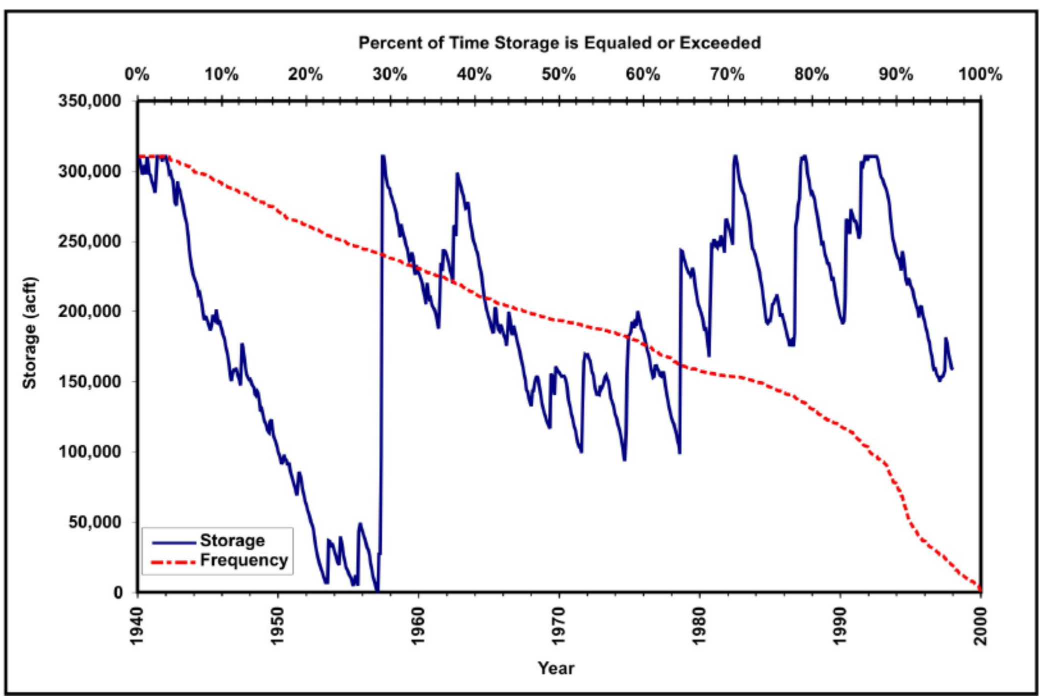


Figure 5-23. Simulated storage in Cedar Ridge Reservoir (conservation elevation=1,430 feet; diversion=36,891 acre-feet per year).
acft=acre-feet

Table 5-15. Cost estimate — Cedar Ridge Reservoir at elevation 1,430 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | | LS | | $2,170,125 |
| Clearing & grubbing | 100 | AC | $2,000.00 | $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 & conduit | 1 | LS | $6,200,000.00 | $6,200,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Instrumentation | 1 | LS | $550,000.00 | $550,000 |
| Emergency spillway | 1 | LS | $4,250,000.00 | $4,250,000 |
| Engineering contingencies (35%) | | | | $16,172,328 |
| **Subtotal Dam & Reservoir** | | | | **$62,378,978** |
| **Conflicts** | | | | |
| Roads | 1 | LS | $10,980,000.00 | $10,980,000 |
| Existing structures | 1 | LS | $1,250,000.00 | $1,250,000 |
| Oil & gas wells | 65 | EA | $25,000.00 | $1,620,000 |
| Engineering contingencies (35%) | | | | $4,849,500 |
| **Subtotal Conflicts** | | | | **$18,704,500** |
| **Land** | | | | |
| Land acquisition | 10,066 | AC | $850.00 | $8,556,100 |
| Environmental studies & mitigation | | | | $8,556,100 |
| **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 (Brazos River Authority) | 5,000 | acft/yr | $45.75 | $228,750 |
| **Total Annual Costs** | | | | **$8,473,631** |
| **Firm Yield (acre-feet per year)** | | | | **36,891** |
| **Unit Costs of Water ($/acre-foot )** | | | | **$230** |

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

Table 5-16. Acreage and percent landcover for Cedar Ridge Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

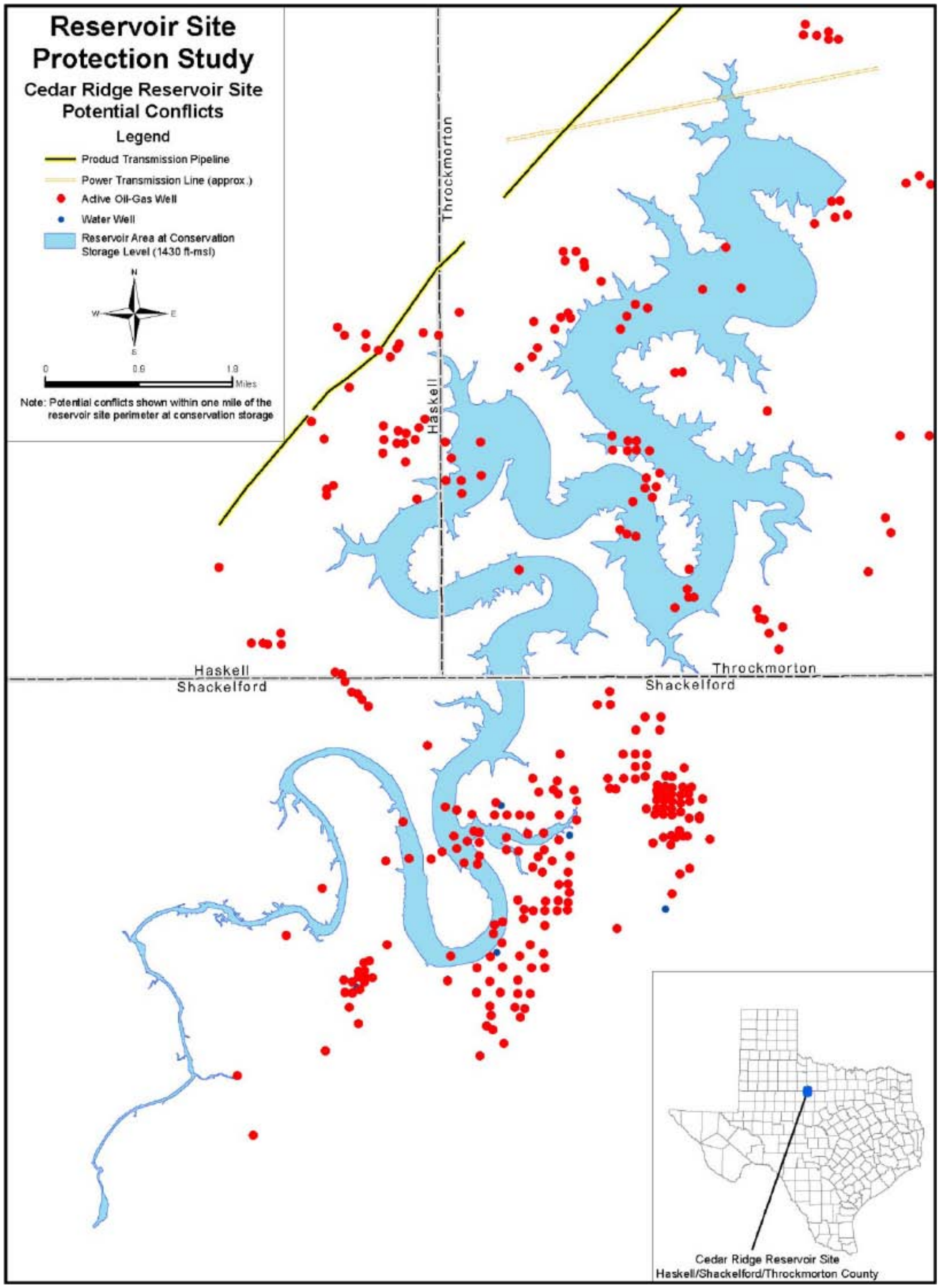


Figure 5-24. Potential major conflicts for Cedar Ridge Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

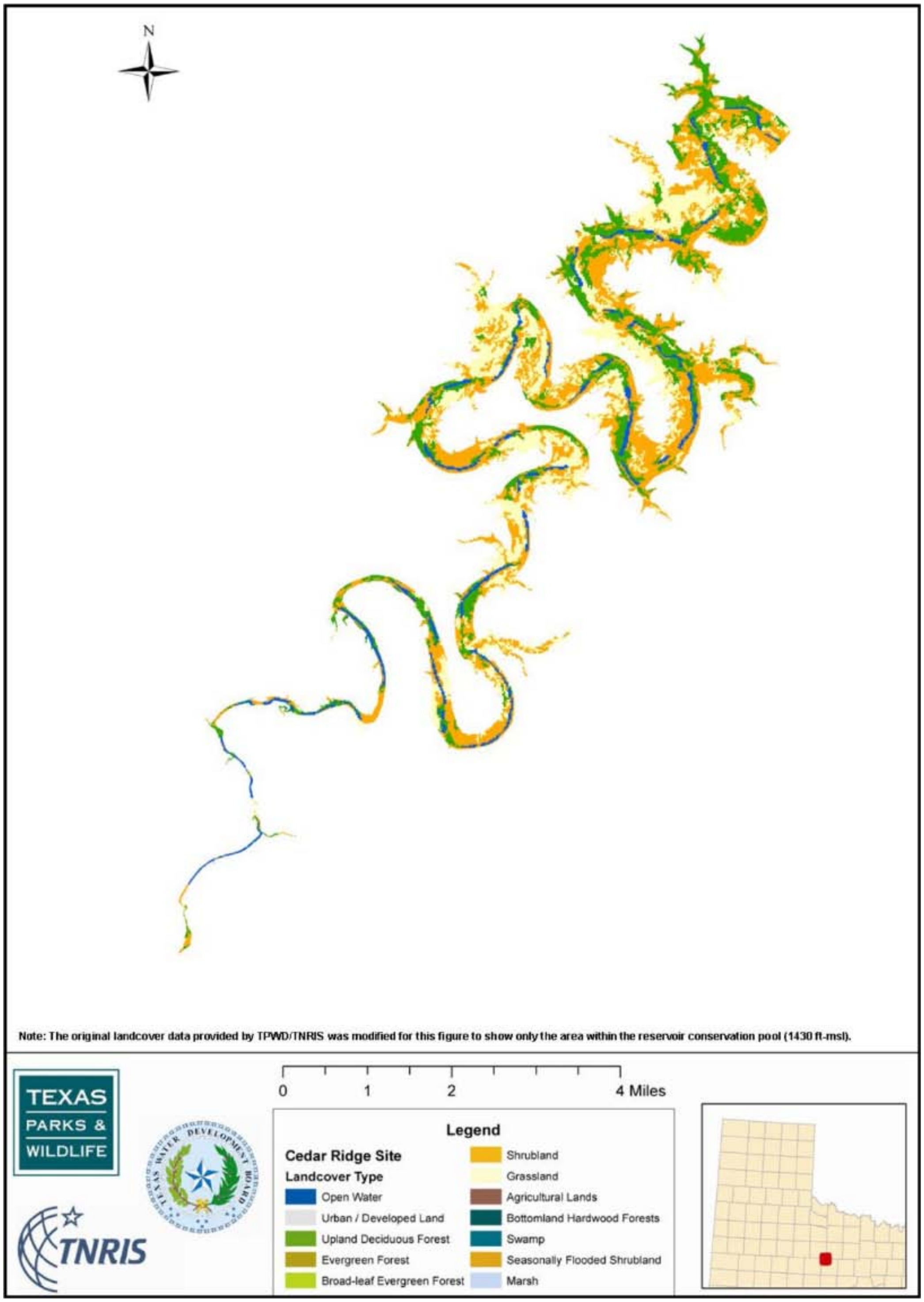


Figure 5-25. Existing landcover for Cedar Ridge Reservoir.
ft-msl=feet above mean sea level

## 5.5 Cuero II Reservoir (Sandies Creek Reservoir or Lindenau Reservoir)

Cuero II Reservoir, also known as Sandies Creek Reservoir or Lindenau Reservoir in previous studies, is a proposed reservoir that will be located on Sandies Creek, a tributary of the Guadalupe River in DeWitt and Gonzales counties (Figure 5-26). The project will 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 in the mid-1960s (BOR, 1965). Subsequent studies of the reservoir have been performed (TWDB, 1966), the latest of which was in the 2001 South Central Texas Regional Water Plan.

The dam will impound runoff from the 678 square mile watershed and extend about 2 miles across the Sandies Creek valley. At its conservation elevation, the reservoir will have a conservation storage capacity of 583,975 acre-feet, inundating 28,154 acres. The spillway design flood elevation will be 240.5 feet and inundate approximately 36,967 acres.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply by year 2060 total 346,140 acre-feet per year 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).

### 5.5.1 *Reservoir Yield Analysis*

The elevation-area-capacity relationship for Cuero II Reservoir is presented in Table 5-17 and Figure 5-27 and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data were derived from the 1:24,000-scale (7.5-minute) quadrangle

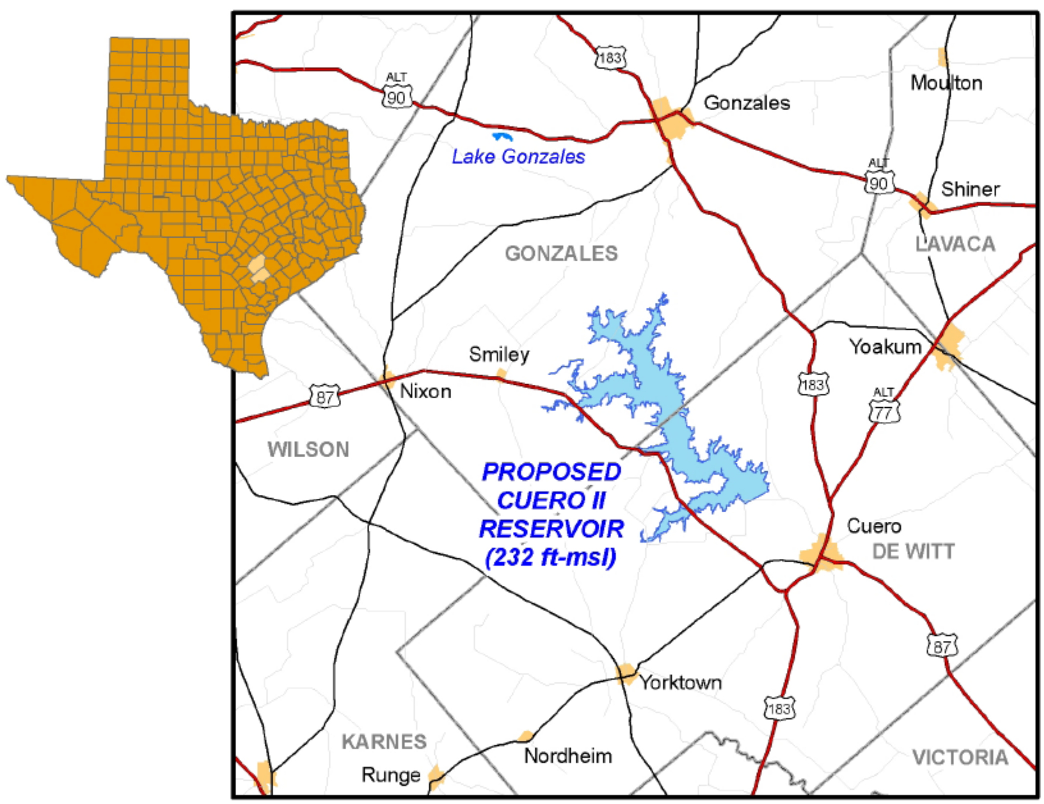


Figure 5-26. Location map of Cuero II Reservoir.
ft-msl=feet above mean sea level

maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-28. Surface areas and capacities associated with 232 feet are computed by linear interpolation between values for 230 and 240 feet and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 232 feet, Cuero II Reservoir will inundate 28,154 acres and have a capacity of 583,975 acre-feet.

The Consensus Criteria for Environmental Flow Needs were used for modeling 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 values used include the median and quartile flows in Table 5-18 and the 7Q2 value of 3.5 cubic feet per second published in the Texas Surface Water Quality Standards (30 Texas Administrative Code §307.10).

In addition, the waters diverted from the Guadalupe River to supplement runoff into Cuero II Reservoir are subject to the Consensus Criteria for Environmental Flow Needs. Triggers for run-of-river diversions are based on streamflow

Table 5-17. Elevation-area-capacity relationship for Cuero II Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

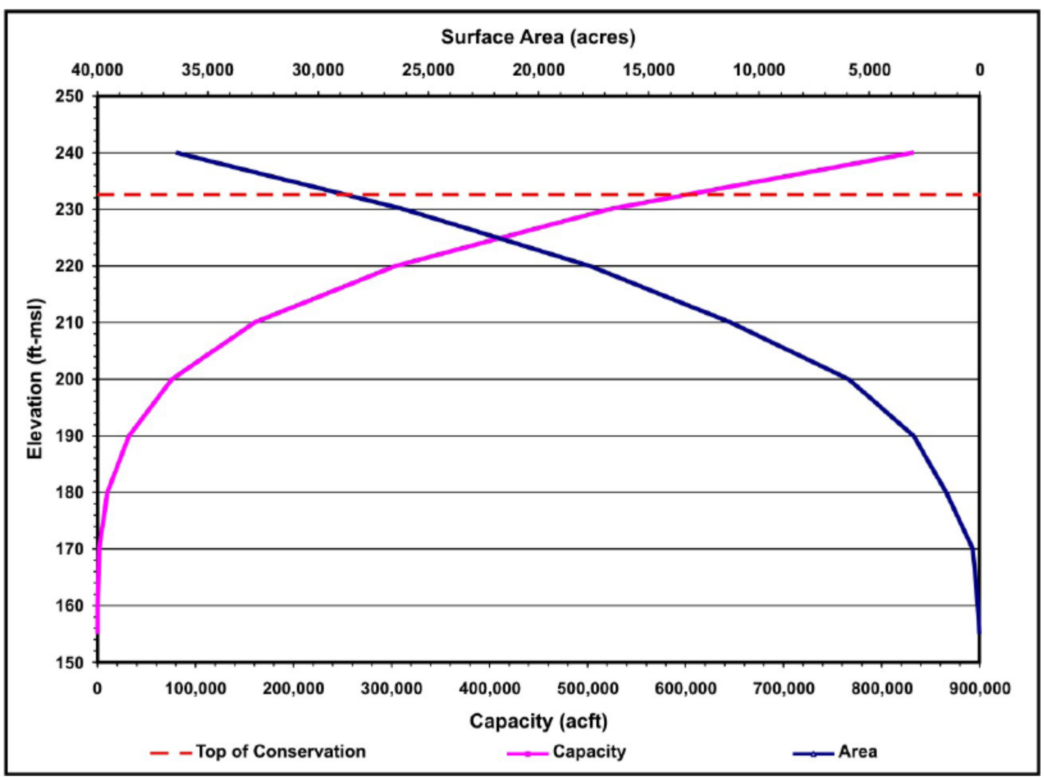


Figure 5-27. Elevation-area-capacity relationship for Cuero II Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

passing the diversion point. Table 5-19 lists the median and quartile flows for the Guadalupe River at Cuero. The published 7Q2 value for this segment of the Guadalupe River is 317.1 cubic feet per second (30 Texas Administrative Code §310.10).

The firm yield of Cuero II Reservoir was estimated using the Guadalupe-San Antonio River Basin water availability model data sets and the Water Rights Analysis Package. The model simulates a repeat of the natural streamflows over the 56-year period of 1934 through 1989,

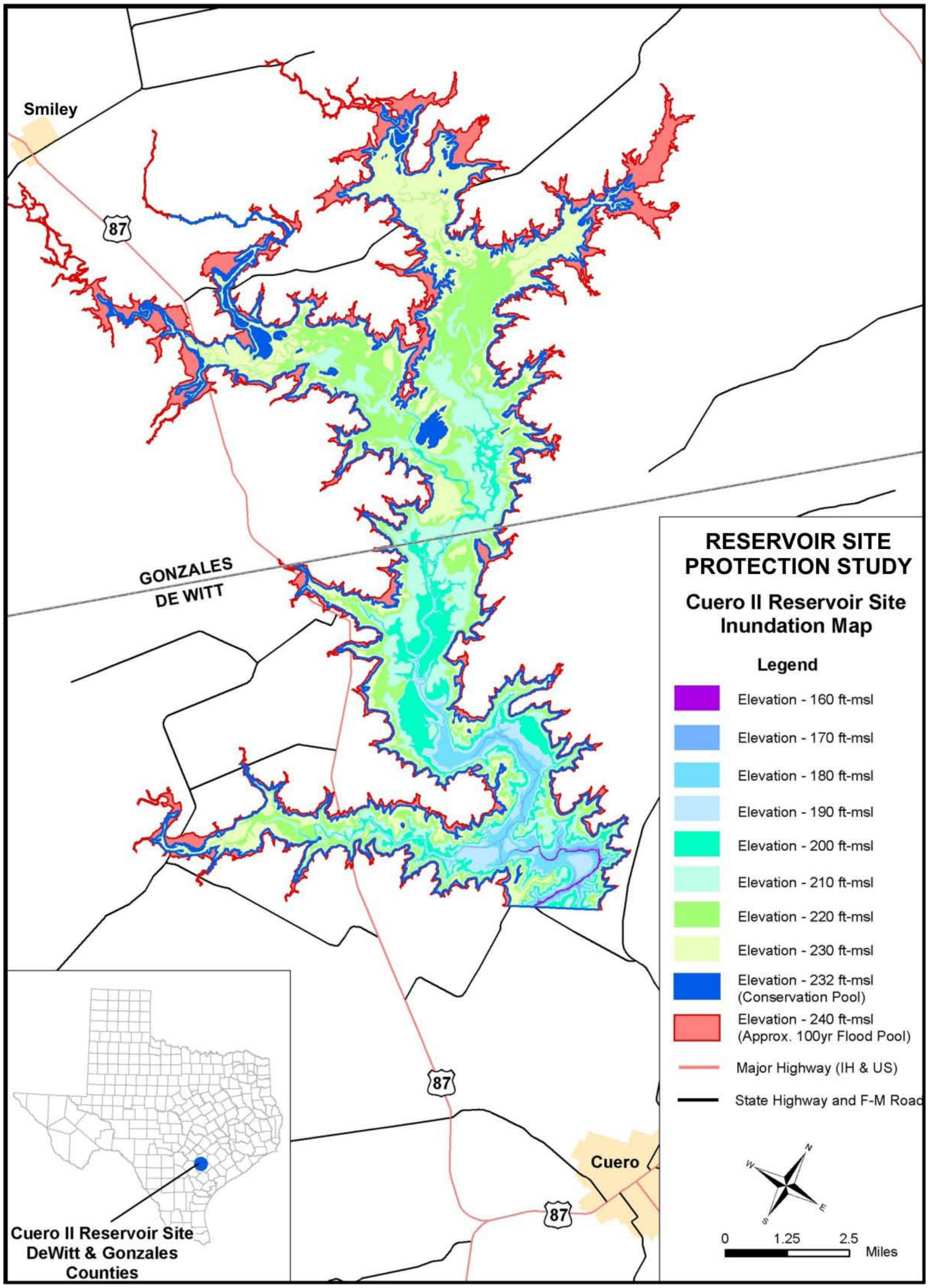


Figure 5-28. Inundation map for Cuero II Reservoir.
ft-msl=feet above mean sea level

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.

We modeled four potential conservation storage capacities for Cuero II Reservoir associated with 240 feet, 232 feet, 225 feet, and 220 feet conservation pool elevations. Table 5-20 includes the storage capacities and firm yield associated with these four conservation pool elevations. For the purposes of this study, one maximum diversion rate of 786 cubic feet per second from the Guadalupe River to Cuero II Reservoir has been assumed for all four conservation storage capacities.

Cuero II Reservoir was simulated with a priority date junior to all existing water rights in the Guadalupe-San Antonio River Basin. At a conservation pool elevation of 232 feet, the firm yield is 71,437 acre-feet per year. Figure 5-29 shows the relationship between firm yield and conservation storage capacity for Cuero II Reservoir.

Cuero II Reservoir was most recently evaluated by Region L in the 2001 South Central Texas Regional Water Plan. The firm yield of Cuero II Reservoir was reported as 80,836 acre-feet per year at a conservation pool elevation of 232 feet. The firm yield estimate in the current study differs from the 2001 Region L 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-

Table 5-18. Consensus Criteria for Environmental Flow Needs for Cuero II Reservoir.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 1,023 | 16.6 | 651 | 10.6 | 215 | 3.5 |
| Feb | 1,092 | 19.7 | 616 | 11.1 | 194 | 3.5 |
| Mar | 1,054 | 17.1 | 651 | 10.6 | 215 | 3.5 |
| Apr | 960 | 16.1 | 480 | 8.1 | 208 | 3.5 |
| May | 1,240 | 20.2 | 465 | 7.6 | 215 | 3.5 |
| Jun | 1,020 | 17.1 | 420 | 7.1 | 208 | 3.5 |
| Jul | 589 | 9.6 | 215 | 3.5 | 215 | 3.5 |
| Aug | 434 | 7.1 | 215 | 3.5 | 215 | 3.5 |
| Sep | 630 | 10.6 | 240 | 4.0 | 208 | 3.5 |
| Oct | 713 | 11.6 | 310 | 5.0 | 215 | 3.5 |
| Nov | 840 | 14.1 | 420 | 7.1 | 208 | 3.5 |
| Dec | 930 | 15.1 | 558 | 9.1 | 215 | 3.5 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-19. Consensus Criteria for Environmental Flow Needs for Guadalupe River diversions.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 58,032 | 944 | 36,301 | 590 | 19,498 | 317.1 |
| Feb | 56,392 | 1,015 | 35,616 | 641 | 17,611 | 317.1 |
| Mar | 62,403 | 1,015 | 38,037 | 619 | 19,498 | 317.1 |
| Apr | 62,010 | 1,042 | 36,150 | 608 | 18,869 | 317.1 |
| May | 76,291 | 1,241 | 41,261 | 671 | 19,498 | 317.1 |
| Jun | 66,660 | 1,120 | 35,940 | 604 | 18,869 | 317.1 |
| Jul | 51,956 | 845 | 29,326 | 477 | 19,498 | 317.1 |
| Aug | 40,610 | 660 | 21,452 | 349 | 19,498 | 317.1 |
| Sep | 43,350 | 729 | 24,750 | 416 | 18,869 | 317.1 |
| Oct | 51,522 | 838 | 29,822 | 485 | 19,498 | 317.1 |
| Nov | 50,640 | 851 | 31,890 | 536 | 18,869 | 317.1 |
| Dec | 54,188 | 881 | 34,937 | 568 | 19,498 | 317.1 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-20. Firm yield versus conservation storage for Cuero II Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) |
|---|---|---|---|
| 220 | 304,326 | CCEFN[d] | 49,418 |
| 225 | 413,030 | CCEFN | 58,367 |
| 232* | 583,975 | CCEFN | 71,437 |
| | | None | 83,498 |
| 240 | 832,937 | CCEFN | 85,223 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

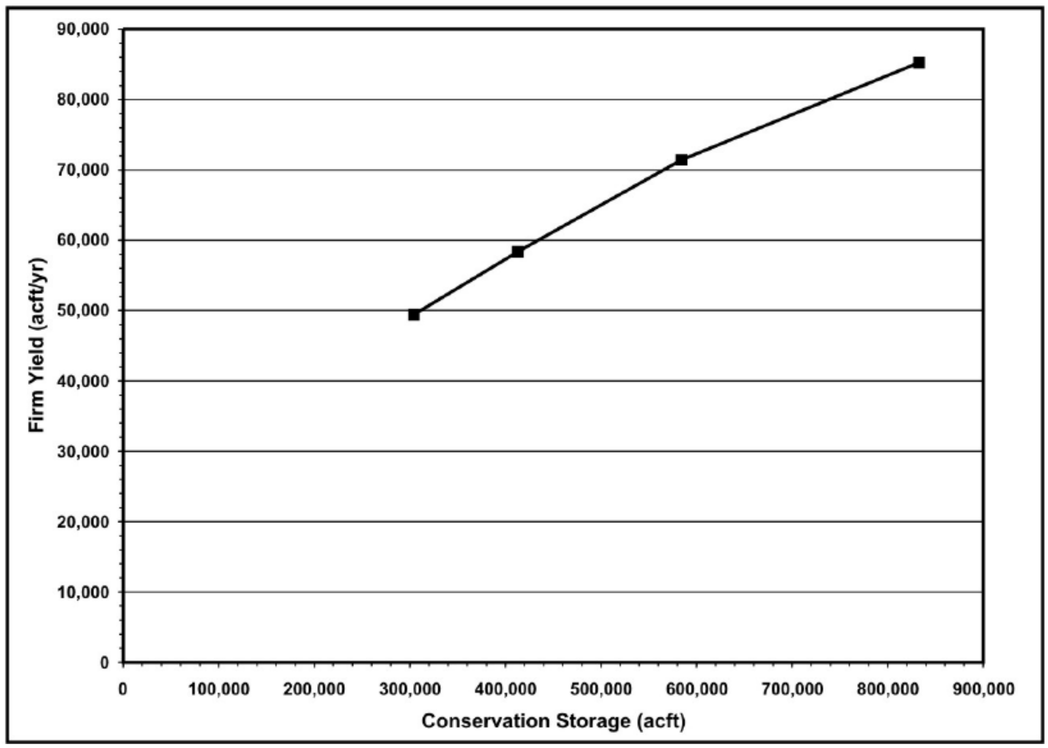


Figure 5-29. Firm yield versus conservation storage for Cuero II Reservoir.
acft/yr=acre-feet per year

capacity relationship in the current study has reduced the conservation capacity at an elevation of 232 feet from 606,280 acre-feet to 583,975 acre-feet.

Figure 5-30 illustrates storage fluctuations through time for Cuero II Reservoir subject to firm yield diversions and the Consensus Criteria for Environmental Flow Needs. The reservoir storage frequency curve indicates that the reservoir will be full about 30 percent of the time and more than half full about 94 percent of the time.

### *5.5.2 Reservoir Costs*

The Cuero II Reservoir includes the construction of an earthen dam, appurtenant structures, and principal and emergency spillways that are roller-compacted concrete. The length of the dam is estimated at 10,640 feet with a maximum height of 101 feet. The service spillway will include an uncontrolled ogee spillway, a hydraulic jump stilling basin, and two 5-foot by 8-foot low-flow sluiceway outlets. The diversion from the Guadalupe

River near Cuero includes a 510 million gallon-per-day intake and pump station, two 1.48-mile, 120-inch pipelines, and a stilling basin.

A summary cost estimate for Cuero II Reservoir at an elevation of 232 feet is shown in Table 5-21. Espey, Huston & Associates (1986) have a detailed explanation of the reservoir and construction costs. Dam and reservoir costs total about $121 million, and relocations total another $34 million. Land, including mitigation lands, totals about $229 million. The diversion intake, pump station, and pipeline from the Guadalupe River to Cuero II Reservoir add 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 per acre-foot ($1.54 per 1,000 gallons).

The potential major conflicts within the conservation pool of Cuero II Reservoir 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 (Figure 5-31). Resolving facility conflicts represents approximately 8 percent of the total construction cost.

### *5.5.3 Environmental Considerations*

Cuero II Reservoir will inundate portions of Texas Commission on Environmental Quality unclassified stream segments 1803A (Elm Creek) and 1803B (Sandies Creek). Neither these segments nor the Guadalupe River near Cuero are listed by the Texas Parks and Wildlife Department as ecologically significant stream segments.

Cuero II Reservoir will inundate 28,154 acres of land at conservation storage capacity. Figure 5-32 and Table 5-22 summarize existing landcover for the Cuero II Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C.

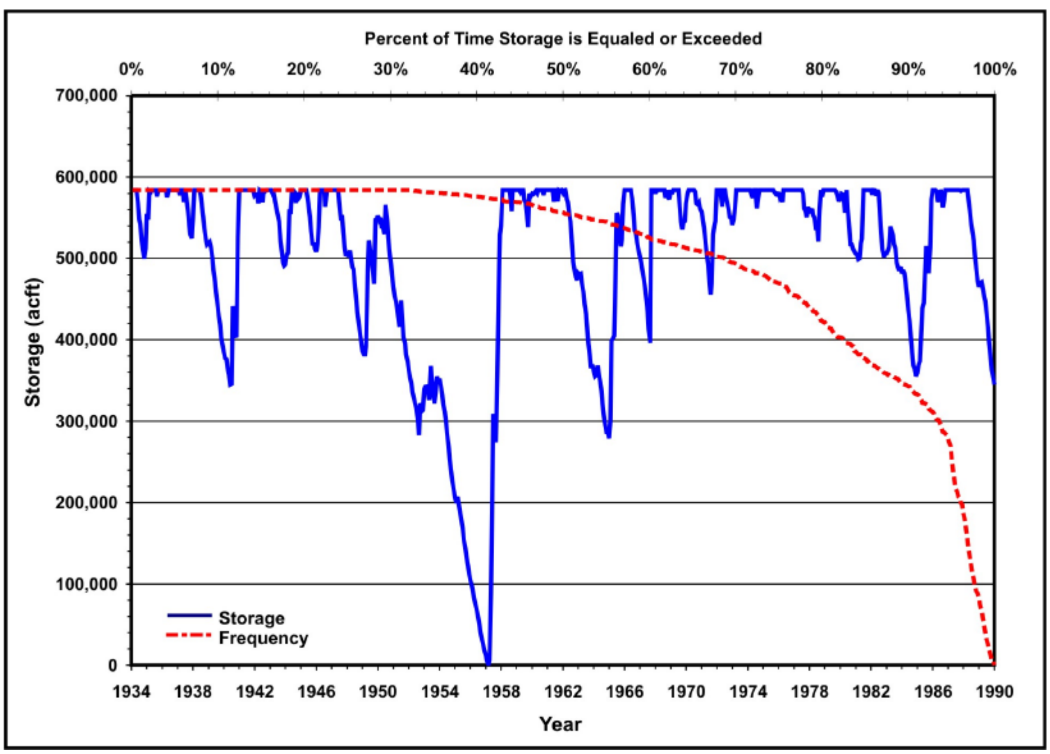


Figure 5-30. Simulated storage in Cuero II Reservoir (conservation elevation=232 feet; diversion=71,437 acre-feet per year).
acft=acre-feet

Table 5-21. Cost estimate—Cuero II Reservoir at elevation 232 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | | LS | | $2,300,329 |
| Clearing & grubbing | 10,066 | AC | $4,000.00 | $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 & conduit | 1 | LS | $2,858,000.00 | $2,858,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Instrumentation | 1 | LS | $550,000.00 | $550,000 |
| Spillway low-flow system | 1 | LS | $400,000.00 | $400,000 |
| Engineering contingencies (35%) | | | | $31,482,888 |
| **Subtotal Dam & Reservoir** | | | | **$121,433,995** |
| Pump & Pipeline | | | | |
| Pump station & intake (510 MGD) | 1 | LS | $28,688,730.00 | $28,688,730 |
| Pipeline (2-120-inch) | 15,629 | LF | $870.00 | $13,597,230 |
| Stilling basin (786 cfs) | 1 | LS | $2,377,650.00 | $2,377,650 |
| Engineering contingencies (35%) | | | | $15,632,264 |
| **Subtotal Pump & Pipeline** | | | | **$60,295,874** |
| Conflicts | | | | |
| Oil & gas pipeline | 7,597 | LF | $48.00 | $364,679 |
| Power transmission line | 7,170 | LF | $450.00 | $3,226,541 |
| Roads | 45,322 | LF | | |
| Major | 18,480 | LF | $900.00 | $16,632,000 |
| Minor | 26,842 | LF | $150.00 | $4,026,271 |
| H20 drill | 4 | EA | $25,000.00 | $100,000 |
| H20 well | 14 | EA | $25,000.00 | $350,000 |
| Oil & gas well | 23 | EA | $25,000.00 | $575,000 |
| Engineering contingencies (35%) | | | | $8,846,072 |
| **Subtotal Conflicts** | | | | **$34,120,564** |
| **Land** | | | | |
| Land acquisition | 36,967 | AC | $3,100.00 | $114,597,700 |
| Environmental studies & mitigation | | | | $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** | | | | **$35,825,553** |
| **Firm Yield (acre-feet per year)** | | | | **71,437** |
| **Unit Costs of Water ($/acre-foot)** | | | | **$501** |

Units: AC=Acre; CY=Cubic Yard; EA=Each; LB=Pound; LF=Linear Foot; LS=Lump Sum; SF=Square Foot; SY=Square Yard; MGD=Million Gallons per Day; cfs=cubic feet per second.

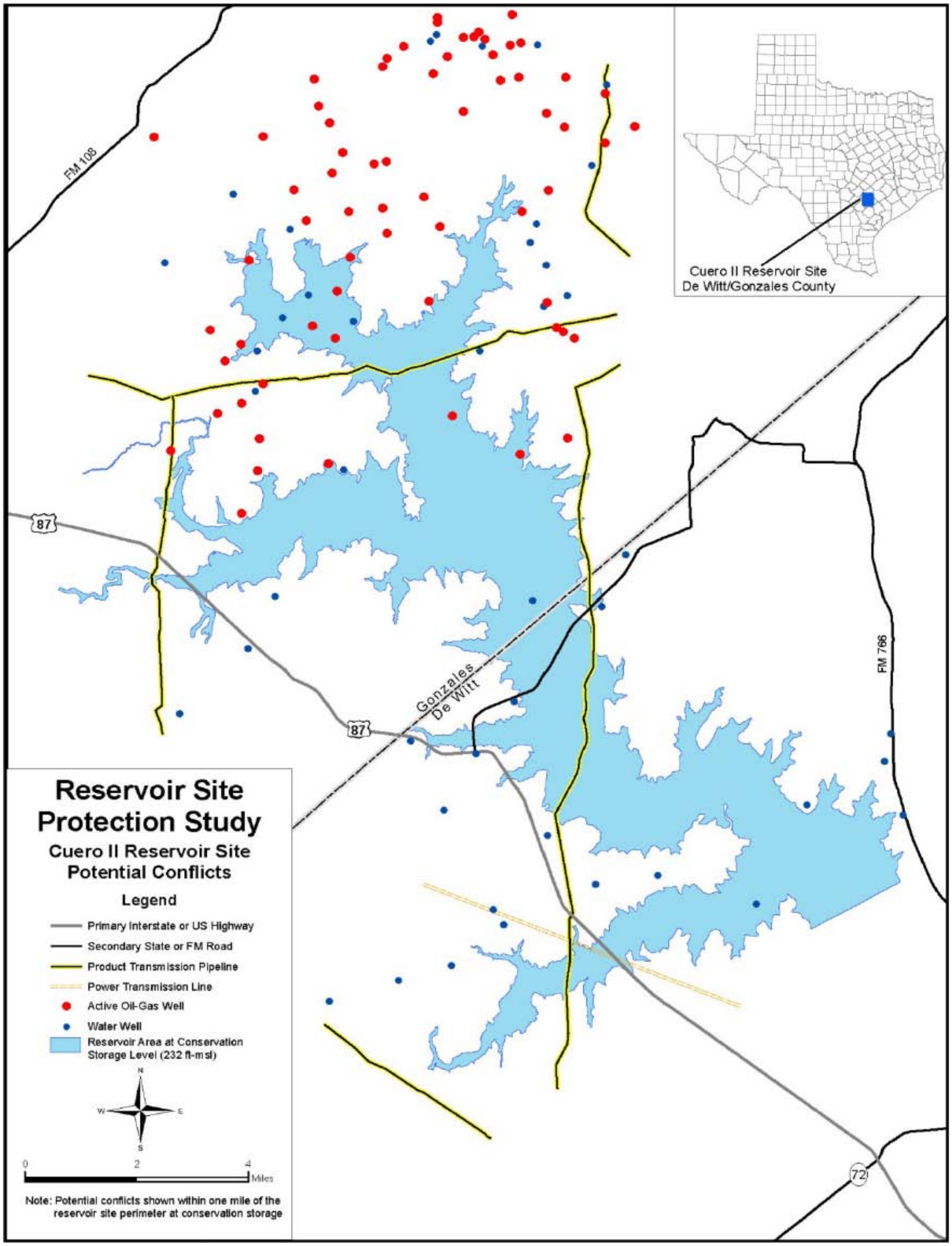


Figure 5-31. Potential major conflicts for Cuero II Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Landcover 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.

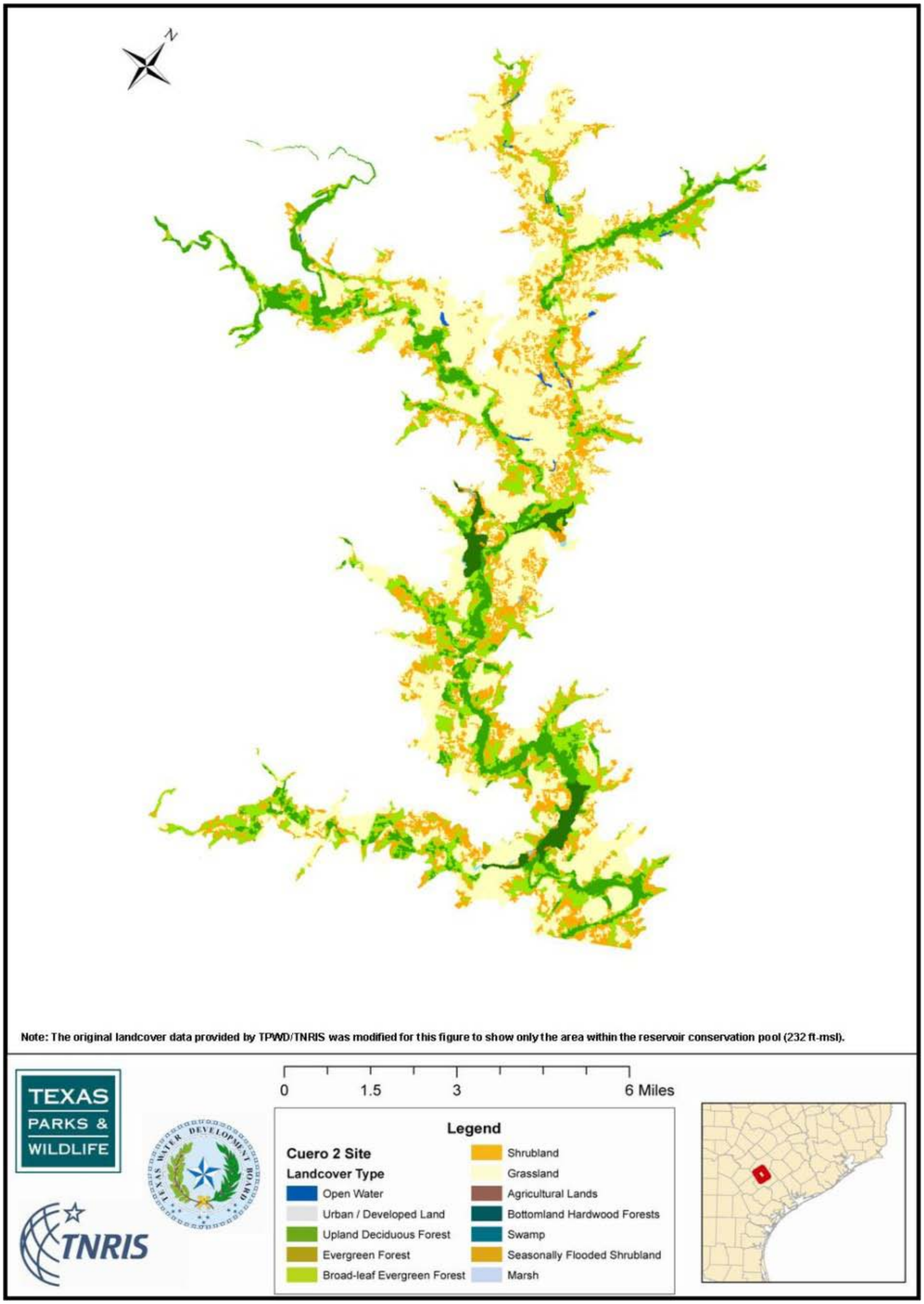


Figure 5-32. Existing landcover for Cuero II Reservoir.
ft-msl=feet above mean sea level

Table 5-22. Acreage and percent landcover for Cuero II Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

## 5.6 Fastrill Reservoir (Weches Reservoir)

The Fastrill Reservoir project in Anderson and Cherokee counties was first identified and evaluated for the Upper Neches River Municipal Water Authority (Forrest and Cotton, 1961). In this plan, Fastrill Reservoir was identified as one among three potential reservoir projects (including Ponta Reservoir and a substantial enlargement of Lake Palestine) for developing new water supplies in the Neches River Basin. The proposed dam location is below State Highway 294, with a conservation storage pool level of 274 feet and flood pool level of approximately 280 feet (Figure 5-33). The reservoir will impound 503,563 acre-feet and inundate 24,948 acres.

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 feet), would inundate the entire Fastrill Reservoir area (Figure 5-34). Conservation storage capacity for Weches Reservoir (~1,402,000 acre-feet) was to have been about 2.8 times that of Fastrill Reservoir (~500,000 acre-feet).

With the advent of regional water planning, Fastrill Reservoir emerged as a potentially feasible project identified in the 2001 East Texas (Region I) Regional Water Plan. In the 2006 Region C Regional Water Plan, 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 Regional

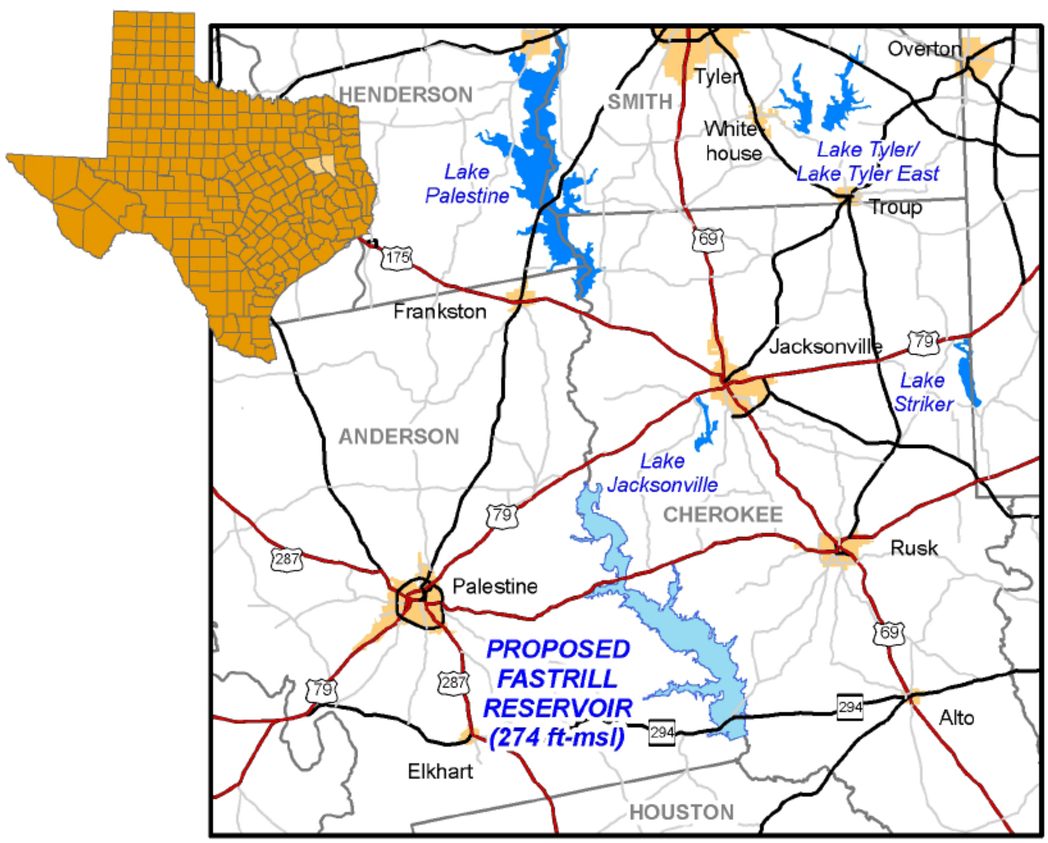


Figure 5-33. Location map of Fastrill Reservoir.
ft-msl=feet above mean sea level

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 uniquely suited to provide water supply for Region C. The 2006 East Texas Regional Water Plan also recognizes Fastrill Reservoir as an alternative water management strategy to meet projected needs in Region I. The 2007 State Water Plan recommends designating the Fastrill site as a unique reservoir site.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply by year 2060 total 136,476 acre-feet per year 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).

Table 5-23. Elevation-area-capacity relationship for Fastrill Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

### *5.6.1*
### *Reservoir Yield Analysis*

The elevation-area-capacity relationship for Fastrill Reservoir is presented in Table 5-23 and Figure 5-35 and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data were derived from the

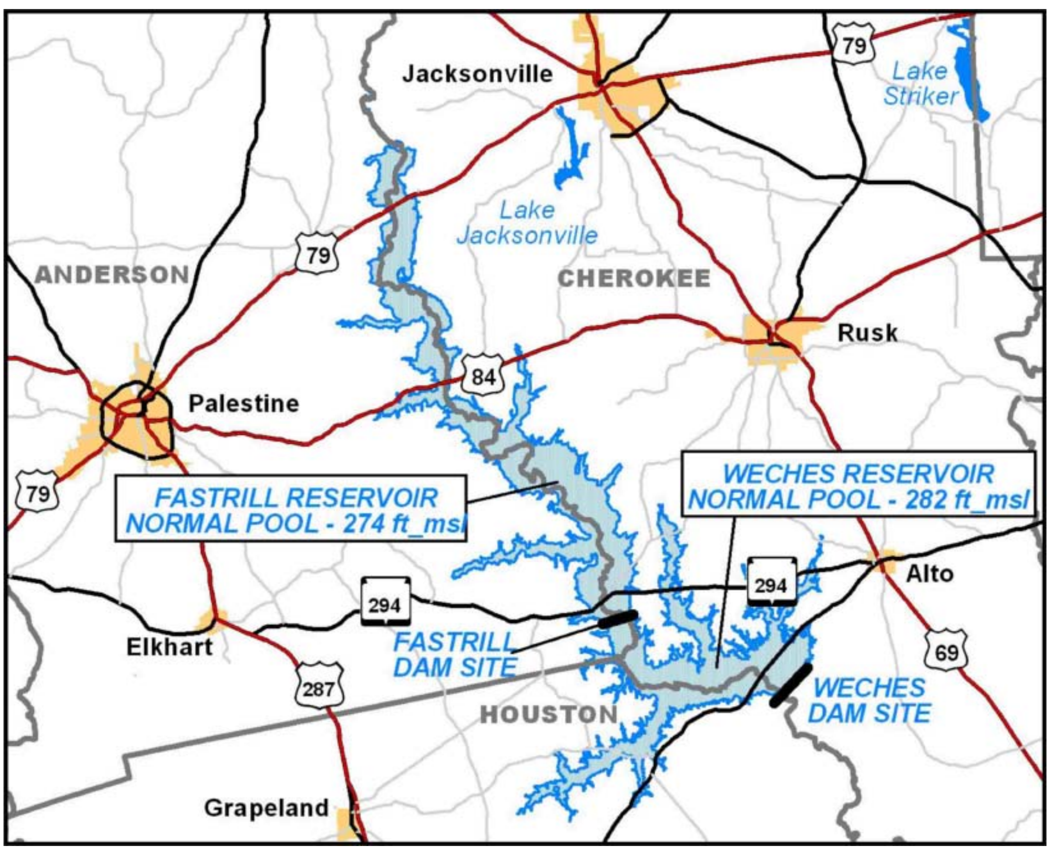


Figure 5-34. Location map of Weches Reservoir.
ft-msl=feet above mean sea level

1:24,000-scale (7.5-minute) quadrangle maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-36. Surface areas and capacities associated with 274 feet are computed by linear interpolation between values for 270 and 280 feet and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 274 feet, Fastrill Reservoir will inundate 24,948 acres and have a capacity of 503,563 acre-feet.

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 (Brown and Root and others, 2000). These monthly flows are then disaggregated to daily naturalized flows using historical records of streamflow for the U.S. Geological Survey gaging station near Neches on the Neches River. 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 5-24.

The Consensus Criteria for Environmental Flow Needs were used for modeling 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 values used include the median and quartile flows in Table 5-24 and the 7Q2 value of 67.4 cubic feet per second published in the Texas Surface Water Quality Standards (30 Texas Administrative Code §310.10). 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 in this report but are assumed to be

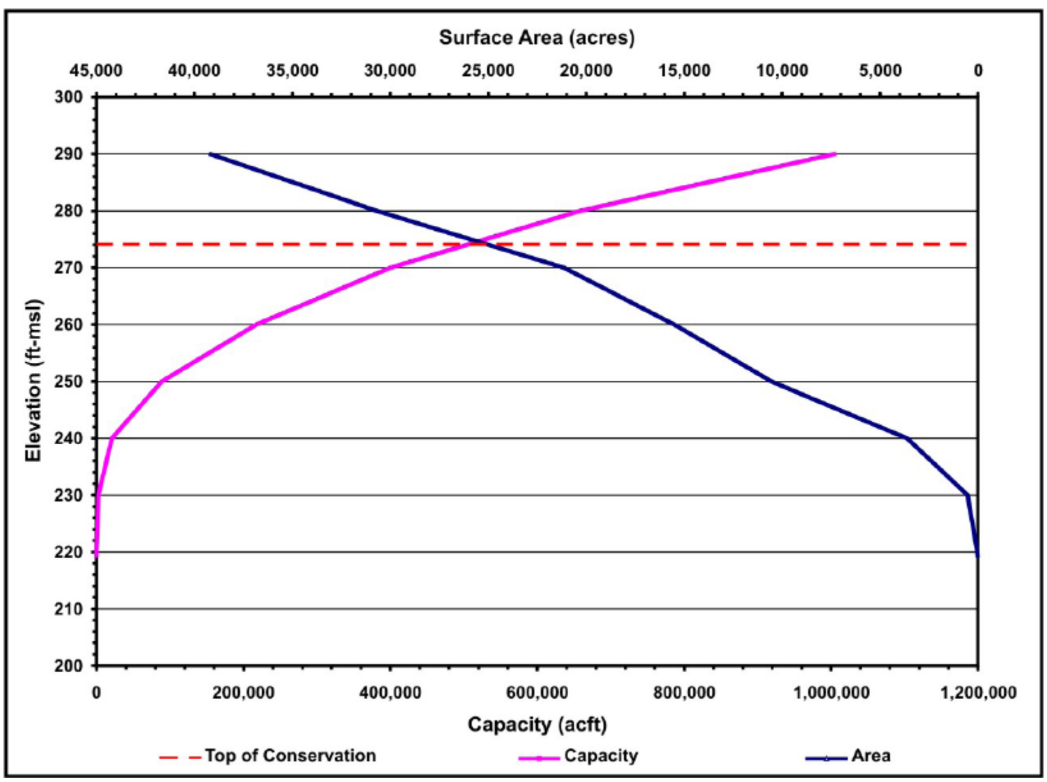


Figure 5-35. Elevation-area-capacity relationship for Fastrill Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

sufficiently addressed by the Consensus Criteria for Environmental Flow Needs.

The firm yield of Fastrill Reservoir was estimated by using the Neches water availability data sets and a modified version of the Water Rights Analysis Package (TCEQ, June 18, 2004, version). It specifically incorporates the special condition in Certificate of Adjudication No. 06-4411 regarding subordination of the B.A. Steinhagen-Sam Rayburn Reservoir System. A daily operations model

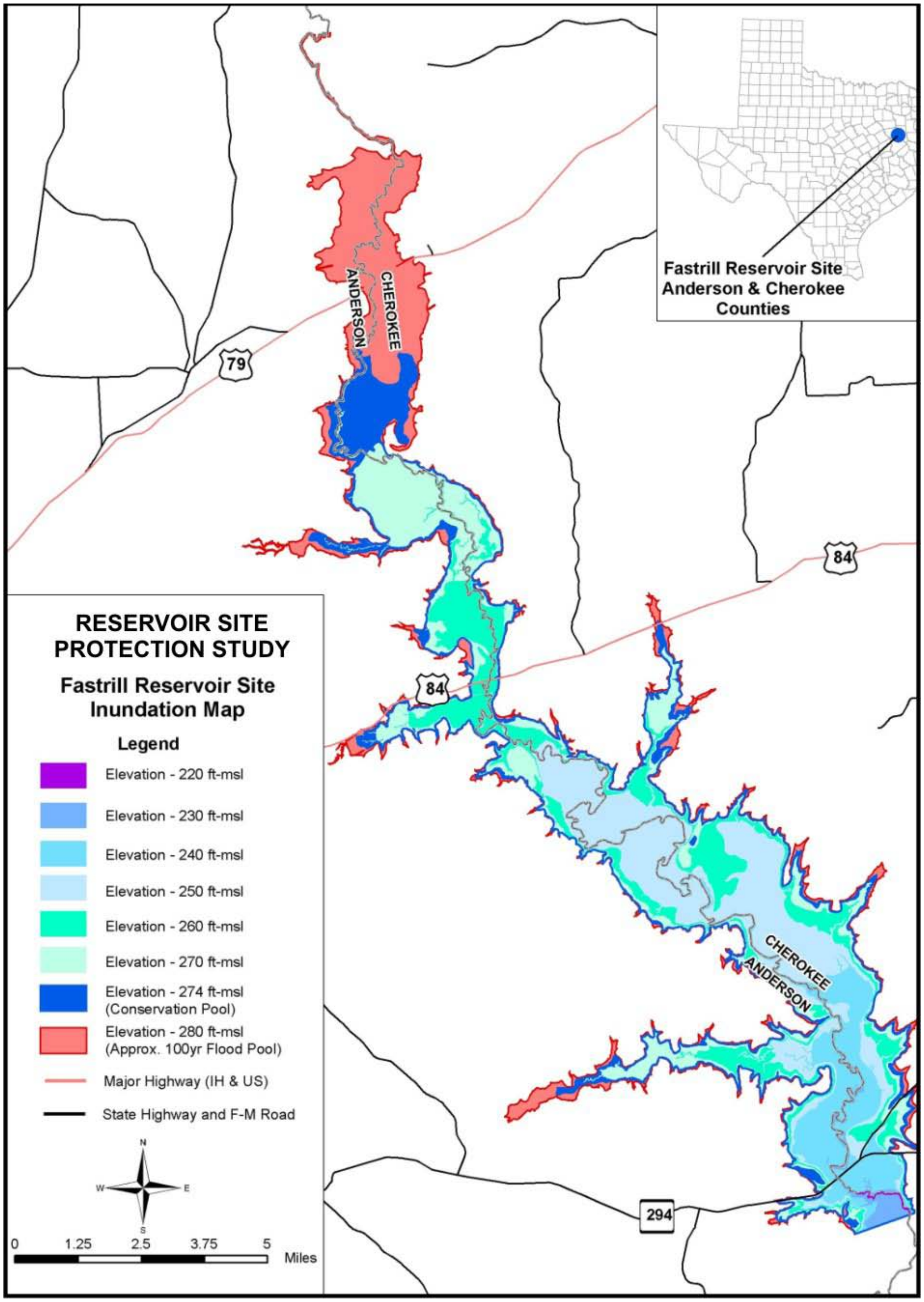


Figure 5-36. Inundation map for Fastrill Reservoir.
ft-msl=feet above mean sea level

Table 5-24. Consensus Criteria for Environmental Flow Needs for Fastrill Reservoir.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 57,920 | 942 | 26,571 | 432 | 4,145 | 67.4 |
| Feb | 71,542 | 1,288 | 35,916 | 647 | 3,744 | 67.4 |
| Mar | 82,807 | 1,347 | 39,124 | 636 | 4,145 | 67.4 |
| Apr | 65,132 | 1,095 | 33,659 | 566 | 4,011 | 67.4 |
| May | 66,571 | 1,083 | 28,551 | 464 | 4,145 | 67.4 |
| Jun | 29,492 | 496 | 12,218 | 205 | 4,011 | 67.4 |
| Jul | 9,930 | 161 | 4,145 | 67 | 4,145 | 67.4 |
| Aug | 4,148 | 67 | 4,145 | 67 | 4,145 | 67.4 |
| Sep | 4,945 | 83 | 4,011 | 67 | 4,011 | 67.4 |
| Oct | 8,551 | 139 | 4,145 | 67 | 4,145 | 67.4 |
| Nov | 20,015 | 336 | 9,865 | 166 | 4,011 | 67.4 |
| Dec | 38,599 | 628 | 19,267 | 313 | 4,145 | 67.4 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-25. Firm yield versus conservation storage for Fastrill Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) |
|---|---|---|---|
| 265 | 309,263 | CCEFN[d] | 88,589 |
| 270 | 400,548 | CCEFN | 111,097 |
| 274* | 503,563 | CCEFN | 134,038 |
| | | None | 179,441 |
| 280 | 658,086 | CCEFN | 153,476 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

developed by HDR Engineering is used to determine the monthly pass-through amounts needed to meet environmental flow requirements for Fastrill Reservoir subject to the Consensus Criteria for Environmental Flow Needs. This model uses monthly inflow and availability quantities from the Neches water availability model 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 water availability model data file.

The Neches water availability model 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 and pattern, storage, and special conditions, including instream flow requirements.

Four potential conservation storage capacities were modeled for Fastrill Reservoir at conservation pool elevations of 280, 274, 270, and 265 feet. Table 5-25

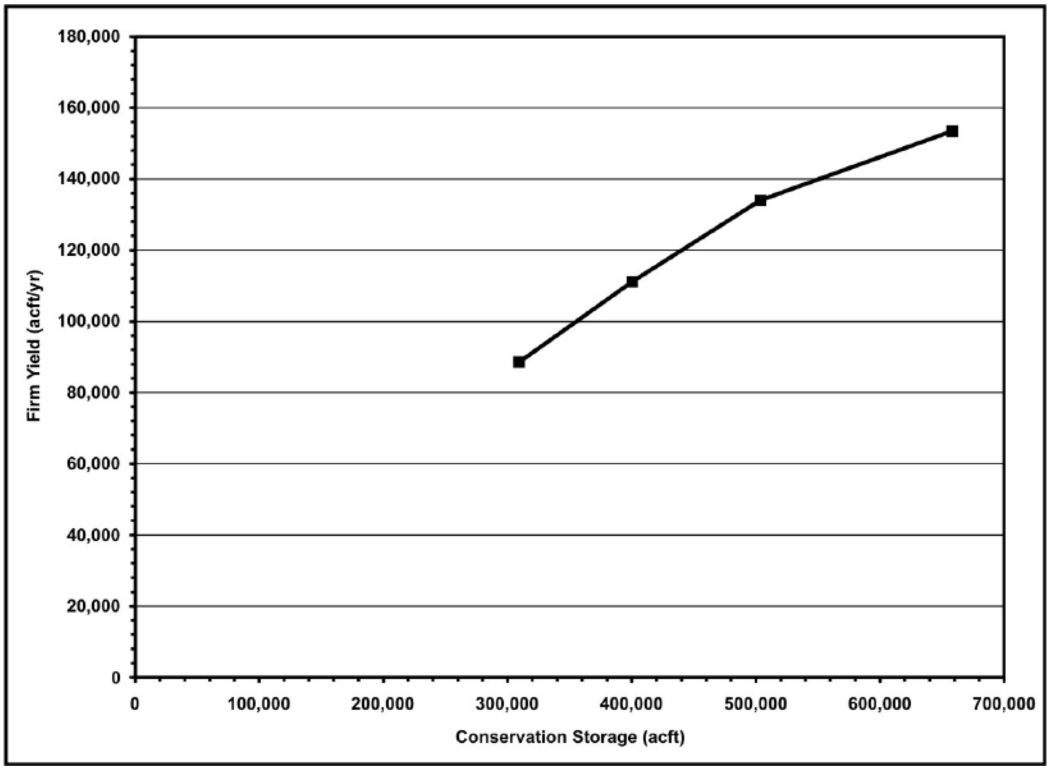


Figure 5-37. Firm yield versus conservation storage for Fastrill Reservoir.
acft/yr=acre-feet per year

includes the conservation storage capacities associated with these four conservation elevations and firm yield estimates.

For the purposes of this study, Fastrill Reservoir was modeled as an independent reservoir that does not rely on makeup water from Lake Palestine. Fastrill Reservoir was simulated with a junior priority date, independent of Lake Palestine. Current planning initiatives envision a conservation elevation of 274 feet for Fastrill Reservoir, thereby yielding a firm water supply of 134,038 acre-feet per year. For comparison purposes, the firm yield of Fastrill Reservoir at a conservation elevation of 274 feet without an environmental flow requirement is 179,441 acre-feet per year, meaning that about 45,000 acre-feet per year (25 percent) of the firm yield potential of Fastrill Reservoir is dedicated to environmental flows. Figure 5-37 shows the relationship between firm yield and conservation capacity for Fastrill Reservoir.

In a recent study for the Upper Neches River Municipal Water Authority and the City of Dallas (HDR, 2006a), the firm yield of Fastrill Reservoir under an independent operation scenario was reported as 137,843 acre-feet per year at a conservation elevation of 274 feet. The firm yield estimate in the current study is less than that in the September 2006 study because treated effluent discharges upstream of Lake Palestine and Fastrill Reservoir have been excluded.

Figure 5-38 illustrates storage fluctuations through time for Fastrill Reservoir under independent operations subject to firm yield diversions and the Consensus Criteria for Environmental Flow Needs. The reservoir storage frequency curve indicates that the reservoir will be full about 13 percent of the time and more than half full about 80 percent of the time.

### *5.6.2 Reservoir Costs*

The geology at the Fastrill Reservoir dam site is conducive to an earthfill dam similar in nature to the existing Blackburn

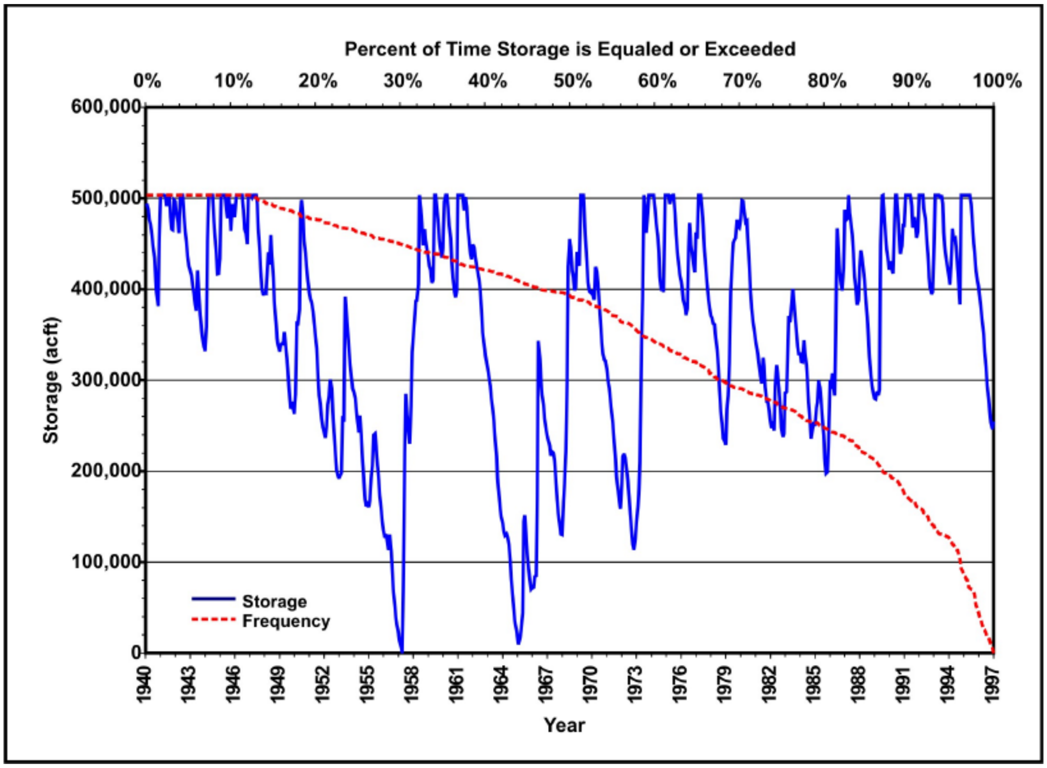


Figure 5-38. Simulated storage in Fastrill Reservoir (conservation elevation=274 feet; diversion=134,038 acre-feet per year).
acft=acre-feet

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 will include a gated intake tower, two 72-inch conduits through the dam, and a conventional St. Anthony Falls outlet structure. Flood flows will be passed through a 700-foot wide, uncontrolled concrete ogee emergency spillway.

Potential conflicts within the conservation pool of Fastrill Reservoir include three major roadways (State Highway 294 and U.S. Highways 84 and 79), minor roadways, two railways (including the Texas State Railroad), power transmission lines, a natural gas pipeline, and oil and gas wells (Figure 5-39). Resolving facility conflicts represents approximately 32 percent of the total capital cost.

A summary cost estimate for Fastrill Reservoir at elevation 274 feet is shown in Table 5-26. Quantities and relocation costs are based upon detailed information from HDR Engineering (2006b). Dam and reservoir costs total about $56 million, and relocations total another $93.5 million. Land, including 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 per acre-foot ($0.47 per 1,000 gallons).

### *5.6.3 Environmental Considerations*

Fastrill Reservoir will inundate a portion of Texas Commission on Environmental Quality classified stream segment 0604. The Texas Parks and Wildlife Department listed the entire length of the Neches River below Lake Palestine as ecologically significant (TPWD, 1999). Inundation by or operations of Fastrill

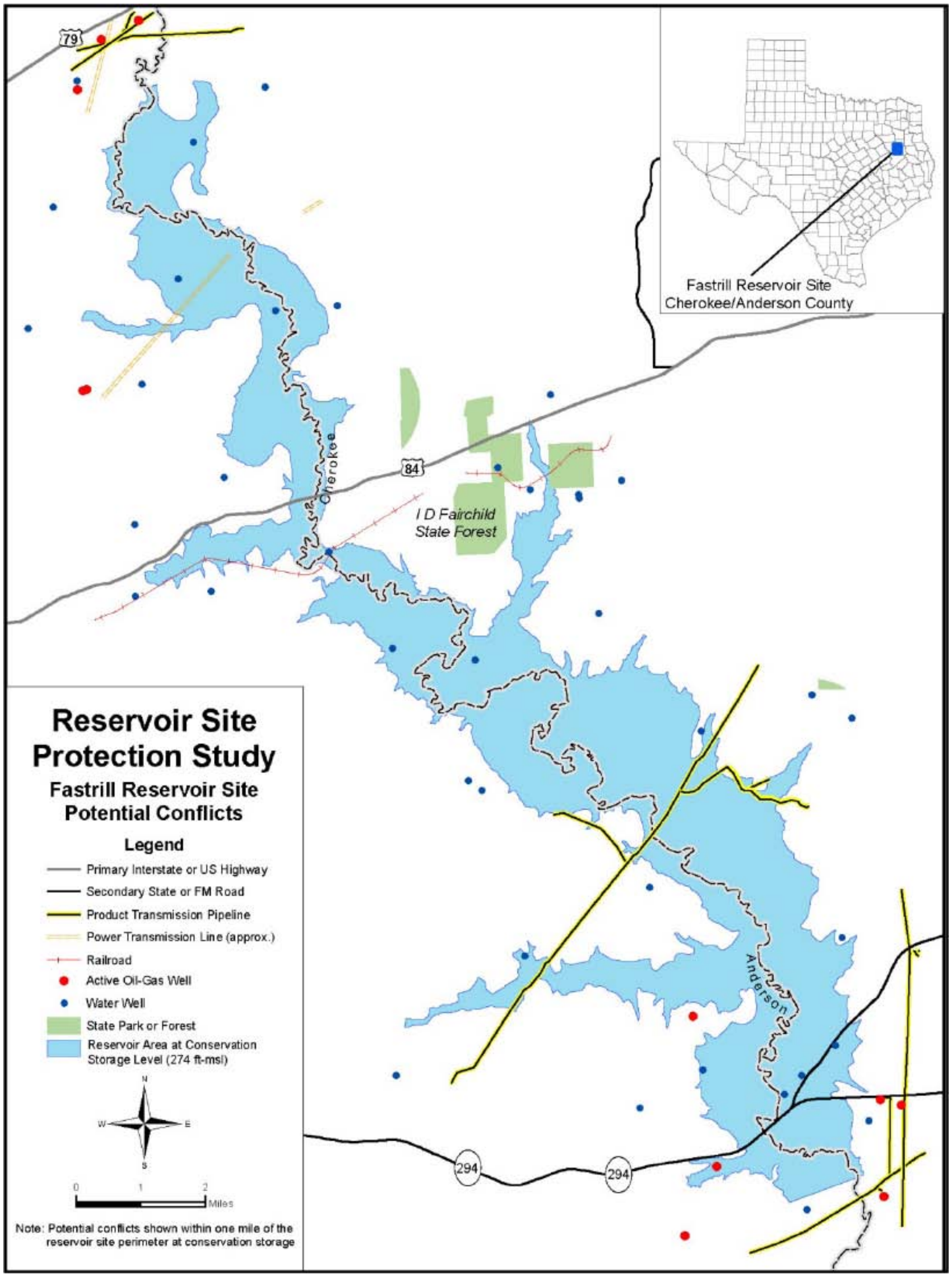


Figure 5-39. Potential major conflicts for Fastrill Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Reservoir could have effects relevant to three Texas Parks and Wildlife Department criteria, as follows:

- Biological function—Texas Natural Rivers System nominee for outstandingly remarkable fish and wildlife values; priority bottomland hardwood habitat displays significant overall habitat value
- High water quality/Exceptional aquatic life/High aesthetic value—National Forest Service wilderness-type area, exceptional aesthetic value

Table 5-26. Cost estimate—Fastrill Reservoir at elevation 274 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | 1 | LS | | $1,907,907 |
| Clearing & grubbing | 78 | AC | $4,000.00 | $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 & operating system | 1 | EA | $250,000.00 | $250,000 |
| Spillway bridge | 199 | LF | $1,300.00 | $258,960 |
| Flex base roadway | 4,264 | SY | $20.00.00 | $85,282 |
| Sand filter drain | 75,218 | CY | $35.00.00 | $2,632,633 |
| Grassing | 39 | AC | $4,500.00 | $174,808 |
| Instrumentation | 1 | LS | $550,000.00 | $550,000 |
| Engineering contingencies (35%) | | | | $14,532,543 |
| **Subtotal Dam & Reservoir** | | | | **$56,054,095** |
| **Conflicts** | | | | |
| Existing structures | 22 | EA | $50,000.00 | $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 | | |
| Railways | 1 | LS | | $5,490,000 |
| Texas State Railroad | 1 | LS | | $16,294,000 |
| Missouri Pacific Railroad | 1 | LS | | $13,267,000 |
| Power transmission | 1 | LS | | $3,562,000 |
| **Natural Gas Lines** | | | | |
| 6.63 inch | 5,600 | LF | | $560,000 |
| 16 inch | 6,300 | LF | | $1,260,000 |
| 10.75 inch | 18,100 | LF | | $3,620,000 |
| Oil & gas wells | 54 | EA | $25,000.00 | $1,350,000 |
| Engineering contingencies (35%) | | | | $24,256,750 |
| **Subtotal Conflicts** | | | | **$93,561,750** |
| **Land** | | | | |
| Land acquisition | 30,668 | AC | $1,825.00 | $55,969,100 |
| Environmental studies & mitigation | | | | $55,969,100 |
| **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 | | | | $840,811 |
| **Total Annual Costs** | | | | **$20,309,639** |
| **Firm Yield (acre-feet per year)** | | | | **134,038** |
| **Unit Costs of Water ($/acre-foot)** | | | | **$152** |

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

Table 5-27. Acreage and percent landcover for Fastrill Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

- Threatened or endangered species/ Unique communities—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 5-27 and Figure 5-40 summarize existing landcover for the Fastrill Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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.

The U.S. Fish and Wildlife Service has designated the Neches River National Wildlife Refuge for the purposes of protecting the habitat for migratory birds, bottomland hardwood forests, and wetlands and providing for compatible wildlife-dependent recreation opportunities (USFWS, 2005). The Neches River National Wildlife Refuge includes a segment of the Neches River and its floodplain as well as surrounding upland areas that coincide with the proposed location of Fastrill Reservoir. This refuge site was one among 14 Priority 1 sites identified by the U.S. Fish and Wildlife Service (USFWS, 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 bottomland preservation site identified as Middle Neches River (N-4).

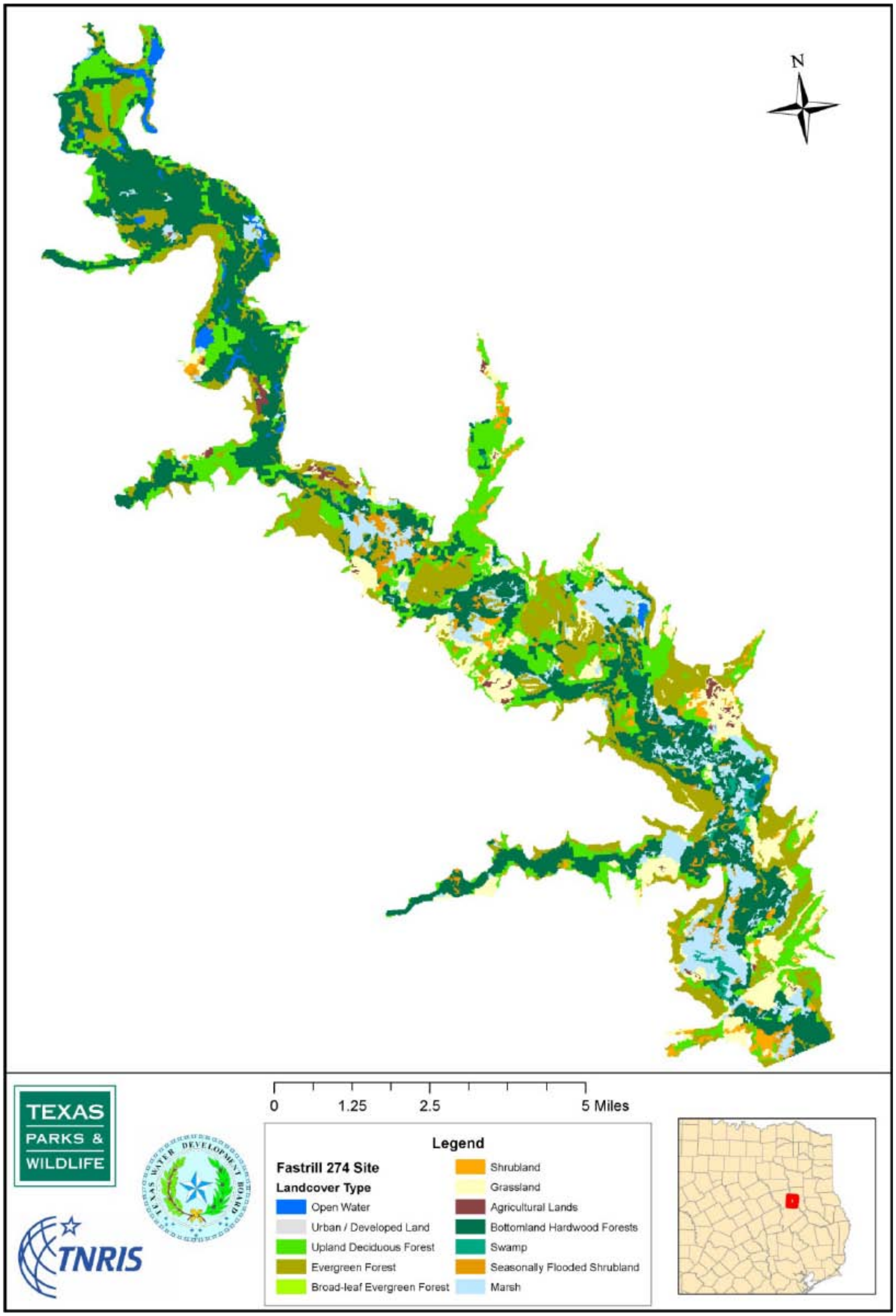


Figure 5-40. Existing landcover for Fastrill Reservoir.

## 5.7 LOWER BOIS D'ARC CREEK RESERVOIR

Lower Bois d'Arc Creek Reservoir is a proposed reservoir on Bois d'Arc Creek, a tributary of the Red River, and will be located in Fannin County in north central Texas (Figure 5-41). 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). It was recommended as a water supply for the North Texas Municipal Water District in the 2001 and 2006 Region C Regional Water Plans and the 2002 and 2007 Texas State Water Plans.

Lower Bois d'Arc Creek Reservoir is also recommended as a unique reservoir site in both the 2001 and 2006 Region C Regional Water Plans. The reservoir is planned to provide water to the North Texas Municipal Water District, which serves customers over an eight-county area in north central Texas. The projected needs of the district for additional supply are 113,000 acre-feet per year in 2010, increasing to over 545,000 acre-feet per year by 2060 (Freese and Nichols and others, 2006). The projected needs for additional water supply within 50 miles of the proposed reservoir site by 2060 are 728,028 acre-feet per year. The nearest major demand center, the Dallas-Fort Worth area, is located approximately 60 miles southwest of the reservoir site. At its proposed elevation of 534 feet, the reservoir will have a capacity of 367,609 acre-feet and inundate 16,526 acres.

### *5.7.1 Reservoir Yield Analysis*

The reservoir area capacity data was developed from U.S. Geological Survey topographic data and aerial photography from March 2004. The photography provided 2-foot contour data at the reservoir site up to an elevation of 540 feet. Table 5-28 and Figure 5-42 show the area-

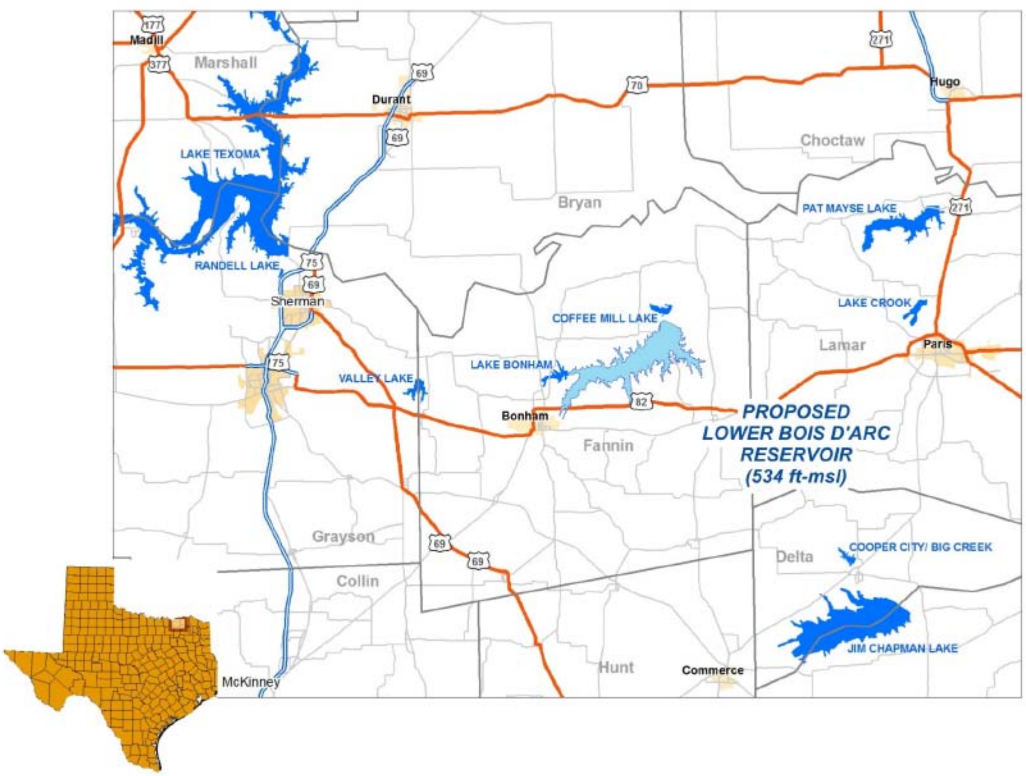


Figure 5-41. Location map of Lower Bois d'Arc Creek Reservoir.
ft-msl=feet above mean sea level

Table 5-28. Elevation-area-capacity relationship for Lower Bois d'Arc Creek Reservoir.

| Elevation (ft-msl[a]) | Area (acre) | Capacity (acft[b]) |
|---|---|---|
| 464 | 5 | 4 |
| 470 | 19 | 76 |
| 480 | 378 | 1,197 |
| 490 | 2,001 | 15,109 |
| 500 | 4,288 | 50,684 |
| 510 | 6,987 | 99,108 |
| 520 | 10,601 | 180,995 |
| 530 | 14,724 | 302,570 |
| 534 | 16,526 | 367,609 |
| 540 | 19,616 | 467,767 |
| 550 | 23,967 | 678,337 |
| 560 | 29,670 | 954,617 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

capacity-elevation data for Lower Bois d'Arc Creek Reservoir, and Figure 5-43 shows inundation at 10-foot contours.

The firm yields for Lower Bois d'Arc Creek Reservoir were developed using a modified version of the Red River water availability model. We calculated yields at elevations 530, 534, 536, and 538 feet. The conservation elevation for the proposed reservoir is 534 feet. The yield at this elevation is 126,280 acre-feet per year.

The hydrology at the Lower Bois d'Arc Creek dam site was calculated outside the water availability model and input directly into it. This adjustment was made because the original model underestimates the flows in the Bois d'Arc Creek watershed. From December 1962 to September 1985, the U.S. Geological Survey operated the Bois d'Arc Creek gage near Randolph, 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, 2006). 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 Texas Commission on Environmental Quality Red River water availability model. The study recommended adding a new primary control 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

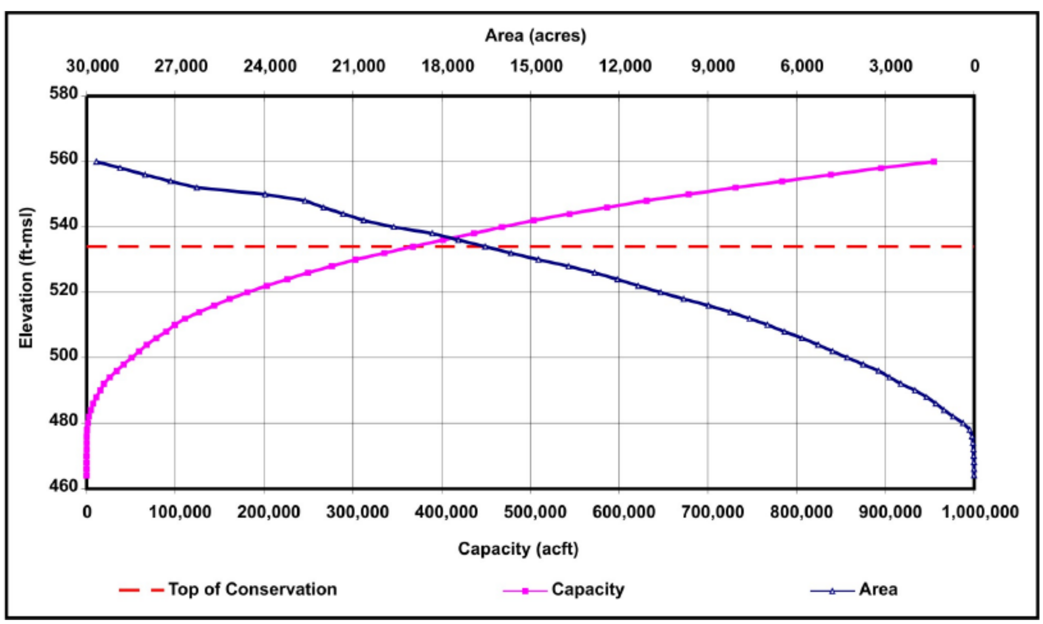


Figure 5-42. Elevation-area-capacity relationship for Lower Bois d'Arc Creek Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

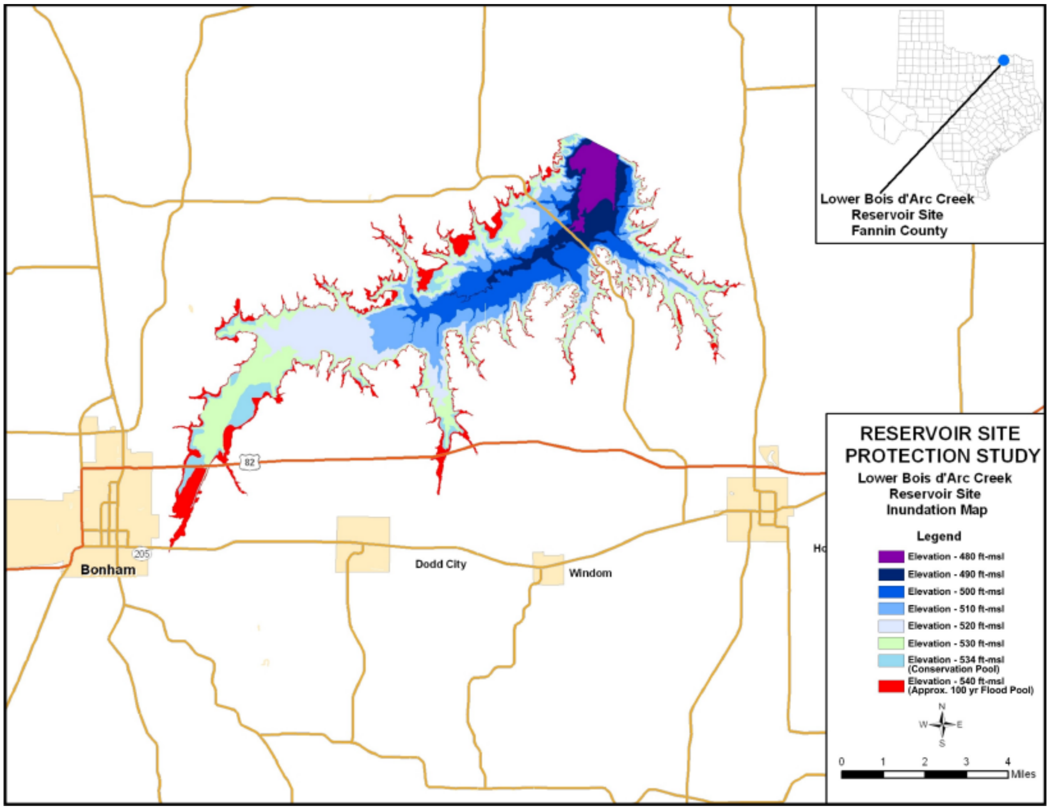


Figure 5-43. Inundation map for Lower Bois d'Arc Creek Reservoir.
ft-msl=feet above mean sea level

Table 5-29. Consensus Criteria for Environmental Flow Needs for Lower Bois d'Arc Creek Reservoir.

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

[a]acft/month=acre-feet per month
[b]cfs=cubic feet per second

for the current yield evaluations. More information can be found in Freese and Nichols (2006).

For the hydrologic analyses, a new control point was added to the Red River water availability model 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 water availability model Run 3.

The yield studies used the Consensus Criteria for Environmental Flow Needs bypass criteria developed in the 2006

Table 5-30. Firm yield versus conservation storage for Lower Bois d'Arc Creek Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 530 | 302,570 | CCEFN[d] | 117,190 | 7/75–8/80 |
| 534* | 367,609 | CCEFN | 126,280 | 7/75–2/81 |
| | | None | 127,160 | 7/75–2/81 |
| 536 | 401,647 | CCEFN | 130,820 | 7/75–2/81 |
| 538 | 436,333 | CCEFN | 139,570 | 7/51–2/57 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

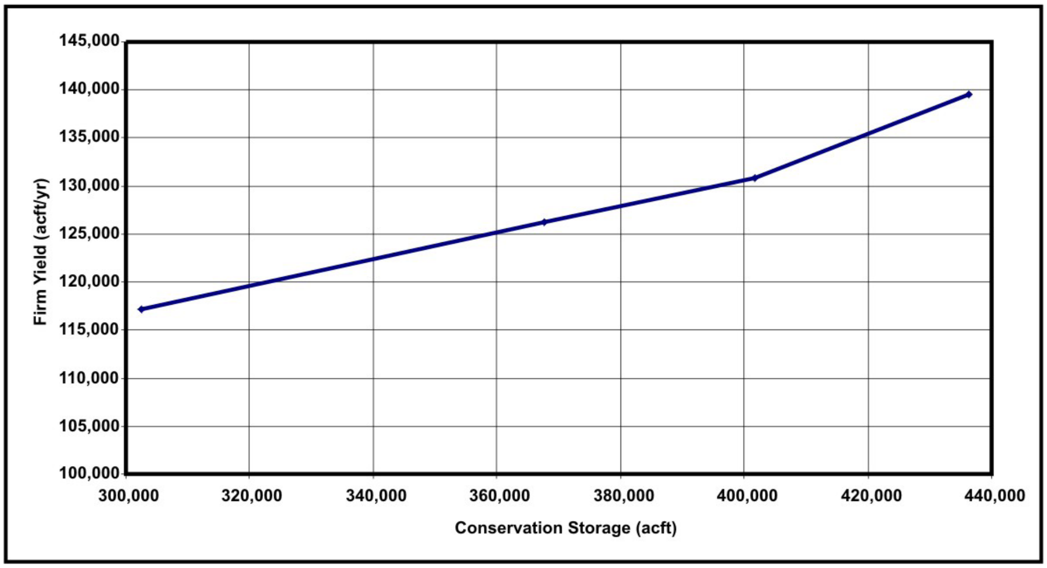


Figure 5-44. Firm yield versus conservation storage for Lower Bois d'Arc Creek Reservoir.
acft/yr=acre-feet per year

study of the reservoir (Table 5-29). At the recommended conservation elevation, the bypass criteria reduce the yield of the reservoir by 880 acre-feet per year.

Table 5-30 and Figure 5-44 show the results of the yield studies. Note that in Figure 5-45 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 will impact the existing dam for Lake Bonham and increase the potential for flooding in Bonham. The storage trace for the recommended conservation pool elevation and the storage frequency curve are shown in Figure 5-45. This figure shows that at the proposed conservation elevation of 534 feet, the reservoir will be full about 13 percent of the time and will be holding less than 50 percent of its capacity (183,805 acre-feet) less than 20 percent of the time.

### *5.7.2 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 will include an approach channel, a 150-foot uncontrolled concrete weir, chute, hydraulic

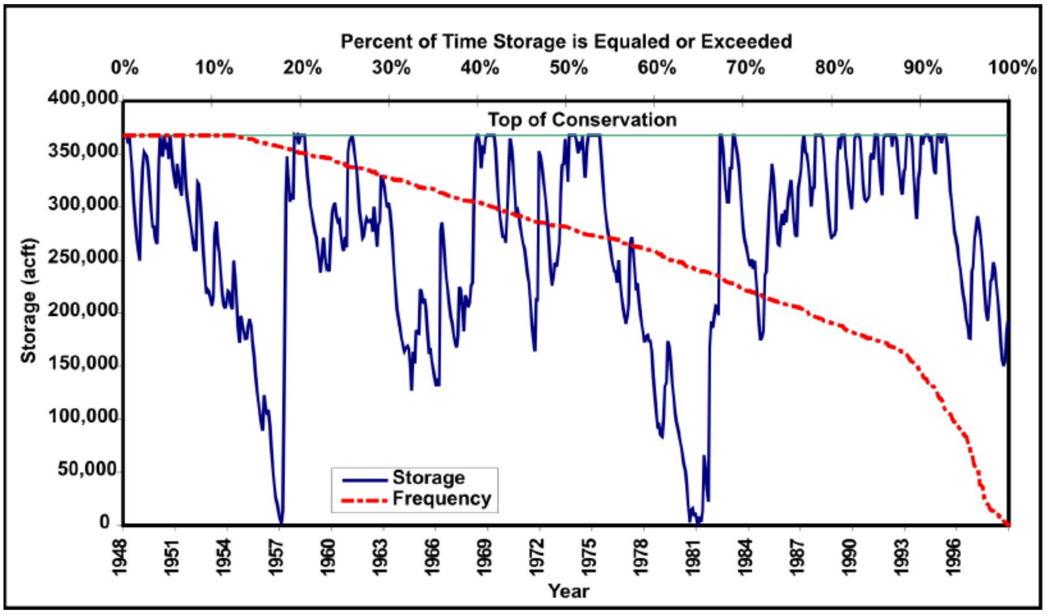


Figure 5-45. Simulated storage in Lower Bois d'Arc Creek Reservoir (conservation elevation=534 feet; diversion=126,280 acre-feet per year)
acft=acre-feet

jump stilling basin, and outlet channel.

Conflicts identified at the site include a cemetery, electrical lines, several roads (including U.S. Highway 82 and Farm to Market road 1396), a 10-inch gas line, and several other structures (Figure 5-46). In addition to these conflicts, the cost estimate includes protecting 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 the Texas Natural Resources Information System and from the study report in support of the water right permit application for Lower Bois d'Arc Creek Reservoir (Freese and Nichols, 2006).

Table 5-31 shows the estimated capital costs for the Lower Bois d'Arc Creek Reservoir project, including construction, engineering, permitting, and mitigation costs. Unit costs for the dam and reservoir are based on the unit cost assumptions used in this study. Local costs could vary. Using these unit costs, the total estimated cost of the project is $248 million (2005 prices). Assuming a yield of 126,200 acre-feet per year, raw water from the project will cost approximately $140 per acre-foot ($0.43 per 1,000 gallons) during the debt service period.

### *5.7.3 Environmental Considerations*

Lower Bois d'Arc Creek Reservoir is located on an ecologically significant stream as identified by the Texas Parks and Wildlife Department (TPWD, 1999). 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 their 2006 Regional Water Plan. Portions of the creek that will be affected 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 will 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

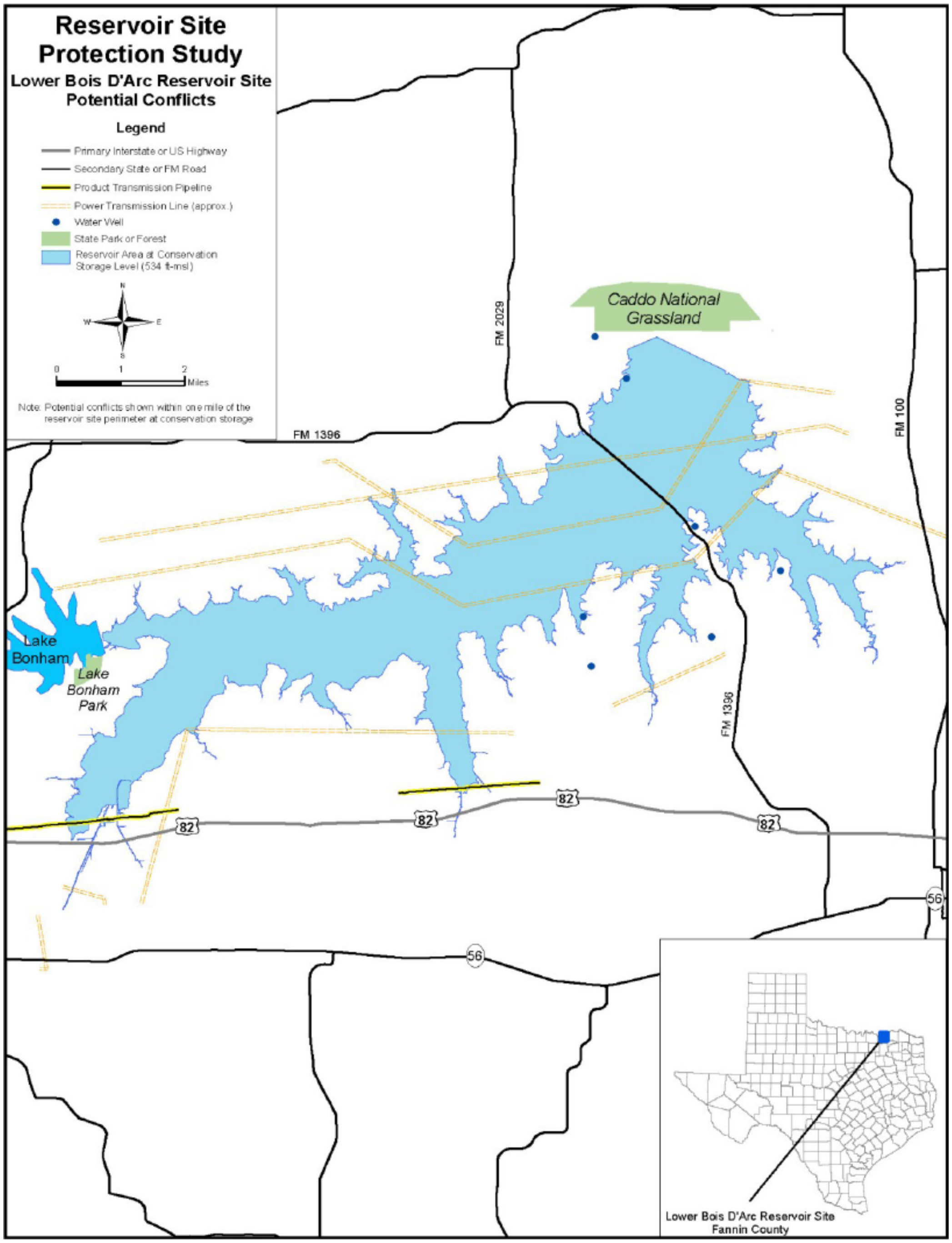


Figure 5-46. Potential major conflicts for Lower Bois d'Arc Creek Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

inundate 16,526 acres of land at conservation storage capacity. Figure 5-47 and Table 5-32 summarize existing landcover for the Lower Bois d'Arc Creek Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by upland deciduous forest (42 percent), with sizeable areas of grassland (28 percent) and agricultural land (17 percent). Bottomland hardwood forest constitutes only about 2.2 percent of the reservoir area. Marsh, swamp, and open water total about 3.5 percent of the reservoir area.

Table 5-31. Cost estimate—Lower Bois d'Arc Creek Reservoir at elevation 534 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | 1 | LS | $2,976,100.00 | $2,976,000 |
| Clearing & grubbing | 85 | AC | $4,000.00 | $340,000 |
| Care of water during construction (1%) | 1 | LS | $589,300.00 | $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 | $4,500.00 | $185,000 |
| Intake tower for low-flow outlet | 527 | CY | $750.00 | $395,000 |
| Conduit for low-flow outlet | 660 | CY | $500.00 | $330,000 |
| Impact basin for low-flow outlet | 160 | CY | $500.00 | $80,000 |
| Gates & miscellaneous for low-flow outlet | 1 | LS | $200,000.00 | $200,000 |
| Electrical system & instrumentation for low-flow outlet | 1 | LS | $195,000.00 | $195,000 |
| Spillway structure & reinforced concrete | 19,700 | CY | $375.00 | $7,388,000 |
| Roller compacted concrete | 49,900 | CY | $60.00 | $2,994,000 |
| Bridge | 3,000 | SF | $150.00 | $450,000 |
| Barrier & warning system | 1 | LS | $50,000.00 | $50,000 |
| Embankment instrumentation | 1 | LS | $250,000.00 | $250,000 |
| Timber guard posts & guard rail | 1 | LS | $55,000.00 | $55,000 |
| Miscellaneous internal drainage | 1 | LS | $50,000.00 | $50,000 |
| Engineering & contingencies | | | | $21,874,000 |
| **Subtotal for Dam & Reservoir** | | | | **$84,371,000** |
| | | | | |
| **Conflicts** | | | | |
| Utilities | | | | |
| 10-inch gas pipeline | 3,720 | LF | $27.00 | $100,000 |
| 138 kilovolt line | 1 | LS | N/A | $1,500,000 |
| 345 kilovolt line | 1 | LS | N/A | $3,735,000 |
| Other structures | 1 | LS | N/A | $3,000,000 |
| Cemeteries | 27 | EA | $6,000.00 | $162,000 |
| Major roads (raised) | 5,000 | LF | $900.00 | $4,500,000 |
| Other roads | 7,200 | LF | $150.00 | $1,080,000 |
| Lake Bonham (protection) | 1 | LS | $175,000.00 | $175,000 |
| Engineering & contingencies at 35% | | | | $4,988,000 |
| | | | | |
| **Land acquisition—conservation pool plus 10%** | 22,000 | AC | $2,675.00 | **$58,850,000** |
| **Environmental studies & mitigation** | 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; SY=Square Yard

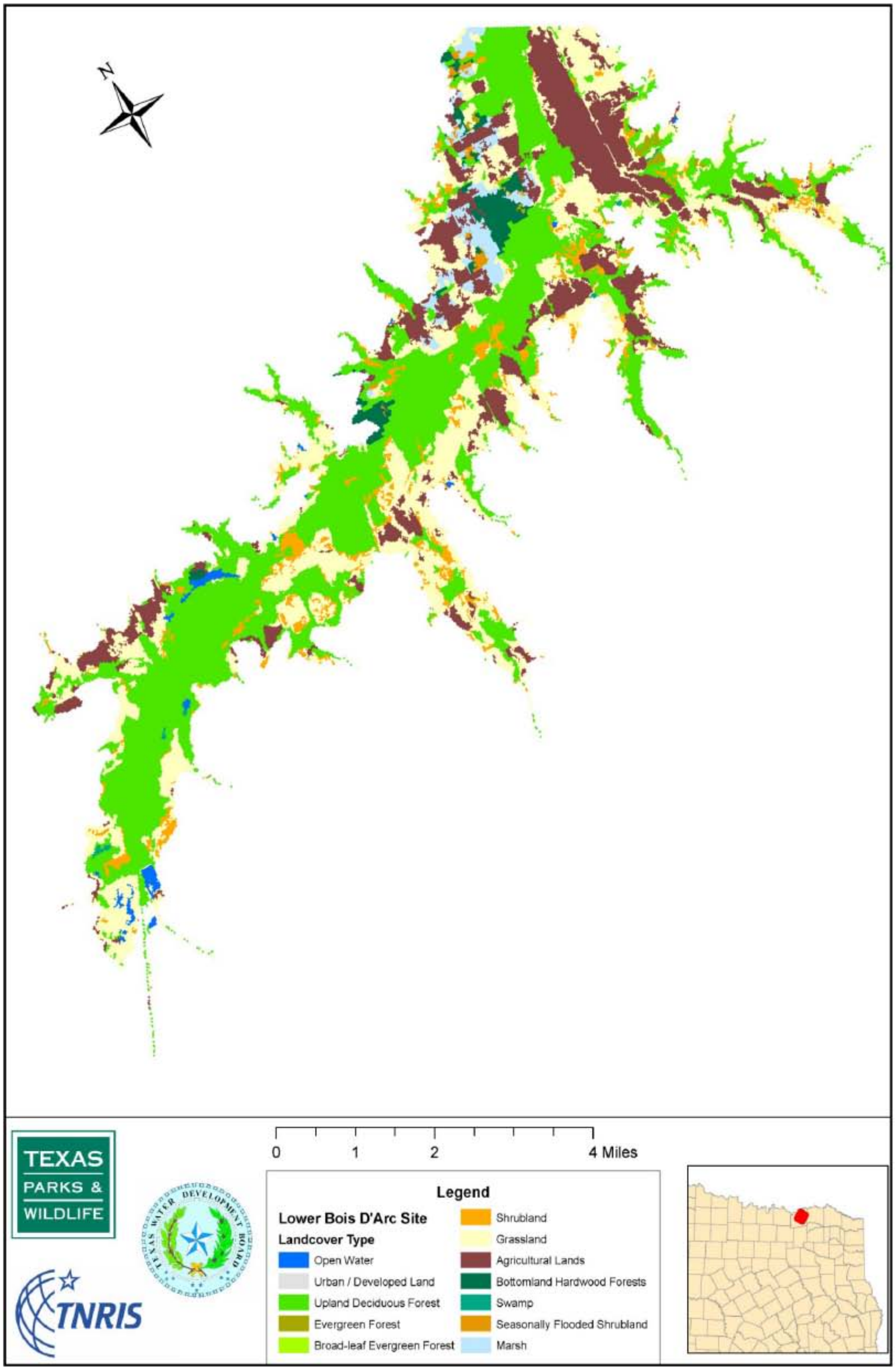


Figure 5-47. Existing landcover for Lower Bois d'Arc Creek Reservoir.

Table 5-32. Acreage and percent landcover for Lower Bois d'Arc Creek Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

## 5.8 Marvin Nichols Reservoir (Site IA)

The proposed Marvin Nichols Reservoir (Site IA) will be located on the Sulphur River in Red River and Titus counties, with a conservation pool elevation of 328 feet and a conservation capacity of 1,562,669 acre-feet (Figure 5-48). The inundated area at the top of the 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 Jim Chapman Lake.

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 Regional Water Plan and the 2007 State Water Plan. It is also an alternate strategy for the City of Dallas.

Marvin Nichols IA Reservoir is a recommended unique reservoir site in both the 2001 and 2006 Region C Regional Water Plans. The reservoir will 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 acre-feet per year by 2060 (Freese and Nichols and others, 2006). The projected water shortages within 50 miles of the proposed reservoir site by 2060 are 53,141 acre-feet per year. The nearest major demand center is the Dallas-Fort Worth area, located approximately 115 miles southwest of the reservoir site.

### *5.8.1 Reservoir Yield Analysis*

The elevation-area-capacity relationship for Marvin Nichols IA Reservoir is

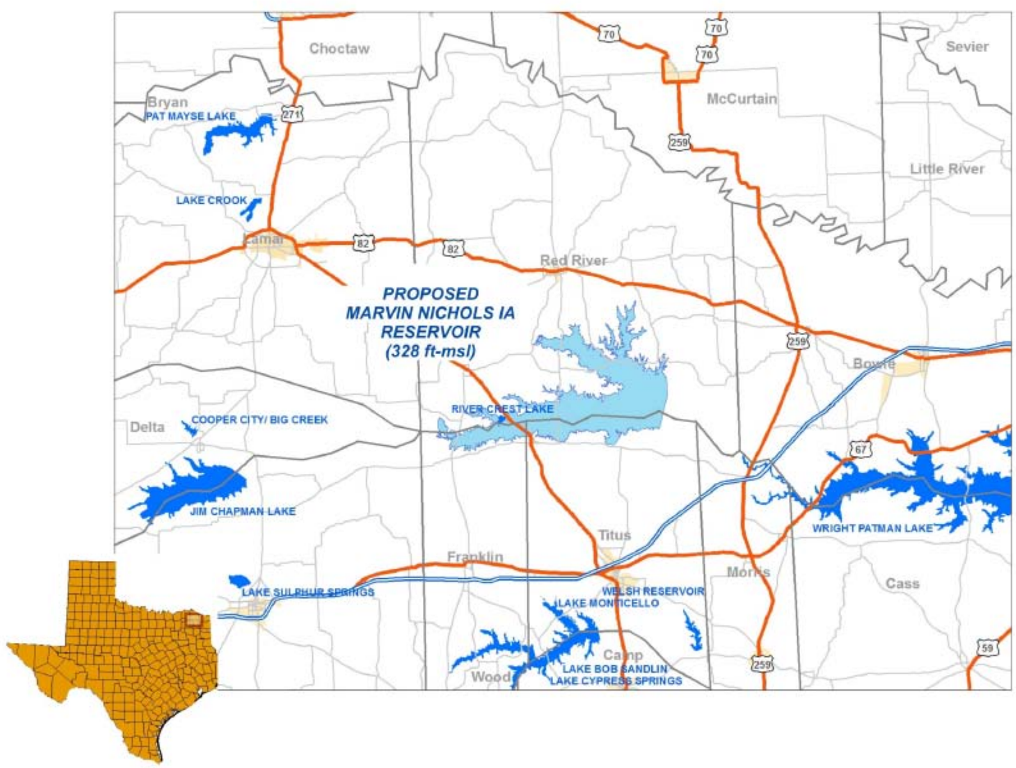


Figure 5-48. Location map for Marvin Nichols Reservoir (Site IA).
ft-msl=feet above mean sea level

included in Table 5-33 and Figure 5-49. Freese and Nichols (2000) derived the data from the 1:24,000 scale U.S. Geological Survey topographic quadrangle maps with 10-foot contour intervals. Figure 5-50 shows the reservoir inundation at different elevations in 10-foot intervals. The reservoir will be subject to regulatory bypass to meet environmental needs. For this study, we used the Consensus Criteria for Environmental Flow Needs (Table 5-34).

The firm yield of Marvin Nichols IA Reservoir was calculated with the full authorization scenario (Run 3) of the Sulphur River Basin water availability model. A control point was added on the North Sulphur River at the dam location.

In the water availability models, flows at ungaged locations are usually calculated using the drainage area ratio method with known flows at gaged locations. The University of Texas Center for Research in Water Resources calculated the drainage areas of the Sulphur water availability model. These areas and their values are different from values published by the U.S. Geological Survey, in some cases by more than 10 percent.

Preliminary yield studies conducted for this report determined that the flows calculated using the Sulphur water availability model are different from previous hydrologic studies because of differences in the drainage areas. The U.S. Geological Survey values are widely accepted and are more accurate than the values developed for the Sulphur Basin water availability model. Therefore, for purposes of estimating the firm yields of the

Table 5-33. Elevation-area-capacity relationship for Marvin Nichols IA Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 260 | 0 | 0 |
| 265 | 96 | 235 |
| 270 | 192 | 954 |
| 275 | 3,435 | 9,944 |
| 280 | 6,678 | 35,207 |
| 285 | 10,690 | 78,612 |
| 290 | 14,703 | 142,084 |
| 295 | 20,072 | 229,008 |
| 300 | 25,441 | 342,780 |
| 305 | 30,778 | 483,319 |
| 310 | 36,114 | 650,543 |
| 315 | 43,726 | 850,130 |
| 320 | 51,337 | 1,087,776 |
| 325 | 61,372 | 1,369,531 |
| 328 | 67,392 | 1,562,669 |
| 330 | 71,406 | 1,701,463 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

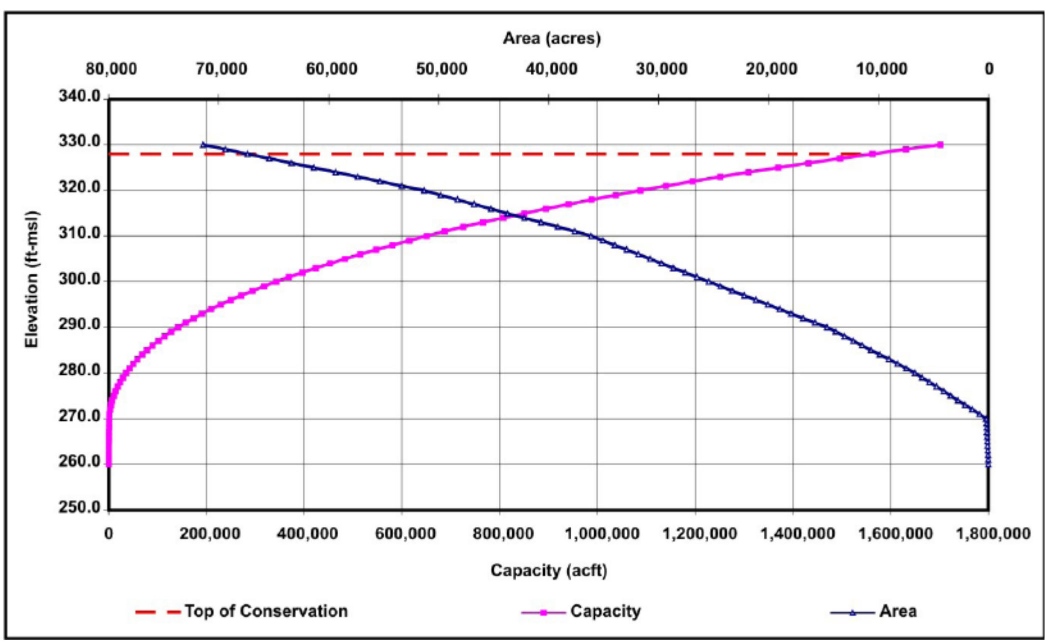


Figure 5-49. Elevation-area-capacity relationship for Marvin Nichols IA Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

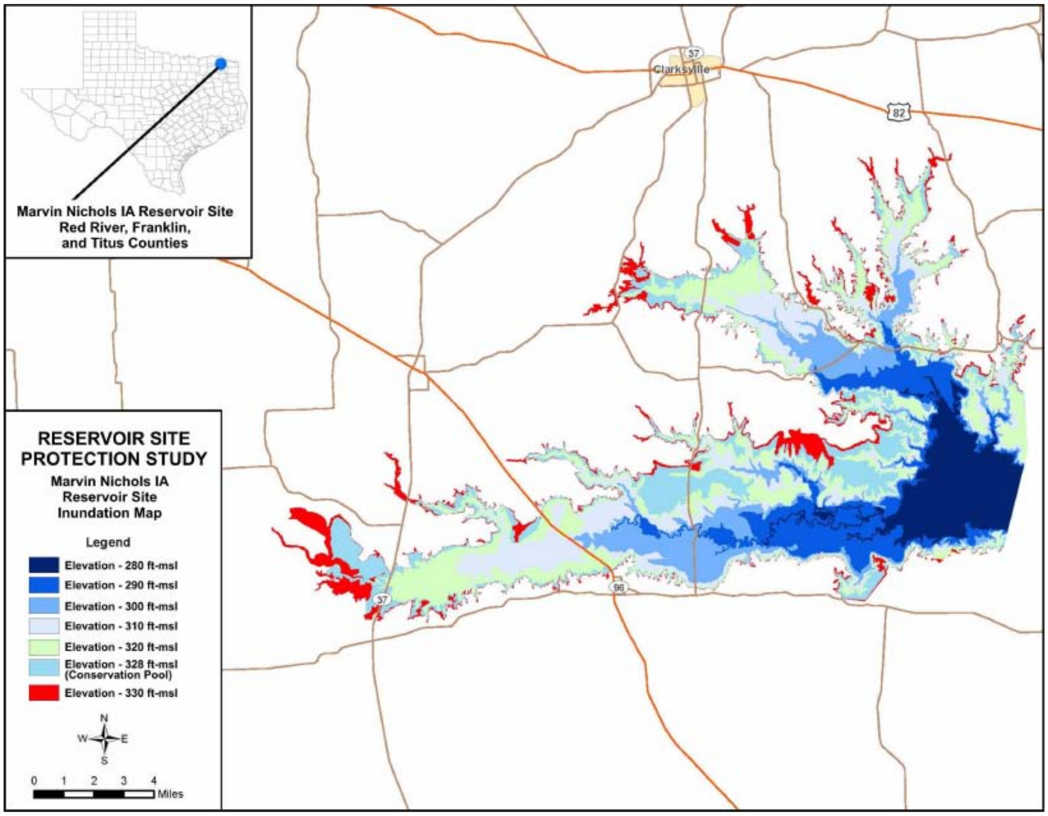


Figure 5-50. Inundation map for Marvin Nichols IA Reservoir.
ft-msl=feet above mean sea level

Table 5-34. Consensus Criteria for Environmental Flow Needs for Marvin Nichols IA Reservoir.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | 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 |

[a]acft/month=acre-feet per month
[b]cfs=cubic feet per second

proposed reservoirs in the Sulphur Basin, we calculated naturalized flows at the reservoir sites using the drainage area ratios obtained from the U.S Geological Survey rather than the Center for Research in Water Resources. For Marvin Nichols IA Reservoir, we calculated naturalized flows using these gages: South Sulphur River near Talco (control point C10); the White Oak Creek near Talco (control point D10); and the Sulphur River near Darden (control point E10).

The scope of work of this study does not include verifying or modifying the drainage areas of the Sulphur water availability model. However, entering the naturalized flow at the reservoir sites is sufficient to produce accurate estimates

Table 5-35. Firm yield versus conservation storage for Marvin Nichols IA Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 318 | 988,151 | CCEFN[d] | 465,300 | 5/53–1/57 |
| 323 | 1,250,808 | CCEFN | 527,800 | 5/53–1/57 |
| 328* | 1,562,669 | CCEFN | 602,000 | 5/53–1/57 |
| | | None | 614,800 | 5/53–1/57 |
| 330 | 1,701,463 | CCEFN | 635,200 | 5/53–1/57 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

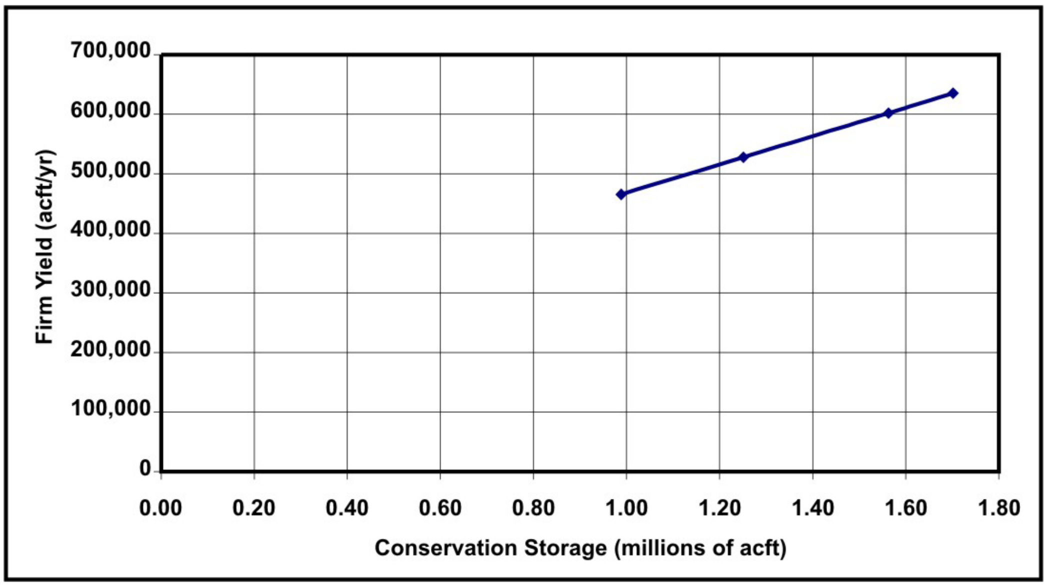


Figure 5-51. Firm yield versus conservation storage for Marvin Nichols IA Reservoir.
acft/yr=acre-feet per year

of firm yield.

We calculated yields for elevations 330, 328, 323, and 318 feet, subject to the 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 5-35 and Figure 5-51. At the conservation pool level of 328 feet, the firm yield is 602,000 acre-feet per year. Environmental flow requirements reduce the yield of the reservoir by 12,800 acre-feet per year.

An evaluation of the impacts of constructing other reservoirs 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 IA 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 IA has a junior priority to any of these reservoirs. Because the U.S. Army Corps of Engineers Section 404 permit application for Lake Ralph Hall was submitted in October 2006, that lake will likely be senior to Marvin Nichols IA. Yield analysis determined that Lake Ralph Hall will reduce the firm yield of Marvin Nichols IA by 17,900 acre-feet per year, 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 IA will be 460,800, which is

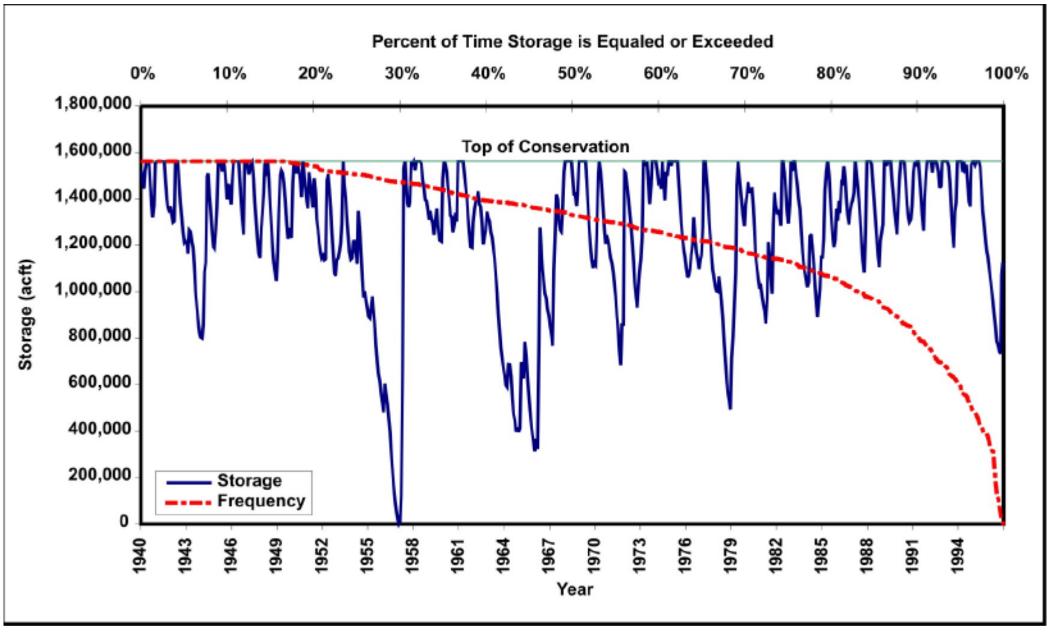


Figure 5-52. Simulated storage in Marvin Nichols IA Reservoir (conservation elevation=328 feet; diversion=602,000 acre-feet per year).
acft=acre-feet per year

141,200 acre-feet per year less than the stand-alone yield (or a reduction of 23 percent).

Figure 5-52 presents a simulated storage trace derived using the Sulphur water availability model and a storage frequency curve. At the conservation pool elevation of 328 feet, the reservoir will be full about 17 percent of the time and will be below 50 percent of the conservation storage about 10 percent of the time.

### *5.8.2*
### *Reservoir Costs*

The costs for the Marvin Nichols IA dam are based on data developed by Freese and Nichols (2000) and used in the 2006 Region C Regional 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 feet. The service spillway includes a gated, concrete ogee-type weir, thirteen tainter gates, a stilling basin, and discharge channel.

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 (Figure 5-53). We developed the costs and quantities for these conflict resolutions from data provided by the Texas Natural Resources Information System and from the Region C Regional Water Plan. The conflict costs represent approximately 10 percent of the total construction cost of the reservoir project.

Table 5-36 shows the estimated capital costs for the Marvin Nichols IA Reservoir project, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, raw water from the project will cost approximately $61 per acre-foot ($0.19 per 1,000 gallons) during the debt service period.

### *5.8.3*
### *Environmental Considerations*

The Marvin Nichols IA Reservoir is not located on an ecologically significant

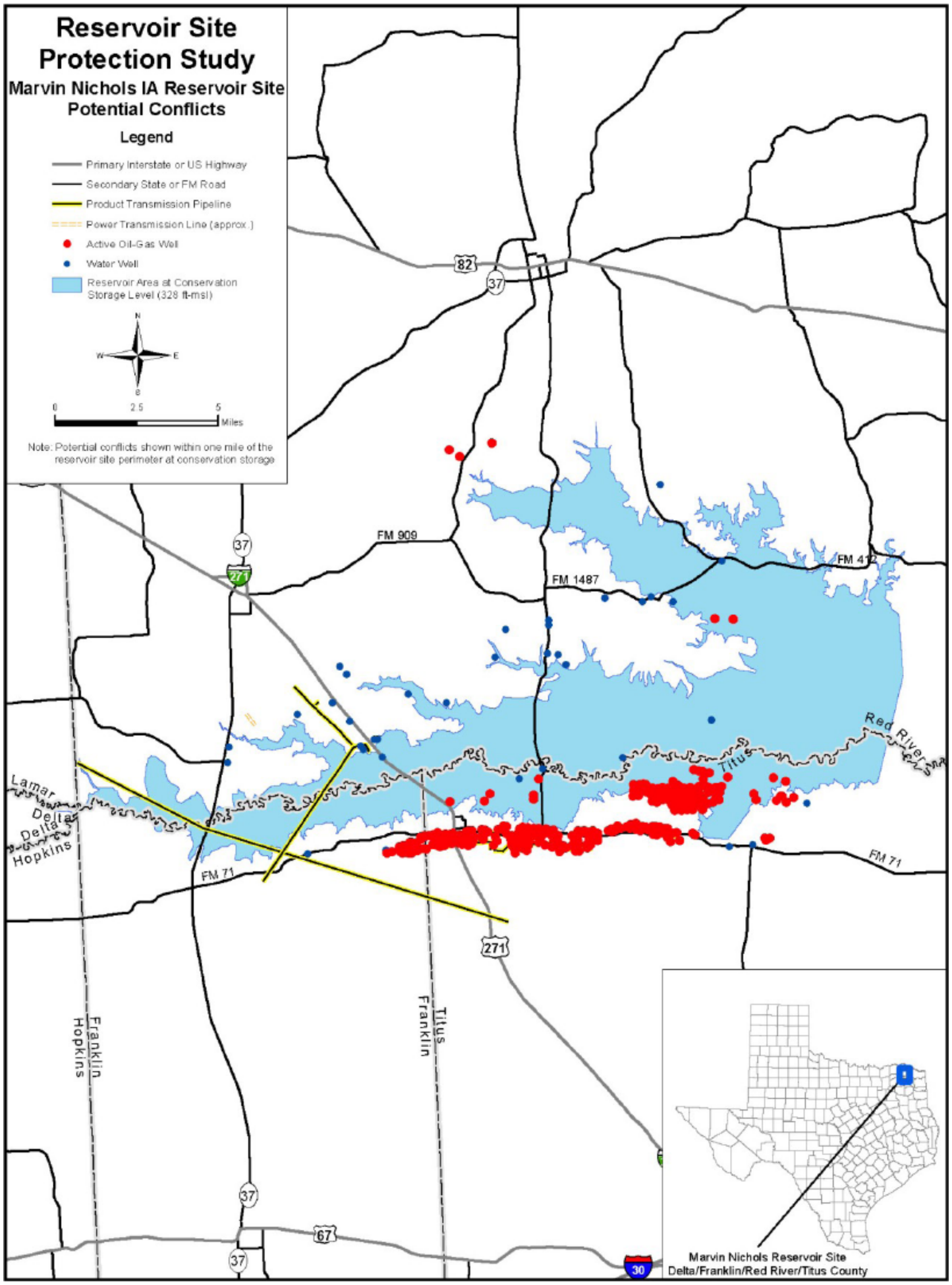


Figure 5-53. Potential major conflicts for Marvin Nichols IA Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

stream segment but is approximately 29 river miles upstream of one identified by the Texas Parks and Wildlife Department (TPWD, 1999). The Sulphur River downstream of the Interstate 30 bridge in Morris County is considered an ecologically significant stream based on biological function associated with bottomland hardwood forests and the presence of paddlefish, which is a state-listed threatened species. The Region D Water Planning Group did not identify the Sulphur River as ecologically unique in their 2006 Regional Water Plan.

Table 5-36. Cost estimate—Marvin Nichols IA Reservoir at elevation 328 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | 1 | LS | $8,183,300.00 | $8,183,000 |
| **Spillway Construction** | | | | |
| Mass concrete | 87,300 | CY | $150.00 | $13,095,000 |
| Reinforced concrete | 26,800 | CY | $400.00 | $10,720,000 |
| Soil cement | 3,600 | CY | $65.00 | $234,000 |
| Spillway bridge | 640 | LF | $1,300.00 | $832,000 |
| Gates, including anchoring system | 14,040 | SF | $275.00 | $3,861,000 |
| Gate hoist & operating system | 13 | EA | $250,000.00 | $3,250,000 |
| Stop gate & lift beam | 640 | LF | $2,000.00 | $1,280,000 |
| Instrumentation | 640 | LF | $700.00 | $448,000 |
| Excavation | 2,894,000 | CY | $3.00 | $7,235,000 |
| Structural fill | 121,000 | CY | $12.00 | $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 | $100.00 | $64,000 |
| Electrical system | 1 | LS | $550,000.00 | $550,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Spillway low-flow system | 1 | LS | $400,000.00 | $400,000 |
| Stop gate monorail system | 640 | LF | $1,000.00 | $640,000 |
| Grassing | 100 | AC | $4,500.00 | $450,000 |
| Clearing & grubbing/site preparation | 321 | AC | $4,000.00 | $1,284,000 |
| Care of water (3%) | 1 | LS | $4,209,100.00 | $4,209,000 |
| Reservoir land clearing | 16,800 | AC | $1,000.00 | $16,800,000 |
| **Subtotal of Other Items** | | | | **$24,647,000** |
| | | | | |
| **Engineering & contingencies—dam & reservoir** | | | | **$57,283,000** |
| | | | | |
| **Conflicts** | | | | |
| Roads | | | | |
| Federal highway | 16,300 | LF | $900.00 | $14,670,000 |
| State highway | 6,000 | LF | $900.00 | $5,400,000 |
| F.M. | 33,400 | LF | $150.00 | $5,010,000 |
| Oil & gas pipelines | | | | |
| 30-inch | 27,000 | LF | $98.00 | $2,646,000 |
| 16-inch | 28,000 | LF | $42.00 | $1,176,000 |
| 8-inch | 20,000 | LF | $23.00 | $460,000 |
| 6-inch | 42,000 | LF | $20.00 | $840,000 |
| Power lines | 3,600 | LF | $450.00 | $1,620,000 |
| Cemeteries | | | | |
| Wims | 25 | EA | $6,000.00 | $150,000 |
| Singleton | 10 | EA | $6,000.00 | $60,000 |
| Evergreen | 75 | EA | $6,000.00 | $450,000 |

Table 5-36 (continued).

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| Wells (each) | | | | |
| Oil & gas wells | 94 | EA | $25,000.00 | $2,350,000 |
| Water wells | 9 | EA | $49,000.00 | $441,000 |
| Engineering & contingencies—conflicts | | | | $12,346,000 |
| **Land purchase** | 77,427 | AC | $1,201.00 | **$92,990,000** |
| **Environmental studies & mitigation** | | | | **$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; SY=Square Yard.

Table 5-37. Acreage and percent landcover for Marvin Nichols IA Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

Marvin Nichols IA Reservoir will 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 5-37 and Figure 5-54 summarize existing landcover for the Marvin Nichols IA Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by largely contiguous bottomland hardwood forest (39

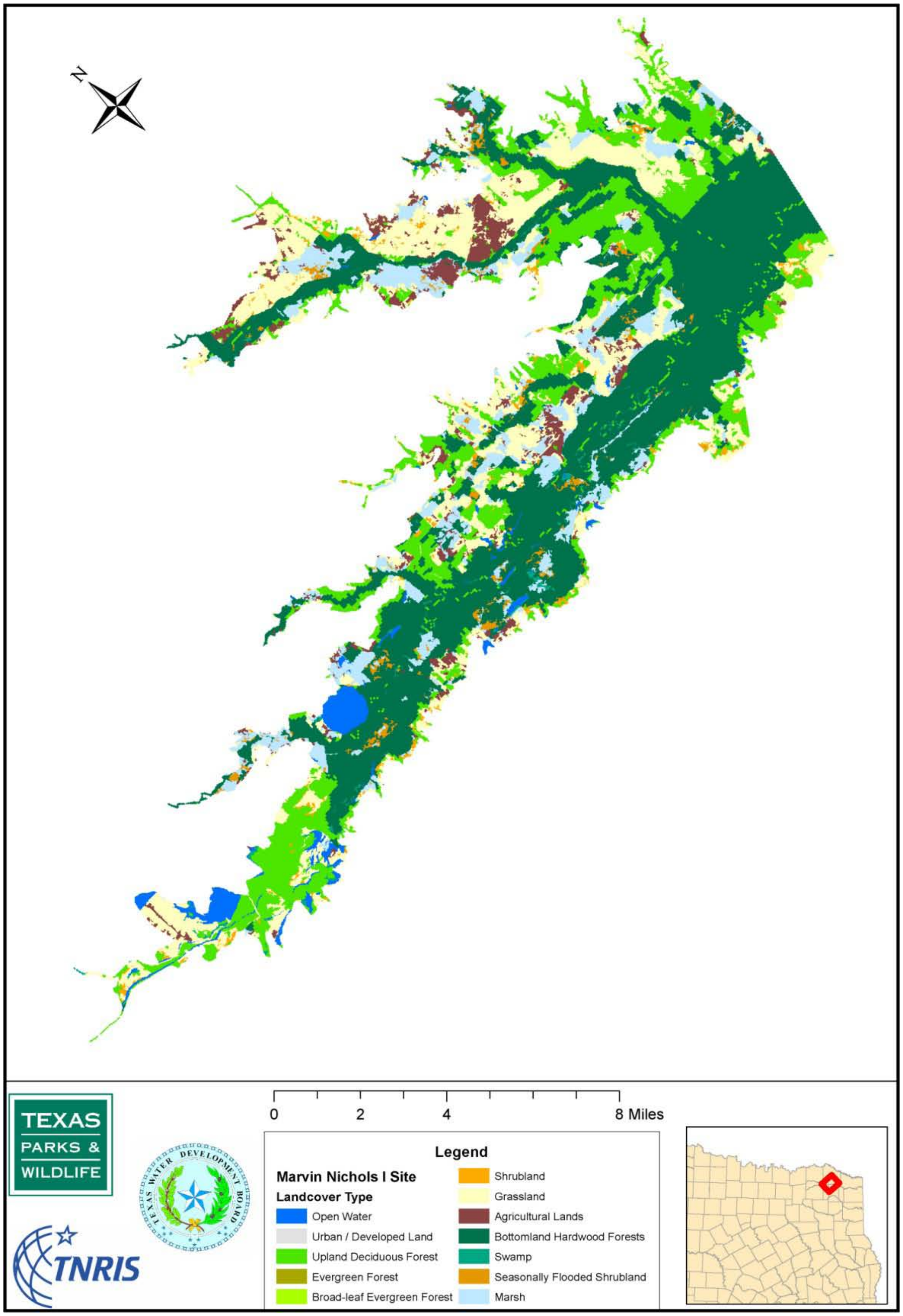


Figure 5-54. Existing landcover for Marvin Nichols IA Reservoir.

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.

## 5.9 NUECES OFF-CHANNEL RESERVOIR

The Nueces Off-Channel Reservoir is recommended in the 2006 Coastal Bend Regional Water Plan as a strategy to increase the firm yield of the Choke Canyon Reservoir/Lake Corpus Christi System and potentially provide ecosystem restoration benefits. Choke Canyon Reservoir has a storage capacity of approximately 695,000 acre-feet and a contributing drainage area of approximately 5,500 square miles. Lake Corpus Christi has a storage capacity of approximately 257,000 acre-feet but a contributing drainage area of approximately 16,500 square miles. With this configuration, the smallest reservoir has the largest potential for capturing storm flows because of the larger contributing drainage area. As a result, the yield of the 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, it often fills and spills flow to Nueces Bay when there is available capacity in Choke Canyon Reservoir. However, with the proposed Nueces Off-Channel Reservoir, water could be pumped from Lake Corpus Christi into the off-channel reservoir, resulting in more water in storage and an improved system yield.

The Nueces Off-Channel Reservoir will be located near the upper western section of Lake Corpus Christi (Figure 5-55) and require an intake and pump station at Lake Corpus Christi to pump available water from it to the off-channel reservoir. At its proposed elevation of 275.3 feet, the reservoir will have a capacity of 250,000 acre-feet and inundate 5,294 acres.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply by year 2060 total 159,640 acre-feet

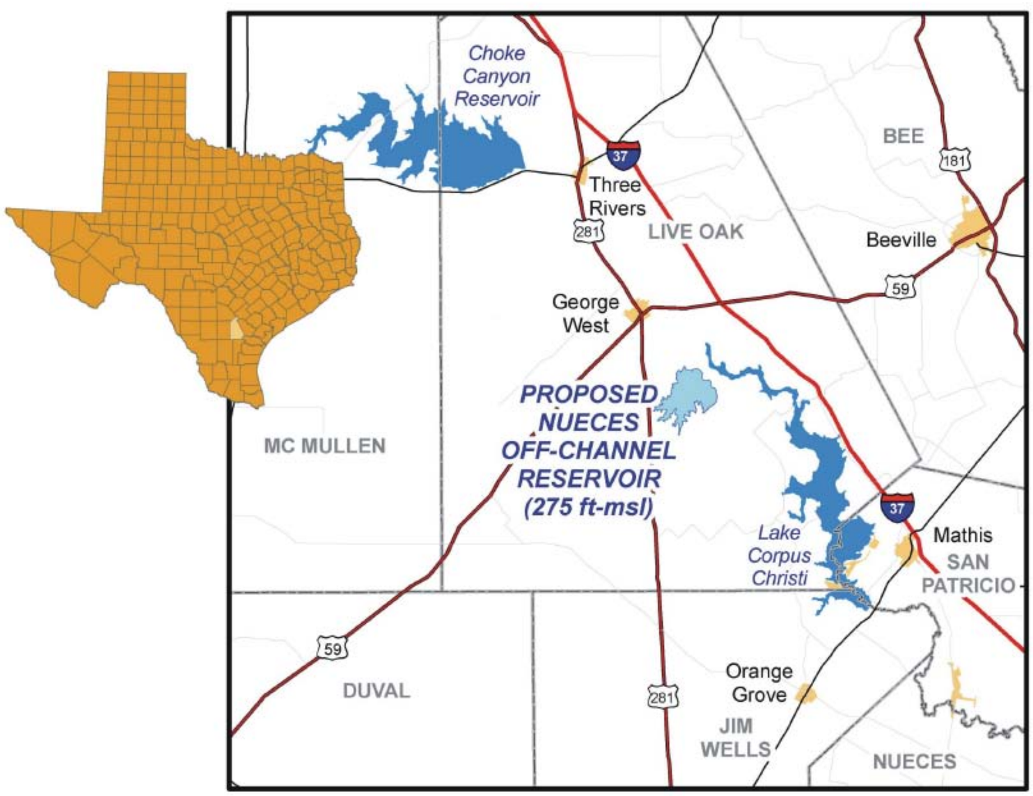


Figure 5-55. Location map of Nueces Off-Channel Reservoir.
ft-msl=feet above mean sea level

per year for counties within a 50-mile radius of the Nueces Off-Channel Reservoir site. This 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).

### *5.9.1 Reservoir Yield Analysis*

The elevation-area-capacity relationship for the Nueces Off-Channel Reservoir is presented in Table 5-38 and Figure 5-56 and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data are derived from the 1:24,000-scale (7.5-minute) quadrangle maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-57. At the conservation storage pool elevation of 275.3 feet, the Nueces Off-Channel Reservoir will inundate 5,294 acres and have a capacity of 250,000 acre-feet.

We developed firm yield simulations for 1934 to 2003 using the City of Corpus Christi's Phase IV Operations Plan (Naismith Engineering, 1999), the 2001 Texas Commission on Environmental

Table 5-38. Elevation-area-capacity relationship for Nueces Off-Channel Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

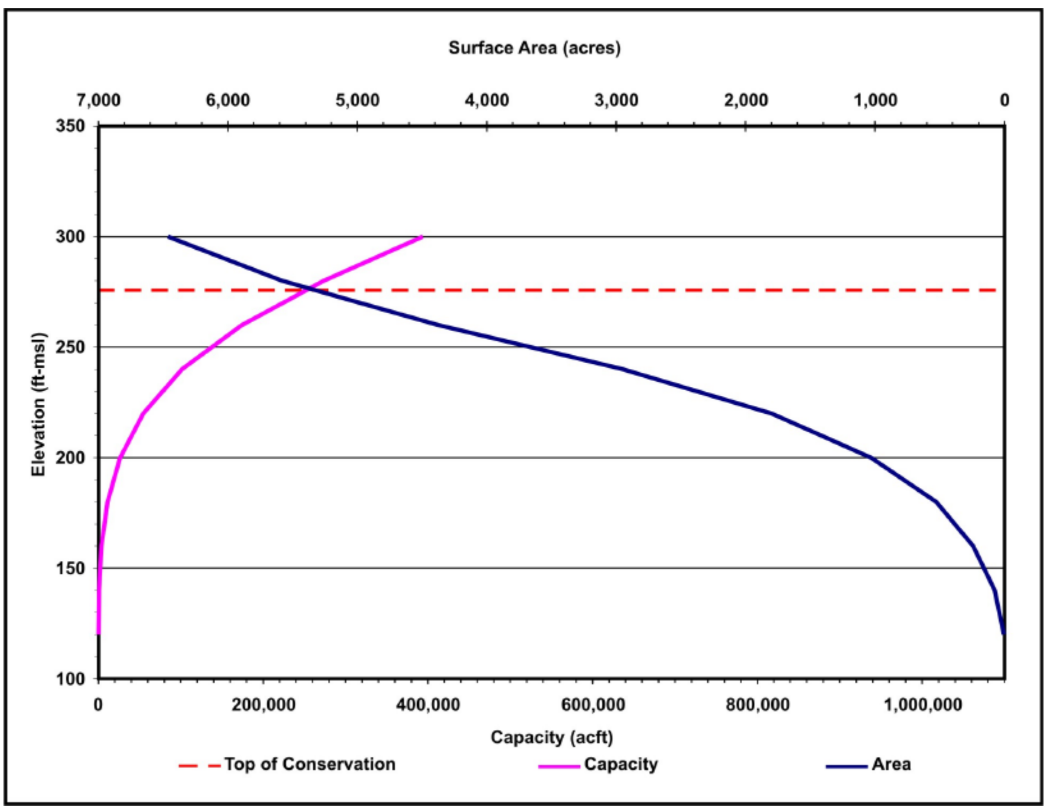


Figure 5-56. Elevation-area-capacity relationship for Nueces Off-Channel Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

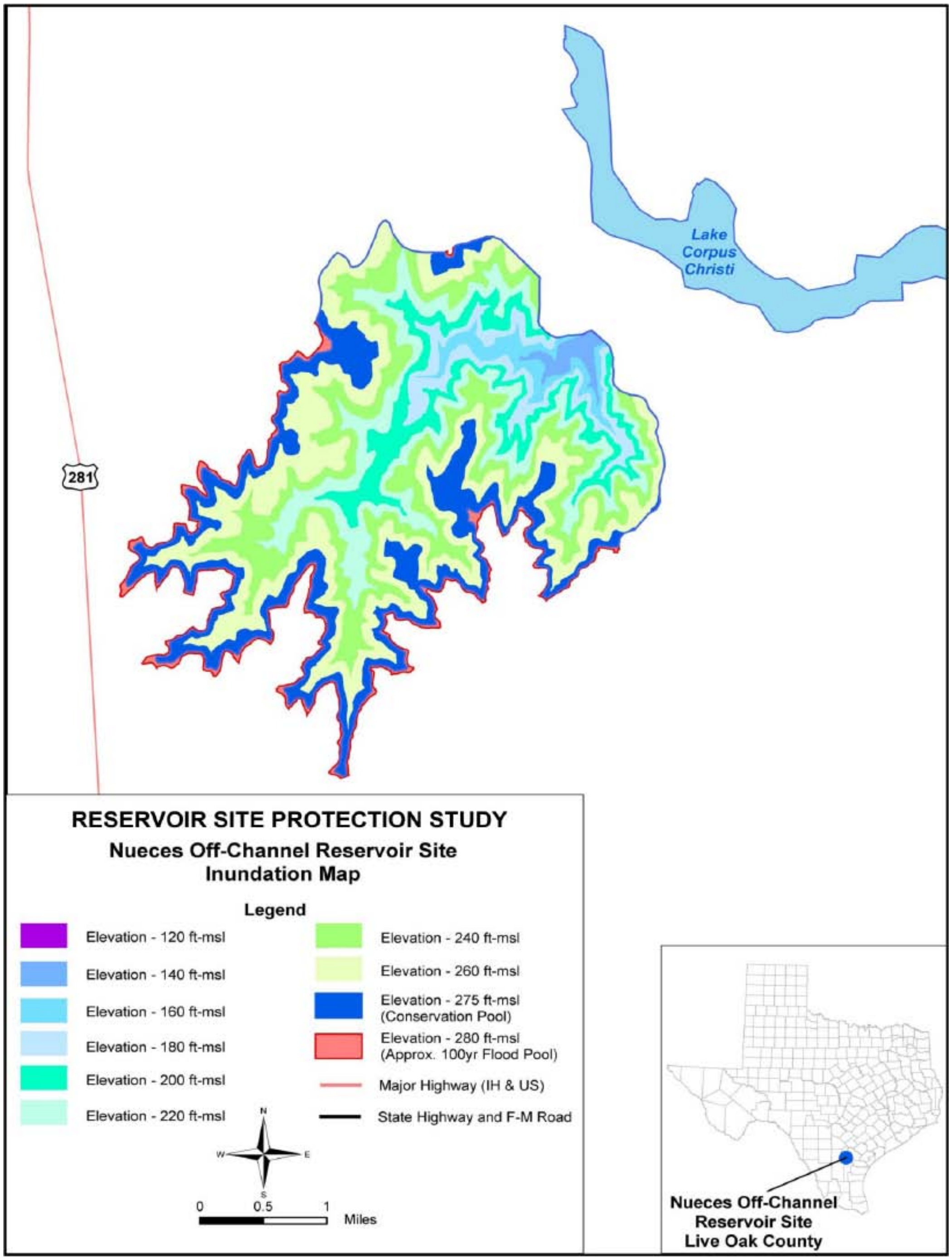


Figure 5-57. Inundation map for Nueces Off-Channel Reservoir.
ft-msl=feet above mean sea leve

Quality Agreed Order (TCEQ, 2001), and 2010 reservoir sedimentation conditions. We assumed that the 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. The simulations were performed using an updated version of Corpus Christi's Lower Nueces River Basin and Estuary Model (HDR, 2006b) that includes the capability to simulate the Nueces Off-Channel Reservoir.

Operational guidelines for the reservoir, pump station, and pipelines for the Nueces Off-Channel Reservoir were developed to identify pipeline capacity, storage capacity, and the optimum set of Lake Corpus Christi elevation triggers. We also considered 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:

- Water will 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 is 93 feet or greater and storage is available in the Nueces Off-Channel Reservoir. The conservation pool elevation of Lake Corpus Christi is 94 feet.
- The Nueces Off-Channel Reservoir will release to Lake Corpus Christi any time the elevation in Lake Corpus Christi is less than or equal to 80 feet.
- Releases from Choke Canyon Reservoir will be triggered when Lake Corpus Christi is less than or equal to 74 feet in elevation.

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

Four potential conservation storage capacities were modeled for this report for the Nueces Off-Channel Reservoir: 150,000, 200,000, 250,000, and 300,000 acre-feet. Firm yield estimates for the reservoir for all four conservation capacities are shown in Table 5-39. Current planning initiatives envision a conservation capacity of 250,000 acre-feet for the reservoir, thereby yielding an additional water supply of 39,935 acre-feet per year above the Lake Corpus Christi/Choke Canyon Reservoir System yield of 231,925 acre-feet per year. Figure 5-58 shows the relationship between firm yield and conservation capacity for the 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 cubic feet per second for all four conservation capacities.

Figure 5-59 illustrates storage fluctuations through time for the Nueces Off-Channel Reservoir, and Figure 5-60 shows the combined system storage in Lake Corpus Christi, Choke Canyon Reservoir, and the Nueces Off-Channel Reservoir. The storage frequency curve indicates that the reservoir will 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. However, the system of reservoirs will be above 50 percent of storage capacity about 72 percent of the time.

Table 5-39. Firm yield versus conservation storage for the Nueces Off-Channel Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | 2010 Firm Yield[c] (acft/yr[d]) | 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
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]Base system yield without Nueces Off-Channel Reservoir is 231,925 acre-feet per year
[d]acft/yr=acre-feet per year

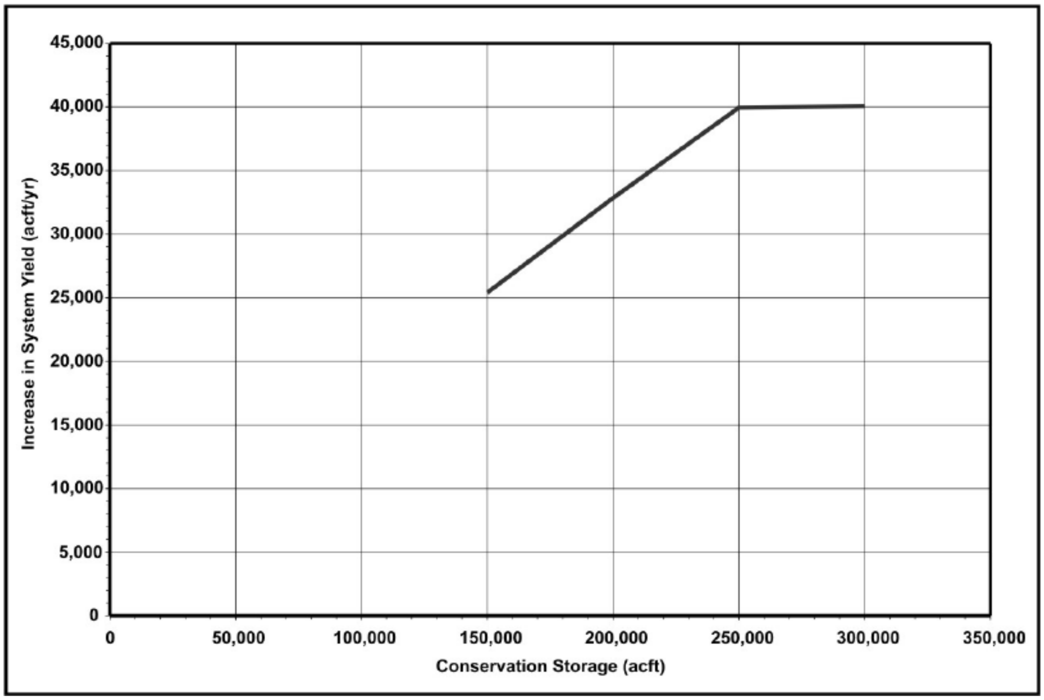


Figure 5-58. Firm yield versus conservation storage for the Nueces Off-Channel Reservoir.
acft/yr=acre-feet per year

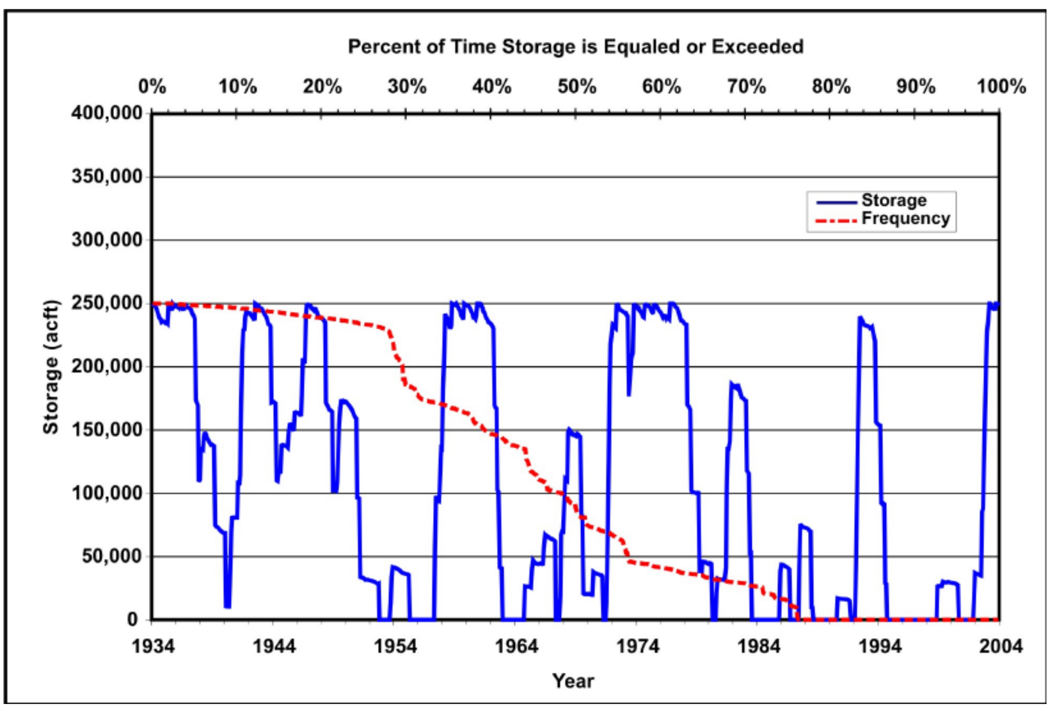


Figure 5-59. Simulated storage in the Nueces Off-Channel Reservoir (conservation elevation=275.3 feet; incremental yield=39,935 acre-feet per year).
acft=acre-feet

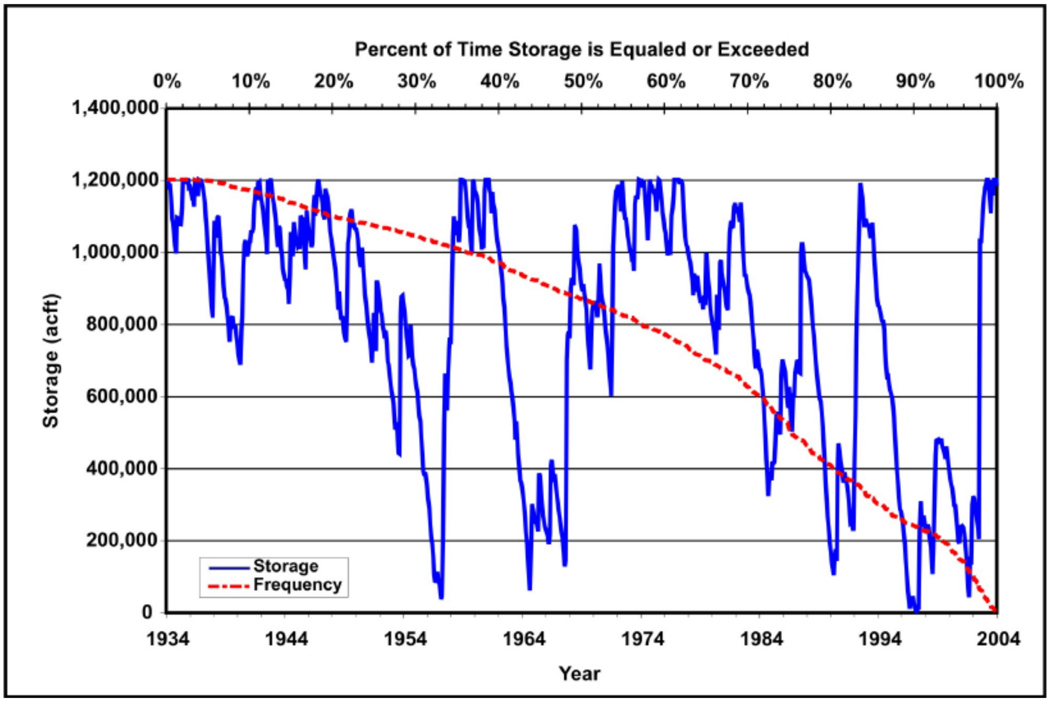


Figure 5-60. Simulated combined storage for Lake Corpus Christi, Choke Canyon Reservoir, and Nueces Off-Channel Reservoir (system diversion=271,860 acre-feet per year).
acft=acre-feet

### *5.9.2 Reservoir Costs*

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 include a 646 million gallon-per-day intake and pump station, a 2.8-mile, 120-inch pipeline, and a stilling basin. The major conflicts within the conservation pool of the Nueces Off-Channel Reservoir include oil and gas wells, water wells, product transmission pipelines, and a power transmission line (Figure 5-61). Resolving facility conflicts represents approximately 5 percent of the total construction cost.

A summary cost estimate for the Nueces Off-Channel Reservoir at an elevation of 275 feet (250,000 acre-feet) is shown in Table 5-40. Quantities and relocation costs are from the 2006 Region N Regional Water Plan. Dam and reservoir costs total about $97 million; relocations total another $9.8 million. Land, including mitigation lands, totals about $15.4 million. The diversion intake, pump station, and pipeline from Lake Corpus Christi to the Nueces Off-Channel Reservoir add another $70 million. Annual costs for the 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 per acre-foot ($1.33 per 1,000 gallons).

### *5.9.3 Environmental Considerations*

The Nueces Off-Channel Reservoir site is adjacent to the Texas Commission on Environmental Quality classified stream segment 2103. Although the Texas Parks and Wildlife Department 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 will be made.

The Nueces Off-Channel Reservoir will inundate 5,294 acres of land at conservation storage capacity. Table 5-41 and

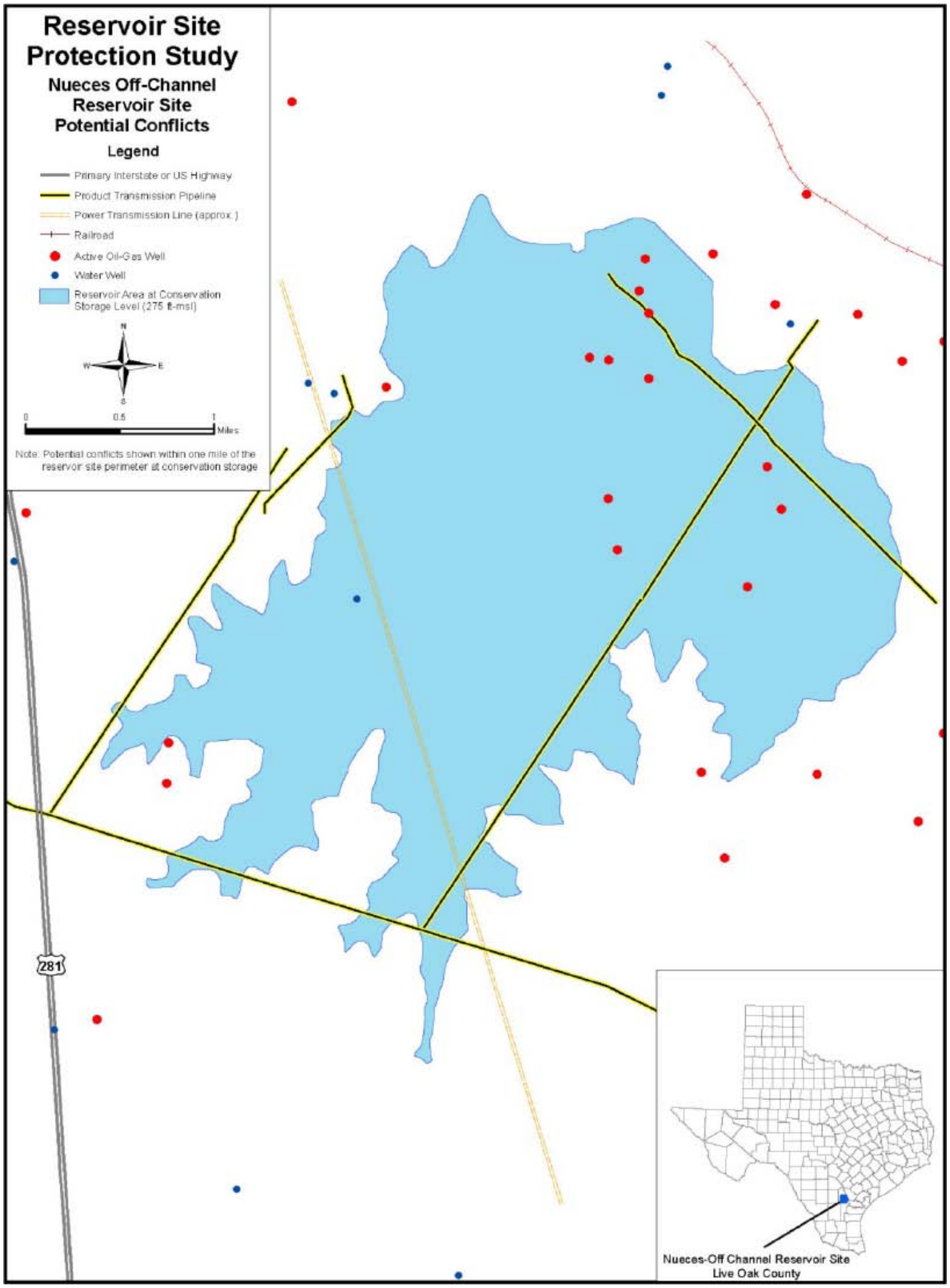


Figure 5-61. Potential major conflicts for the Nueces Off-Channel Reservoir (map from Texas Natural Resources Information System).
ft-msl= feet above mean sea level

Figure 5-62 summarize existing landcover for the Nueces Off-Channel Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by grassland (49 percent) and shrubland (43 percent).

Table 5-40. Cost estimate—Nueces Off-Channel Reservoir at elevation 275.3 feet.

| | Quantity | Unit | Unit Cost | 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 | $35,233,653.00 | $35,233,653 |
| Pipeline (120-inch) | 14,770 | LF | $870.00 | $12,849,900 |
| Stilling basin (1,000 cfs) | 1 | LS | $3,751,000.00 | $3,751,000 |
| Engineering contingencies (35%) | | | | $18,142,093 |
| **Subtotal Pump & Pipeline** | | | | **$69,976,646** |
| **Conflicts** | | | | |
| H20 wells | 2 | EA | $25,000.00 | $50,000 |
| Oil & gas wells | 15 | EA | $50,000.00 | $750,000 |
| Oil & gas pipeline | 55,144 | LF | $42.00 | $2,316,055 |
| Power transmission line | 16,111 | LF | $450.00 | $7,249,989 |
| Engineering contingencies (35%) | | | | $2,537,496 |
| **Subtotal Conflicts** | | | | **$9,787,485** |
| **Land** | | | | |
| Land acquisition | 5,294 | AC | $1,450.00 | $7,676,300 |
| Environmental studies & mitigation | | | | $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** | | | | **$17,257,577** |
| **Firm Yield (acre-feet per year)** | | | | **39,935** |
| **Unit Costs of Water ($/acre-foot)** | | | | **$432** |

Units: AC=Acre; CY=Cubic Yard; EA=Each; LB=Pound; LF=Linear Foot; LS=Lump Sum; SF=Square Foot; SY=Square Yard; MGD=Million Gallons per Day; cfs=cubic feet per second

Table 5-41. Acreage and percent landcover for Nueces Off-Channel Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

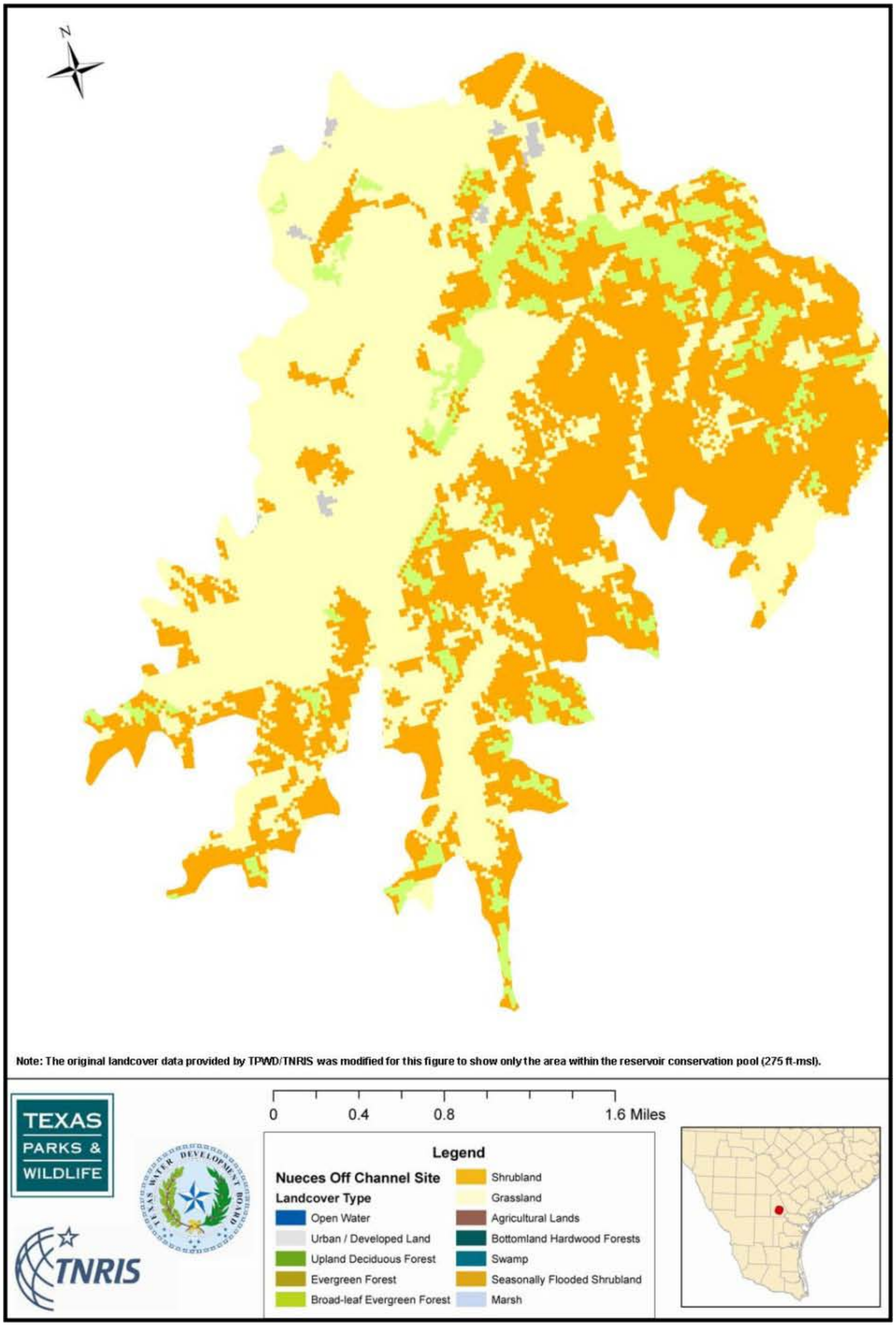


Figure 5-62. Existing landcover for the Nueces Off-Channel Reservoir.
ft-msl=feet above mean sea level

## 5.10 Palmetto Bend Reservoir—Stage II (Texana Stage II)

TWDB and the Lavaca-Navidad River Authority 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. It is operated by the Lavaca-Navidad River Authority for water supply purposes and has a firm yield of 79,000 acre-feet per year.

Originally, the U.S. Bureau of Reclamation proposed that Stage II 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, 1991). As proposed, at the original site, the Certificate of Adjudication states:

> 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 acre-feet per year, for a total of 48,122 acre-feet per year, of which up to 7,150 acre-feet per year shall be for municipal purposes, up to 22,850 acre-feet per year shall be for industrial purposes, and at least 18,122 acre-feet per year 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. (TNRCC,1994)

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 5-63). Since this alternative site results in a different yield from that stated in the certificate, the conditions in the certificate will need to be revised

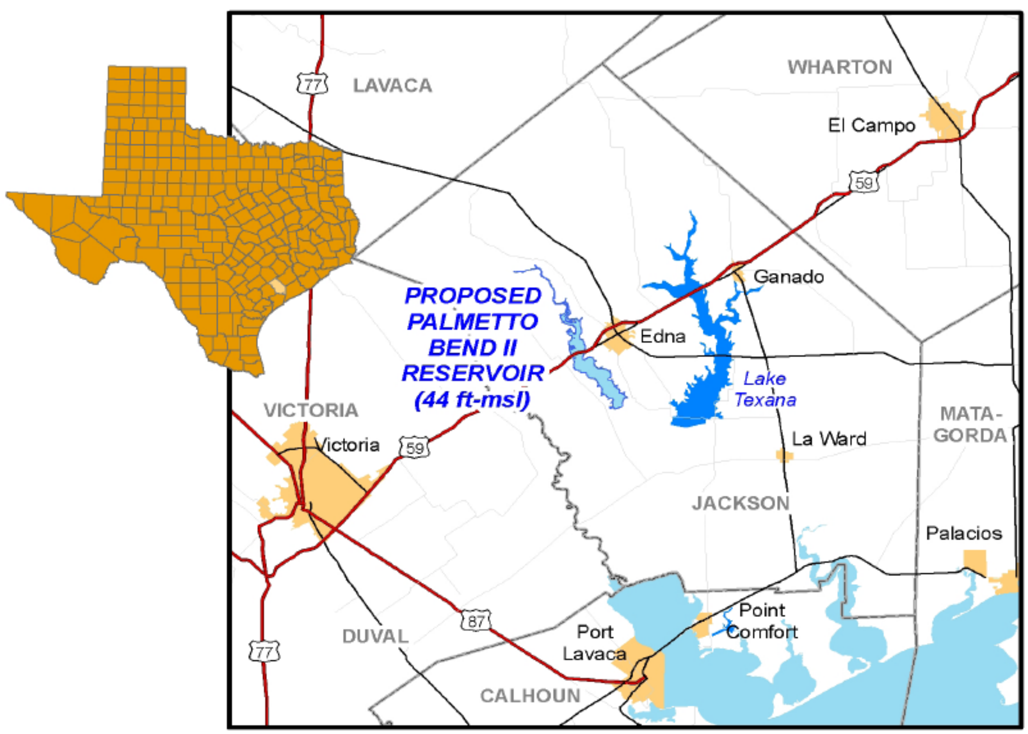


Figure 5-63. Location map of Palmetto Bend Reservoir—Stage II.
ft-msl=feet above mean sea level

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. At the conservation pool elevation of 44 feet, the proposed reservoir will have a capacity of 52,046 acre-feet and inundate 4,564 acres.

The Lavaca-Navidad River Authroity has expressed a renewed interest in the potential development of Stage II. In the 2001 Coastal Bend Regional Water Plan, water supply from the development of Stage II was evaluated as part of an inter-regional 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 Regional 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, they did not recommend these options in either their 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 by year 2060 total 79,857 acre-feet per year for counties within a 50-mile radius of the Palmetto Bend Reservoir–Stage II site. This 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).

### *5.10.1*
### *Reservoir Yield Analysis*

The elevation-area-capacity relationship for Palmetto Bend Reservoir—Stage II is presented in Figure 5-64 and Table 5-42

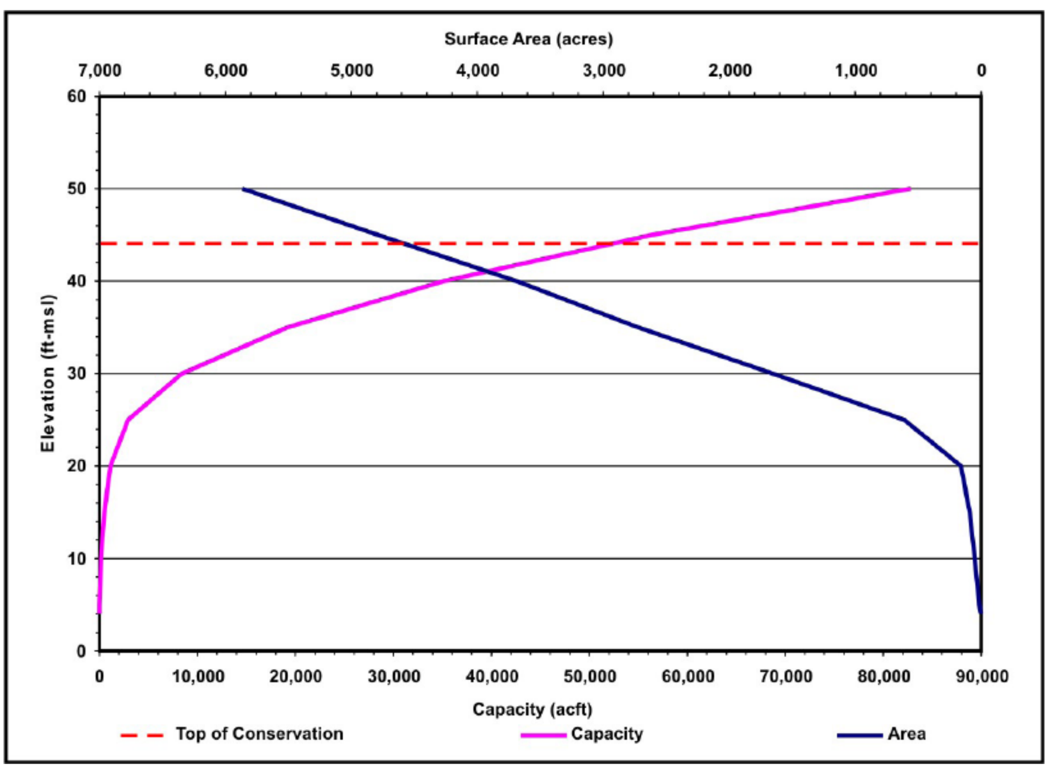


Figure 5-64. Elevation-area-capacity relationship for Palmetto Bend Reservoir–Stage II.
ft-msl=feet above mean sea level; acft= acre-feet

and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data are derived from the 1:24,000-scale (7.5-minute) quadrangle maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-65. Surface areas and capacities associated with an elevation of 44 feet are computed by linear interpolation between values for 40 and 45 feet and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 44 feet, Palmetto Bend Reservoir–Stage II will inundate 4,564 acres and have a capacity of 52,046 acre-feet.

The Consensus Criteria for Environmental Flow Needs were used for modeling 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 values used include the median and quartile flows in Table 5-43 and the 7Q2 value of 21.6 cubic feet per second published in the Texas Surface Water Quality Standards (30 Texas Administrative Code §310.10).

The firm yield of Palmetto Bend Reservoir–Stage II was estimated by using the Texas Commission on Environmental Quality Lavaca River Basin water availability model (BOR, 2001; February 24, 2003, version) data sets and the Water Rights Analysis Package. The water availability model 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 and pattern, storage, and special conditions, including instream flow requirements.

Four potential conservation storage capacities were modeled for Palmetto Bend Reservoir—Stage II associated with 50, 44, 40, and 35 foot conservation pool elevations. Table 5-44 includes the conservation storage capacities and firm yields associated with these four conservation elevations.

Table 5-42. Elevation-area-capacity relationship for Palmetto Bend Reservoir–Stage II.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet per year

Palmetto Bend Reservoir–Stage II is simulated with the priority date as provided by the Texas Commission on Environmental Quality in Certificate of Adjudication No. 16-2095B. Current planning envisions a conservation elevation of 44 feet for Palmetto Bend Reservoir–Stage II, thereby yielding a water supply of 22,964 acre-feet per year. Figure 5-66 shows the relationship between firm yield and conservation capacity for Palmetto Bend Reservoir–Stage II.

Palmetto Bend Reservoir–Stage II was most recently evaluated by the Coastal Bend and South Central Texas Regional Planning Groups in their 2001 Regional Water Plans. They reported the firm yield of Palmetto Bend Reservoir–Stage II as 28,000 acre-feet per year at a conservation elevation of 44 feet. The firm yield estimate in the current study differs from the 2001 Regional Water Plans because the regional plans used SIMDLY (a daily reservoir simulation model) rather than the Water Rights Analysis Package. In addition, the refined elevation-area-capacity relationship in

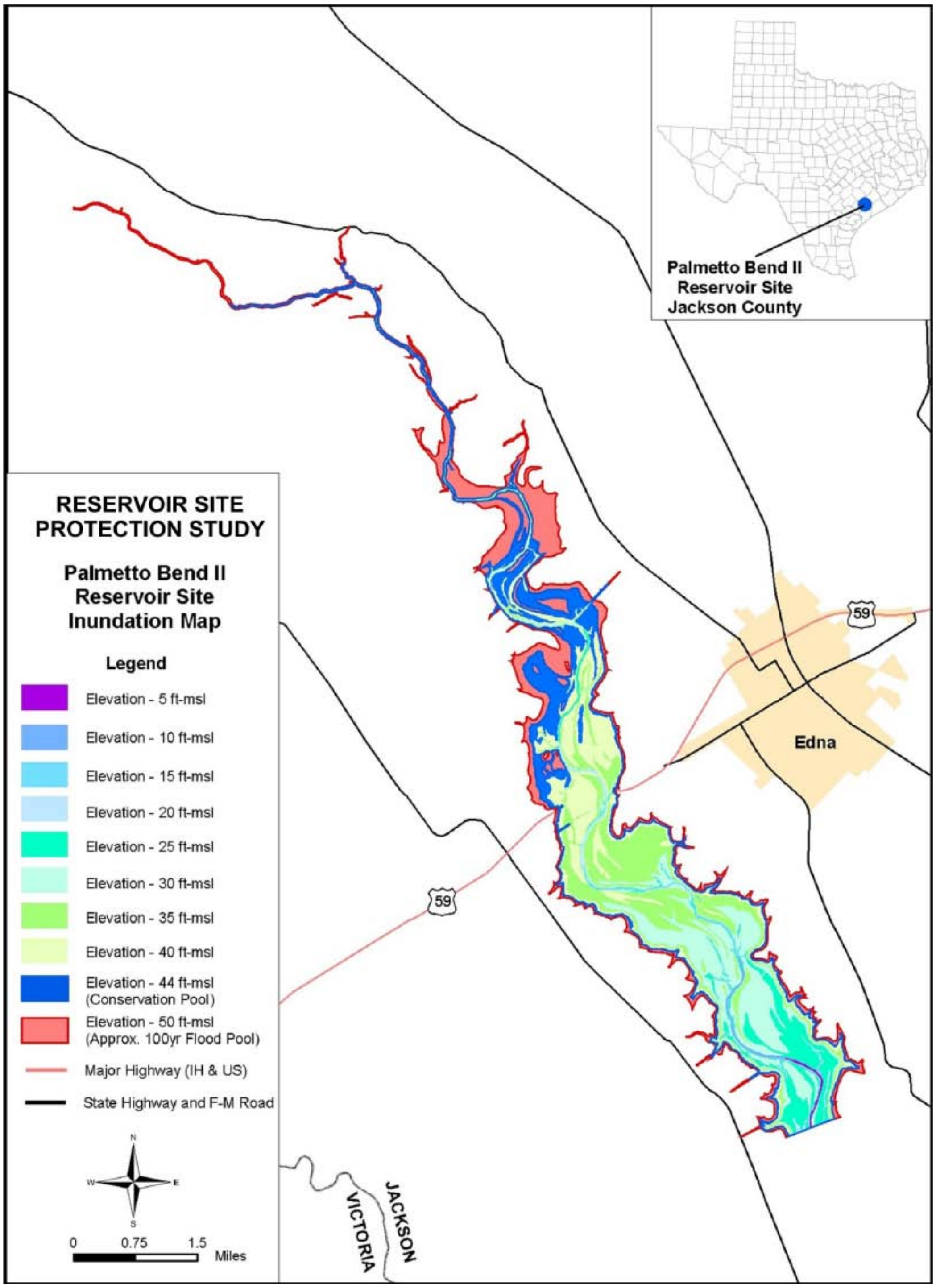


Figure 5-65. Inundation map for Palmetto Bend Reservoir—Stage II.
ft-msl=feet above mean sea level

the current study has reduced the conservation capacity at an elevation of 44 feet from 57,676 to 52,046 acre-feet.

Figure 5-67 illustrates storage fluctuations through time for Palmetto Bend Reservoir–Stage II subject to firm yield diversions and the Consensus Criteria for Environmental Flow Needs. The reservoir storage frequency curve indicates that the reservoir will be full about 38 percent of the time and more than half full about 90 percent of the time.

Table 5-43. Consensus criteria for environmental flow needs for Palmetto Bend Reservoir–Stage II.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 3,874 | 63.0 | 1,605 | 26.1 | 1,328 | 21.6 |
| Feb | 5,154 | 92.8 | 2,166 | 39.0 | 1,200 | 21.6 |
| Mar | 4,728 | 76.9 | 2,312 | 37.6 | 1,328 | 21.6 |
| Apr | 4,695 | 78.9 | 2,190 | 36.8 | 1,285 | 21.6 |
| May | 5,669 | 92.2 | 2,177 | 35.4 | 1,328 | 21.6 |
| Jun | 5,094 | 85.6 | 2,186 | 36.7 | 1,285 | 21.6 |
| Jul | 2,921 | 47.5 | 1,396 | 22.7 | 1,328 | 21.6 |
| Aug | 2,294 | 37.3 | 1,328 | 21.6 | 1,328 | 21.6 |
| Sep | 2,452 | 41.2 | 1,285 | 21.6 | 1,285 | 21.6 |
| Oct | 2,410 | 39.2 | 1,328 | 21.6 | 1,328 | 21.6 |
| Nov | 2,874 | 48.3 | 1,285 | 21.6 | 1,285 | 21.6 |
| Dec | 3,388 | 55.1 | 1,494 | 24.3 | 1,328 | 21.6 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-44. Firm yield versus conservation storage for Palmetto Bend Reservoir–Stage II.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) |
|---|---|---|---|
| 35 | 19,182 | CCEFN[d] | 8,878 |
| 40 | 35,152 | CCEFN | 16,819 |
| 44* | 52,046 | CCEFN | 22,964 |
| | | None | 30,606 |
| 50 | 82,851 | CCEFN | 31,161 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

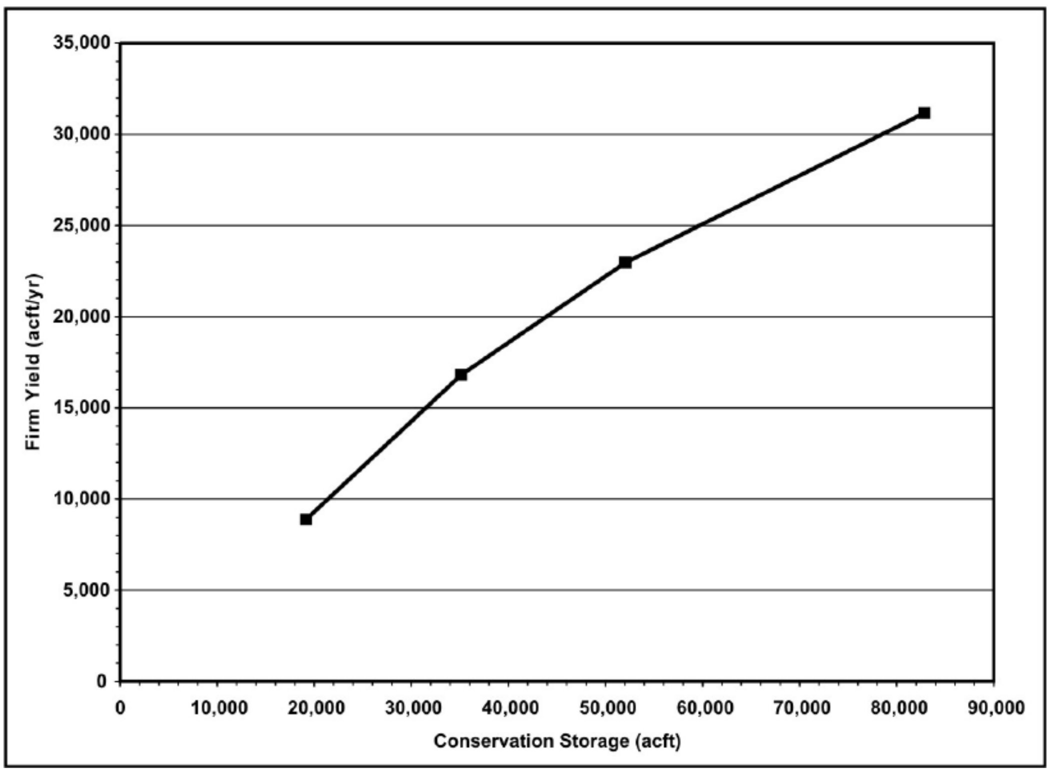


Figure 5-66. Firm yield versus conservation storage for Palmetto Bend Reservoir–Stage II.
acft/yr=acre-feet per year

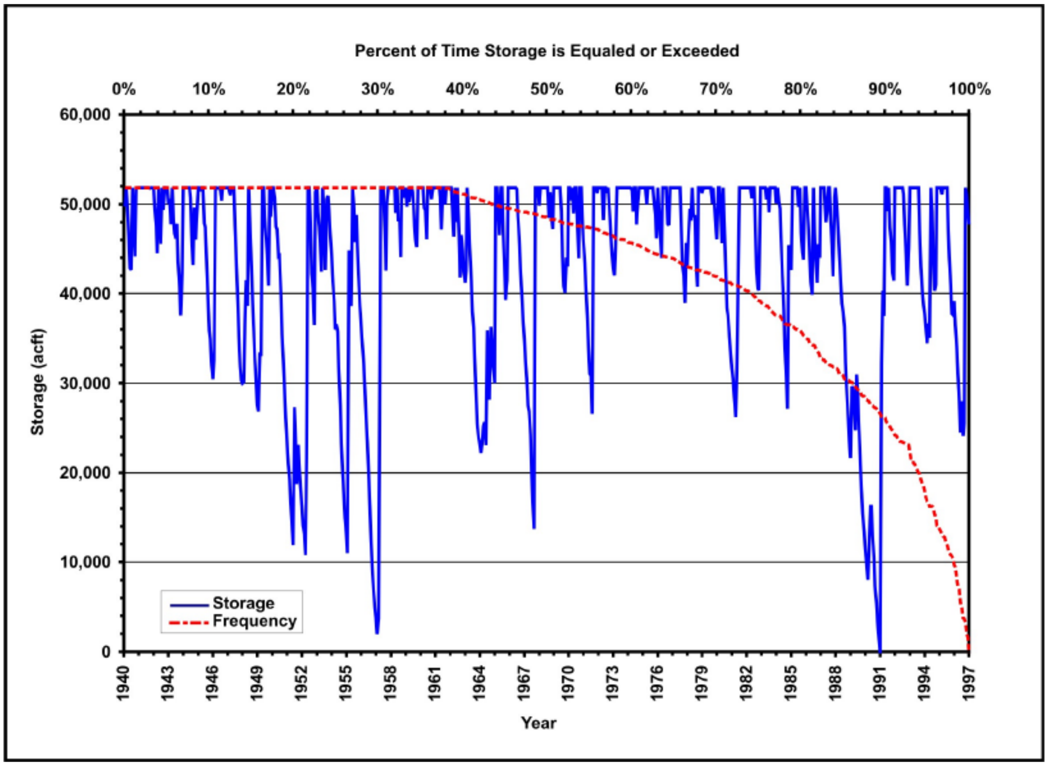


Figure 5-67. Simulated storage in Palmetto Bend Reservoir–Stage II (conservation elevation=44 feet; diversion=2,964 acre-feet per year).
acft=acre-feet

*5.10.2*
***Reservoir Costs***

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, with a maximum height of approximately 50 feet. Potential conflicts include water wells, oil and gas wells, product transmission pipelines, power transmission lines, a railway, and U.S. Highway 59 (Figure 5-68). Resolving facility conflicts represents approximately 29 percent of the total construction cost.

A summary cost estimate for Palmetto Bend Reservoir–Stage II at an elevation of 44 feet is shown in Table 5-45. Dam and reservoir costs total about $83.8 million, and relocations total another $41.3 million. Land, including 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 per acre-foot ($1.58 per 1,000 gallons).

*5.10.3*
***Environmental Considerations***

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

- Biological function—Extensive freshwater wetland habitat displays significant overall habitat value.
- Threatened or endangered species/

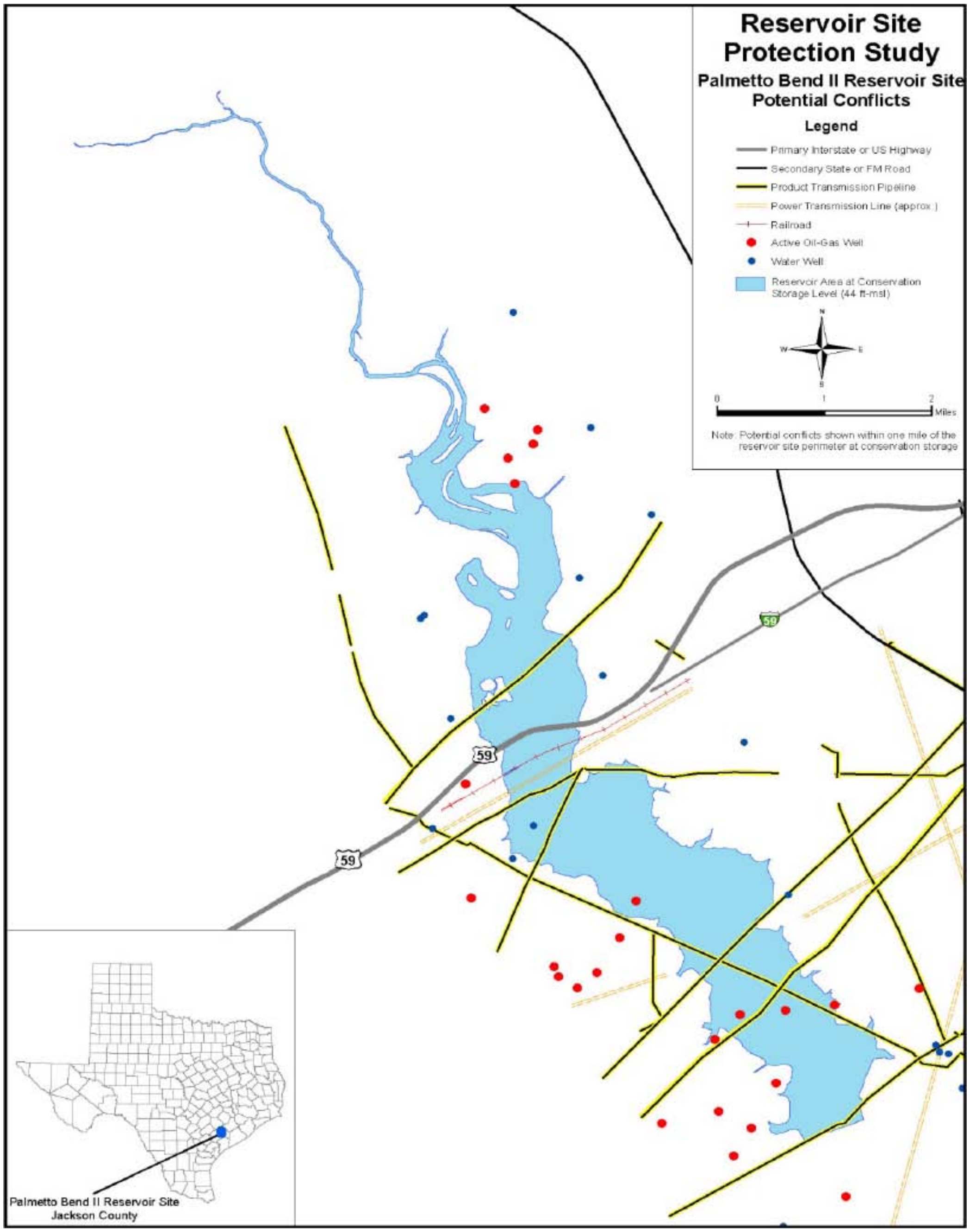


Figure 5-68. Potential major conflicts for Palmetto Bend Reservoir–Stage II (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Unique communities—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 5-46 and Figure 5-69 summarize existing landcover for the reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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 5-45. Cost estimate—Palmetto Bend Reservoir–Stage II at elevation 44 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Dam & Reservoir** | | | | |
| Mobilization (5%) | 1 | LS | | $2,797,713 |
| Clearing & 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** |
| **Land** | | | | |
| Land acquisition | 5,217 | AC | $1,627 | $8,488,059 |
| Environmental studies & mitigation | | | | $8,488,059 |
| **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 | | | | $1,257,323 |
| **Total Annual Costs** | | | | **$11,837,146** |
| **Firm Yield (acre-feet per year)** | | | | **22,964** |
| **Unit Costs of Water ($/acre-foot)** | | | | **$515** |

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

Table 5-46. Acreage and percent landcover for Palmetto Bend Reservoir–Stage II.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

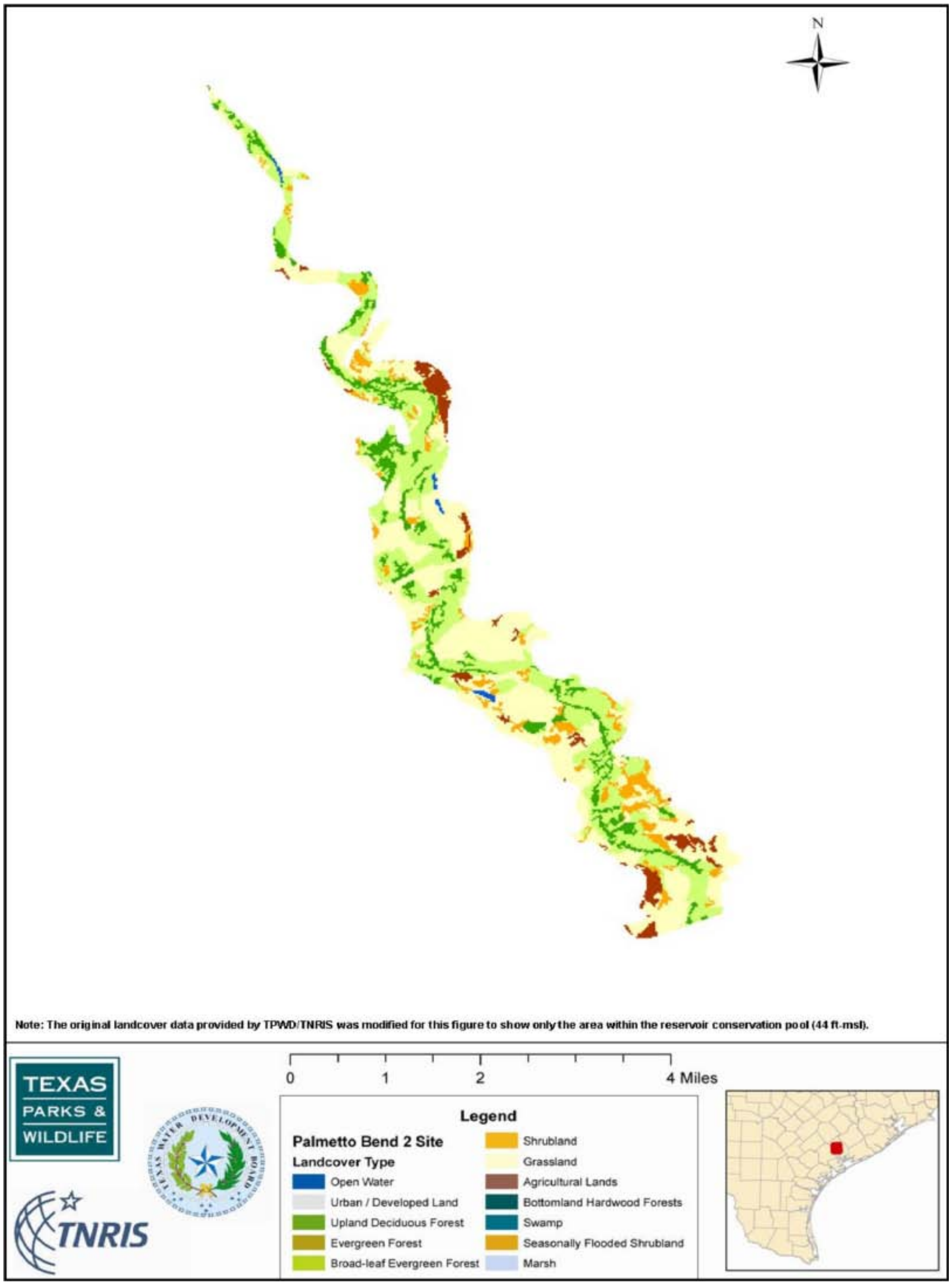


Figure 5-69. Existing landcover for Palmetto Bend Reservoir–Stage II.
ft-msl=feet above mean sea level

## 5.11 PARKHOUSE I LAKE

Parkhouse I Lake is a proposed reservoir that will be located on the South Sulphur River in Delta and Hopkins counties, about 18 miles northeast of the city of Sulphur Springs (Figure 5-70). The proposed conservation pool will be at an elevation of 401 feet, with a conservation capacity of 651,712 acre-feet. The inundated area at the top of the conservation pool is 28,855 acres. The reservoir will have a total drainage area of 654 square miles, of which 479 are above Jim Chapman Lake.

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

The 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 acre-feet per year by year 2060. 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, located approximately 93 miles southwest of the reservoir site.

### 5.11.1 *Reservoir Yield Analysis*

The elevation-area-capacity relationship is included in Table 5-47 and shown in Figure 5-71. Freese and Nichols (2000) derived the data from the 1:24,000 scale U.S. Geological Survey topographic quadrangle maps with 10-foot contours. Figure 5-72 shows the inundation map at different elevations in 10-foot intervals. The elevation of the 100-year flood and the maximum probable flood depend on how the storm is routed through Jim Chapman Lake. Jim Chapman Lake flood control operations may

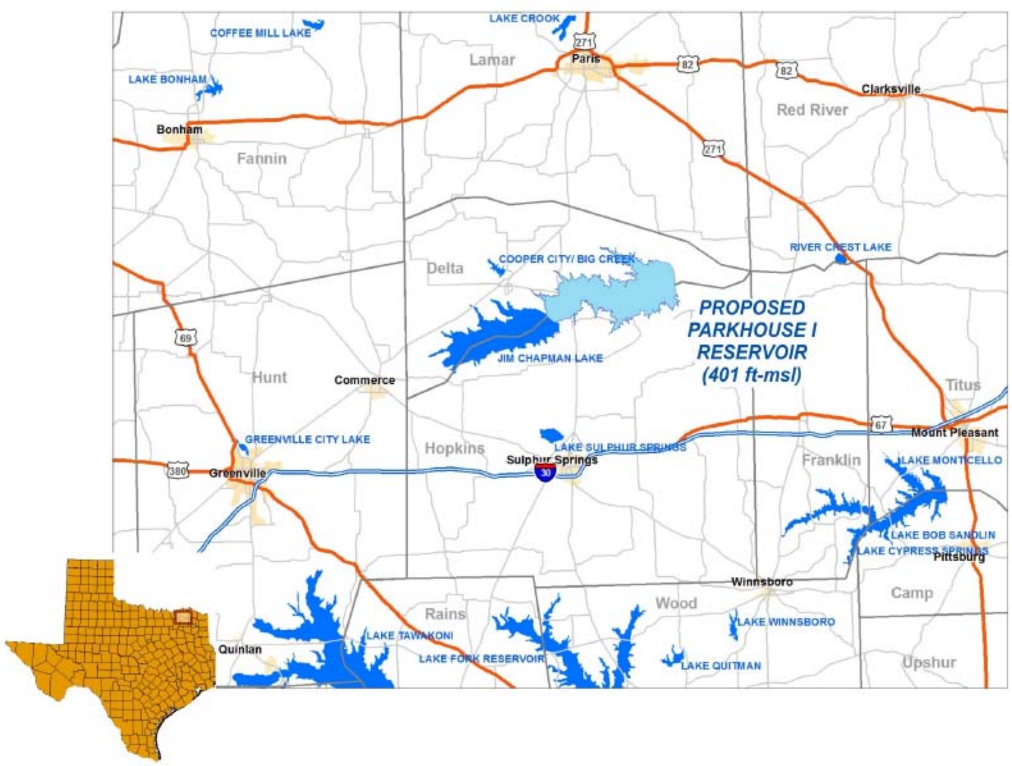


Figure 5-70. Location map of Parkhouse I Lake.
ft-msl=feet above mean sea level

change if 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.

We used the Consensus Criteria for Environmental Flow Needs for modeling Parkhouse I Lake (Table 5-48). The analyses assume that the reservoir will have to pass the lesser of the inflow and the values in the table.

We calculated the firm yield of Parkhouse I Lake with the full authorization scenario (Run 3) of the Sulphur River Basins water availability model. 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 from the water availability model and drainage areas from the U.S. Geological Survey, as was done for Marvin Nichols IA (see section 5-8).

We calculated yields 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 (Table 5-49 and Figure 5-73). We selected a conservation pool elevation of 401 feet for this study to minimize the potential conflicts with Jim Chapman Lake and impacts to the communities of Charleston and Vasco. At a conservation pool elevation of 410 feet or higher, additional protection of the dam and possible

Table 5-47. Elevation-area-capacity relationship for Parkhouse I Lake.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 335 | 0 | 0 |
| 340 | 28 | 74 |
| 345 | 242 | 745 |
| 350 | 456 | 2,489 |
| 355 | 2,513 | 9,884 |
| 360 | 4,571 | 27,584 |
| 365 | 6,567 | 55,423 |
| 370 | 8,563 | 93,245 |
| 375 | 11,158 | 142,543 |
| 380 | 13,752 | 204,814 |
| 385 | 17,270 | 282,363 |
| 390 | 20,787 | 377,499 |
| 395 | 24,563 | 490,868 |
| 400 | 28,338 | 623,116 |
| 401 | 28,855 | 651,712 |
| 405 | 30,922 | 771,264 |
| 410 | 33,506 | 932,332 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

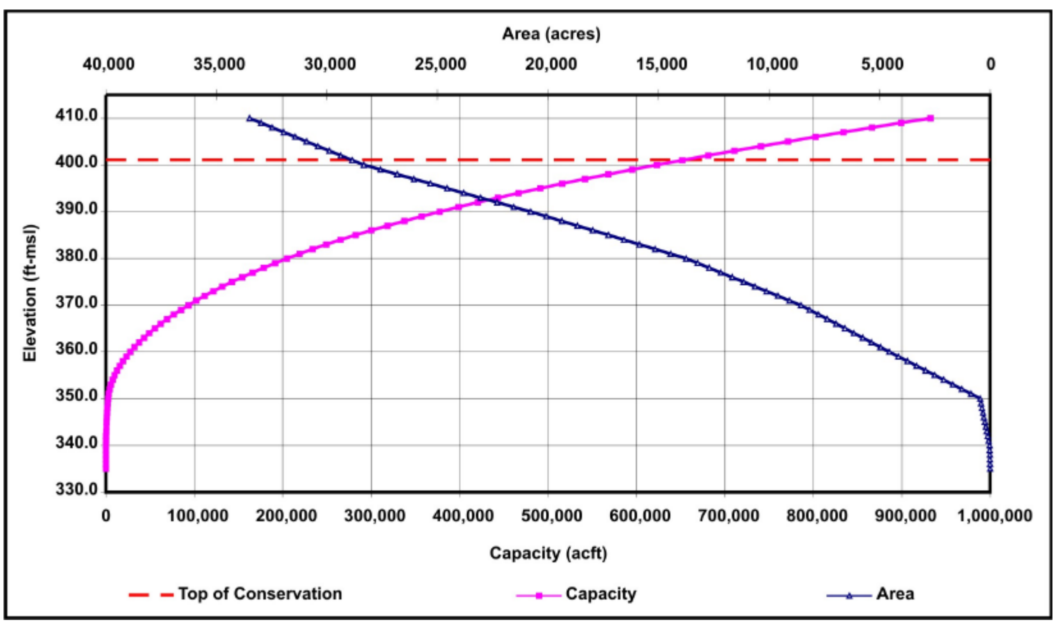


Figure 5-71. Elevation-area-capacity relationship for Parkhouse I Lake.
ft-msl=feet above mean sea level; acft=acre-feet

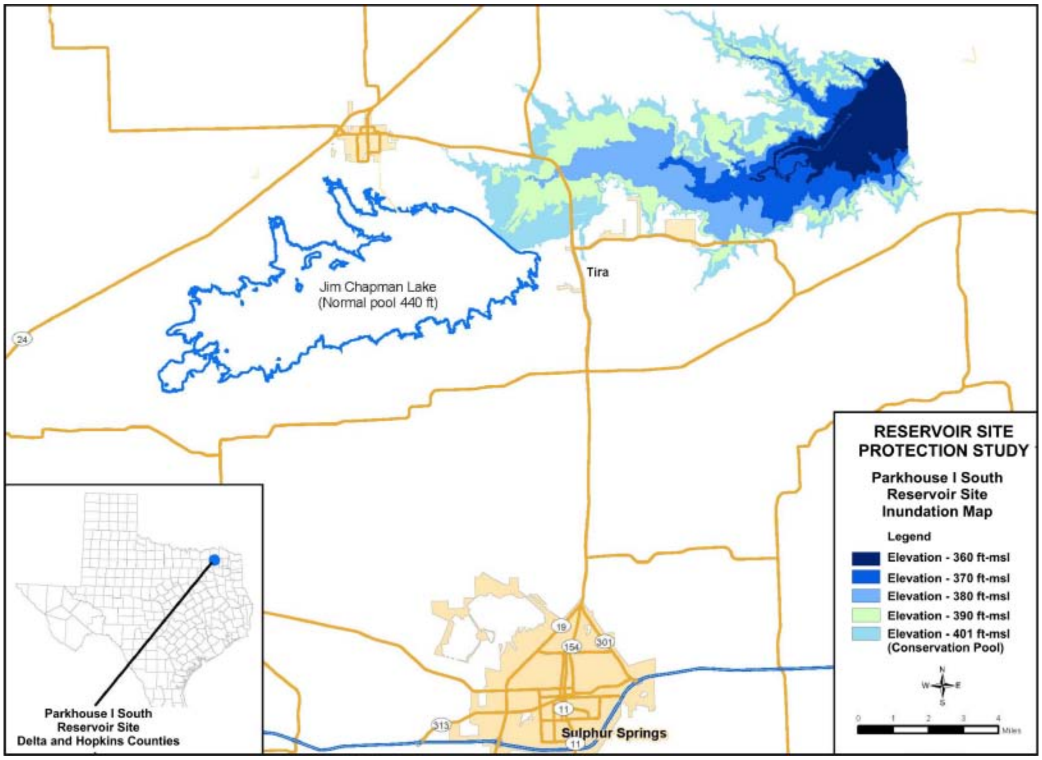


Figure 5-72. Inundation map for Parkhouse I Lake.
ft-msl=feet above mean sea level

Table 5-48. Consensus Criteria for Environmental Flow Needs for Parkhouse I Lake.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | 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 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-49. Firm yield versus conservation storage for Parkhouse I Lake.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 390 | 377,409 | CCEFN[d] | 86,600 | 6/51–1/57 |
| 396 | 515,807 | CCEFN | 104,700 | 9/50 -2/57 |
| 401* | 651,712 | CCEFN | 122,000 | 9/50–2/57 |
| | | None | 124,400 | |
| 410 | 932,332 | CCEFN | 157,300 | 6/50–3/66 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

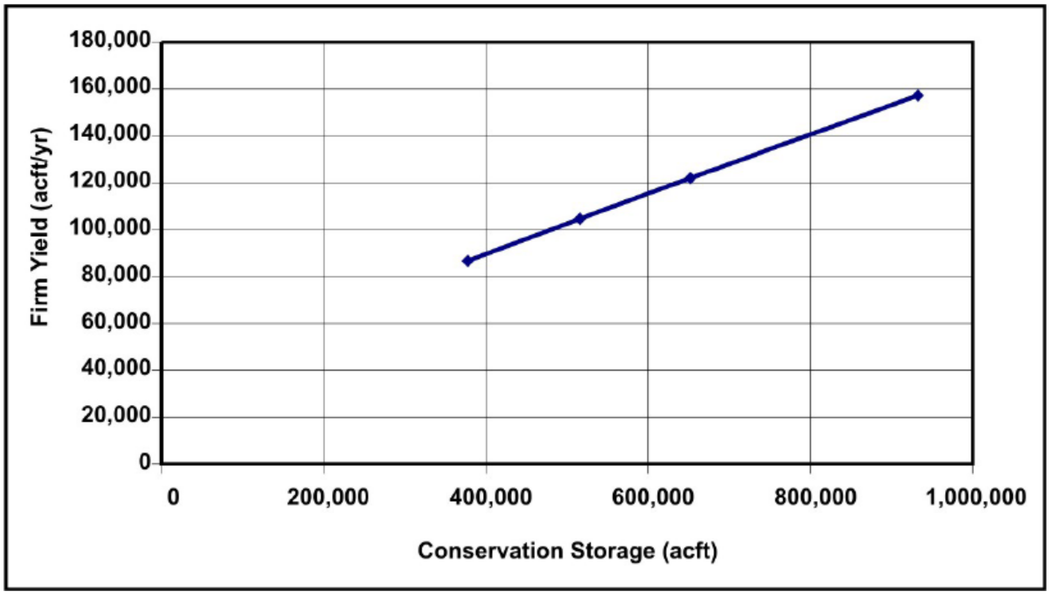


Figure 5-73. Firm yield versus conservation storage for Parkhouse I Lake.
acft/yr=acre-feet per year

modifications to the spillway operation at Jim Chapman Lake might be needed to protect its integrity. Also, the spillway size for the Parkhouse I Lake will need to be increased to keep the probable maximum flood from affecting neighboring communities. At the conservation pool level of 401 feet, the firm yield is 122,000 acre-feet per year. Environmental flow requirements reduce the yield of the reservoir by 2,400 acre-feet per year.

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 IA) 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 will be 48,400 acre-feet per year, or 73,600 acre-feet per year less than if the reservoir is senior to any other proposed reservoir. Because the U.S. Army Corps of Engineers Section 404 permit application for Lake Ralph Hall was submitted in October 2006, that reservoir will likely be senior to Parkhouse I. Appendix A is a memorandum describing the sensitivity of firm yield in the Sulphur Basin to the development of other reservoirs.

Previous evaluations of the yield of the 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 acre-feet per year. The 2006 Region C Regional Water Plan shows that the yield of Parkhouse I is 135,600 acre-feet per year. Both of these studies assume a conservation pool elevation of 410 feet for yield. Other differences in the yields are due to assumptions for drainage areas. The Sulphur water availability model uses maps developed by the University of Texas Center for Research in Water Resources to calculate drainage areas. These drainage areas were used for consistency with the other areas of the Sulphur water availability model and were used in the yield determination for the Region C Regional Water Plan. However, the 2000 study and this study used drainage areas calculated with U.S. Geological Survey data, which results in greater inflow to the reservoir.

Figure 5-74 presents a simulated storage trace and storage frequency curve assuming annual diversions of 122,000

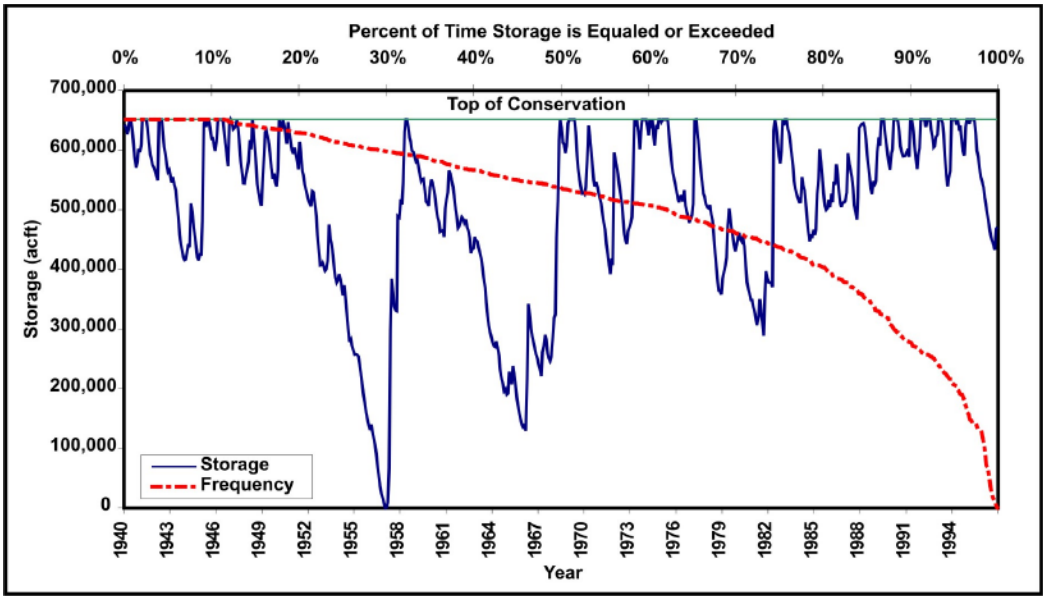


Figure 5-74. Simulated storage in Parkhouse I Lake (conservation elevation=401 feet; diversion= 22,000 acre-feet per year).
acft=acre-feet

acre-feet. At the conservation pool of 401 feet with full diversion, the reservoir will be full about 11 percent of the time and will be below 50 percent of the conservation storage about 13 percent of the time.

### *5.11.2 Reservoir Costs*

The quantities used for the costs for the Parkhouse I dam are based on data developed from previous studies (Freese and Nichols, 1990 and 2006). 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 feet. The service spillway includes a gated, concrete ogee-type weir, 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 (Figure 5-75). Costs for these conflict resolutions are based on data obtained from the Railroad Commission of Texas and the Texas Natural Resources Information System. 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 5-50 shows the estimated capital costs for the Parkhouse I Lake, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, raw water from the project will cost approximately $174 per acre-foot ($0.53 per 1,000 gallons) during the debt service period.

### *5.11.3 Environmental Considerations*

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 their 2006 Regional Water Plan. The reservoir site is located some distance upstream of a Priority 1 bottomland hardwood pres-

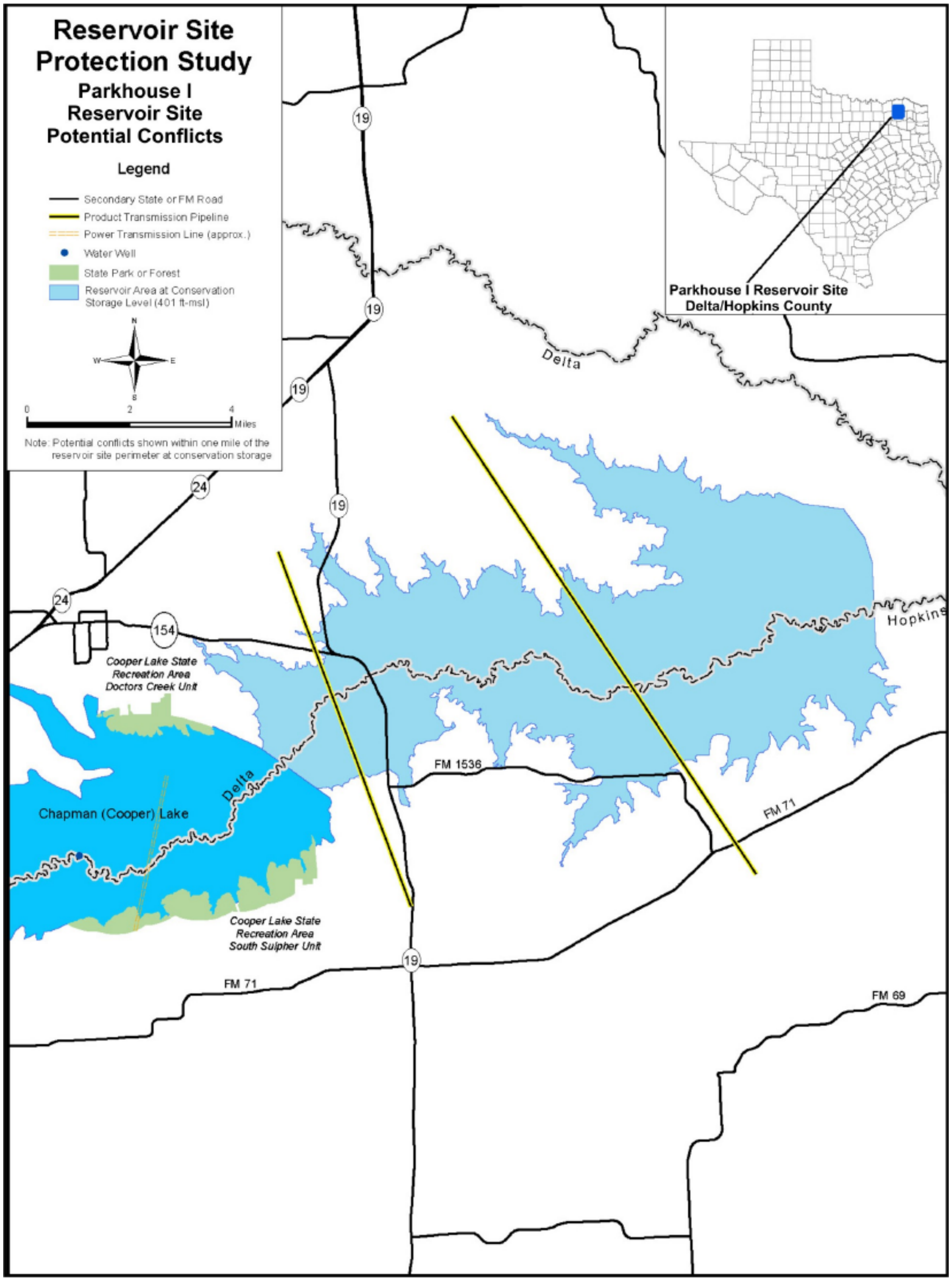


Figure 5-75. Potential major conflicts for Parkhouse I Lake (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

ervation site identified as Sulphur River Bottoms West (USFWS, 1985).

Parkhouse I Lake will inundate approximately 29,000 acres at conservation storage capacity. Table 5-51 and Figure 5-76 summarize existing landcover for the Parkhouse I Lake site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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 5-50. Cost estimate—Parkhouse I Lake at elevation 401 feet.

| | Quantity | Unit | Unit Cost | 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 | $35.00 | $23,387,000 |
| Bridge | 190 | LF | $1,300.00 | $247,000 |
| Roadway | 63,067 | SY | $20.00 | $1,261,000 |
| Slurry trench | 800,000 | SF | $15.00 | $12,000,000 |
| Soil cement | 394,130 | CY | $65.00 | $25,618,000 |
| Elevator | 1 | LS | $100,000.00 | $100,000 |
| Barrier warning system | 456 | LF | $100.00 | $46,000 |
| Gates | | | | |
| Gate & anchor | 2,240 | SF | $275.00 | $616,000 |
| Stop gate & lift | 160 | LF | $2,000.00 | $320,000 |
| Hoist | 8 | EA | $250,000.00 | $2,000,000 |
| Electrical | 1 | LS | $550,000.00 | $550,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Spillway low-flow system | 1 | LS | $400,000.00 | $400,000 |
| Stop gate monorail system | 390 | LF | $1,000.00 | $390,000 |
| Embankment internal drainage | 39,300 | LF | $60.00 | $2,358,000 |
| Guardrail | 780 | LF | $30.00 | $23,000 |
| Grassing | 28 | AC | $4,500.00 | $126,000 |
| Concrete (mass) | 52,000 | CY | $150.00 | $7,800,000 |
| Concrete (walls) | 5,600 | CY | $475.00 | $2,660,000 |
| Mobilization (5% of subtotal) | | | | $5,262,000 |
| Care of water (3% of subtotal) | | | | $3,157,000 |
| Clearing & grubbing | 200 | AC | $4,000.00 | $800,000 |
| Land clearing | 950 | AC | $1,000.00 | $950,000 |
| Engineering & contingencies (35%) | | | | $40,396,000 |
| **Subtotal for Dam & Reservoir** | | | | **$155,812,000** |
| | | | | |
| **Conflicts** | | | | |
| Highways | | | | |
| State Highways (S.H. 154 and S.H. 19) | 35,100 | LF | $900.00 | $31,590,000 |
| F.M. | 18,500 | LF | $150.00 | $2,775,000 |
| Gas pipelines | | | | |
| 30-inch | 95,000 | LF | $98.00 | $9,310,000 |
| 10.75-inch | 81,300 | LF | $30.00 | $2,439,000 |
| Power transmission lines | 5,330 | LF | $450.00 | $2,399,000 |
| Engineering & contingencies (35%) | | | | $16,980,000 |
| **Subtotal of Conflicts** | | | | **$65,493,000** |
| **Dam & Reservoir** | | | | |
| Land acquisition | 31,741 | AC | $1,201.00 | $38,121,000 |
| Environmental studies & mitigation | | | | $38,121,000 |
| | | | | |
| **Total Reservoir Construction Cost** | | | | **$259,426,000** |
| **Interest during Construction (36 months)** | | | | **$31,564,000** |
| | | | | |
| **Total Cost** | | | | **$290,990,000** |

Table 5-50 (continued).

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **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; SY=Square Yard.

Table 5-51. Acreage and percent landcover for Parkhouse I Lake.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship

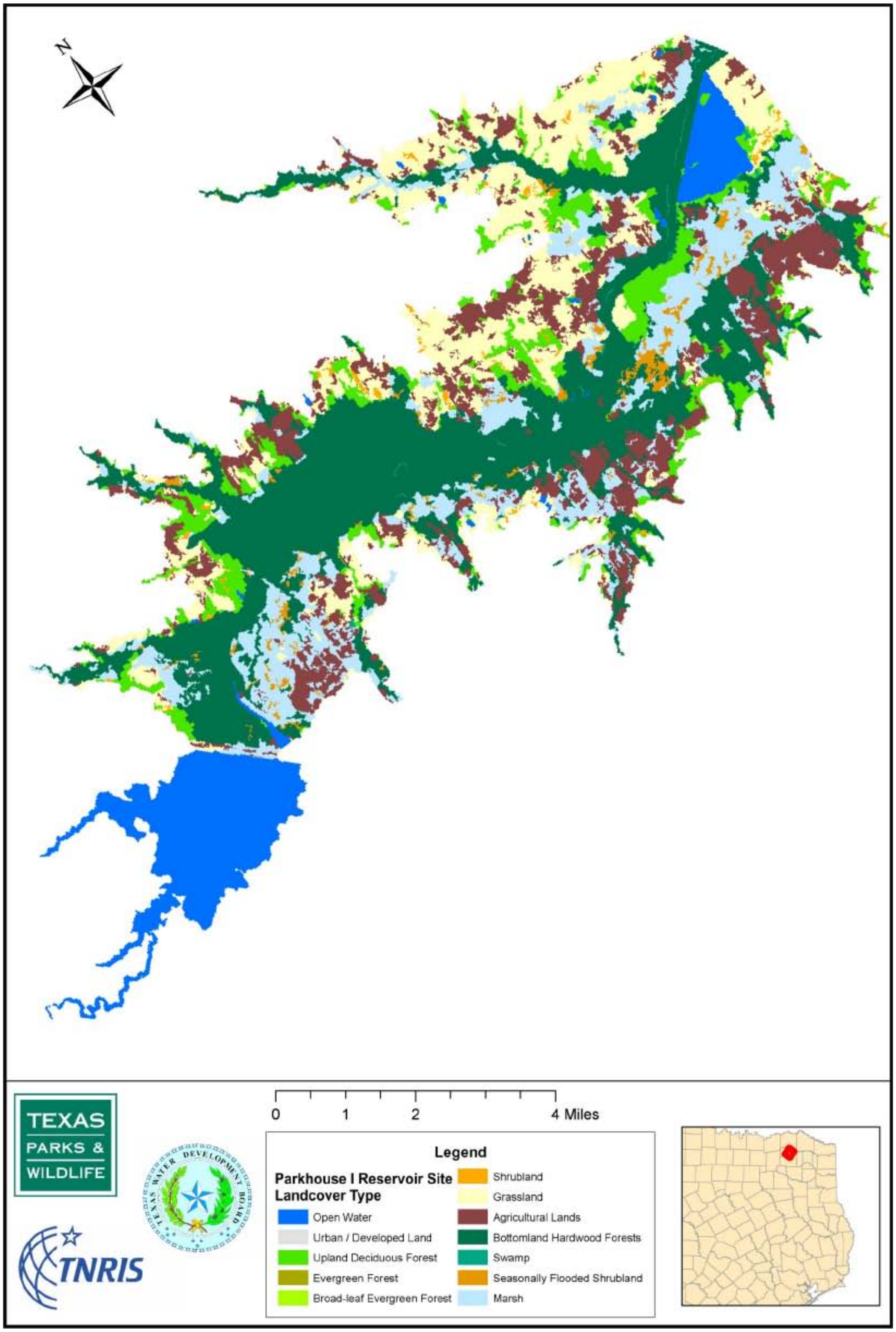


Figure 5-76. Existing landcover for Parkhouse I Lake.

## 5.12
## PARKHOUSE II LAKE

Parkhouse II Lake (North) is a proposed reservoir that will be located on the North Sulphur River in Lamar and Delta counties, about 15 miles southeast of the city of Paris (Figure 5-77). The proposed conservation pool will be at an elevation of 410 feet, with a conservation capacity of 330,871 acre-feet. The inundated area at the top of the conservation pool will be 14,387 acres. The reservoir will have a total drainage area of 421 square miles.

This reservoir has been previously studied by Freese and Nichols (1990, 1996, 2000, and 2006). The Region C Regional Water Plan lists 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.

The 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 acre-feet per year by 2060. 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, located approximately 94 miles southwest of the reservoir site.

### *5.12.1*
### *Reservoir Yield Analysis*

The elevation-area-capacity relationship is included in Table 5-52 and shown in Figure 5-78. Freese and Nichols (2000) derived the data from the 1:24,000 scale U.S. Geological Survey topographic quadrangle maps with 10-foot contour intervals. Figure 5-79 shows the inundation map at different elevations in 10-foot intervals, including the elevation with the

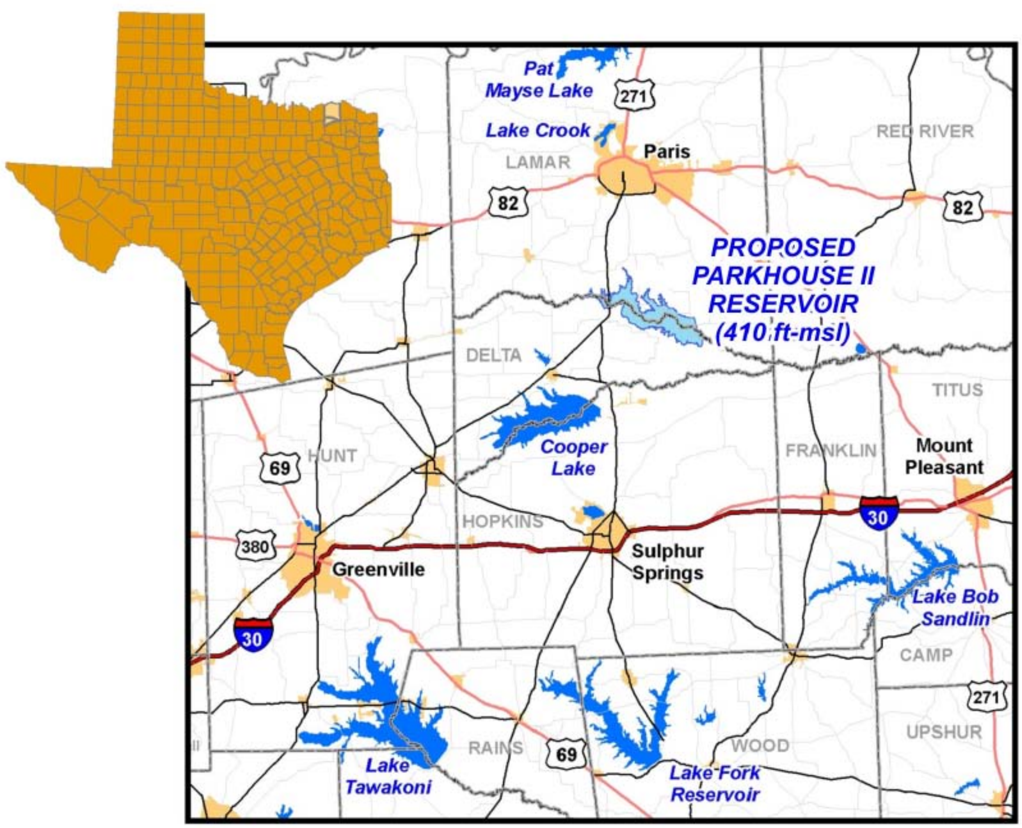


Figure 5-77. Location map of Parkhouse II Lake.
ft-msl=feet above mean sea level

probable maximum flood at 418 feet.

Table 5-53 includes the environmental flows needs calculated using the Consensus Criteria for Environmental Flow Needs. For the yield analyses, we assumed that the reservoir will have to pass the lesser of the inflow and values in the table.

The firm yield of Parkhouse II Lake was calculated with the full authorization scenario (Run 3) of the Sulphur River Basin water availability model A control point was added on the Sulphur River at the dam location.

We calculated the naturalized flows at the reservoir sites using the drainage area ratio method, with the existing naturalized flows at gaged locations from the water availability model and drainage areas obtained from the U.S. Geological Survey (see Marvin Nichols IA section 5.8). 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).

Yields were calculated for elevations at 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 5-54 and Figure 5-80. At the conservation pool level of 410 feet, the firm yield is 144,300 acre-feet per year. Environmental flow requirements reduce the firm yield of the reservoir by 2,500 acre-feet.

The firm yield of Parkhouse II Lake will decrease if one or more of the proposed reservoirs in the Sulphur Basin

Table 5-52. Elevation-area-capacity relationship for Parkhouse II Lake.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 340 | 0 | 0 |
| 345 | 49 | 121 |
| 350 | 99 | 490 |
| 355 | 162 | 1,142 |
| 360 | 226 | 2,113 |
| 365 | 1,334 | 5,997 |
| 370 | 2,442 | 15,432 |
| 375 | 3,532 | 30,364 |
| 380 | 4,621 | 50,744 |
| 385 | 6,097 | 77,536 |
| 390 | 7,573 | 111,707 |
| 395 | 9,255 | 153,773 |
| 400 | 10,937 | 204,252 |
| 405 | 12,662 | 263,249 |
| 410 | 14,387 | 330,871 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

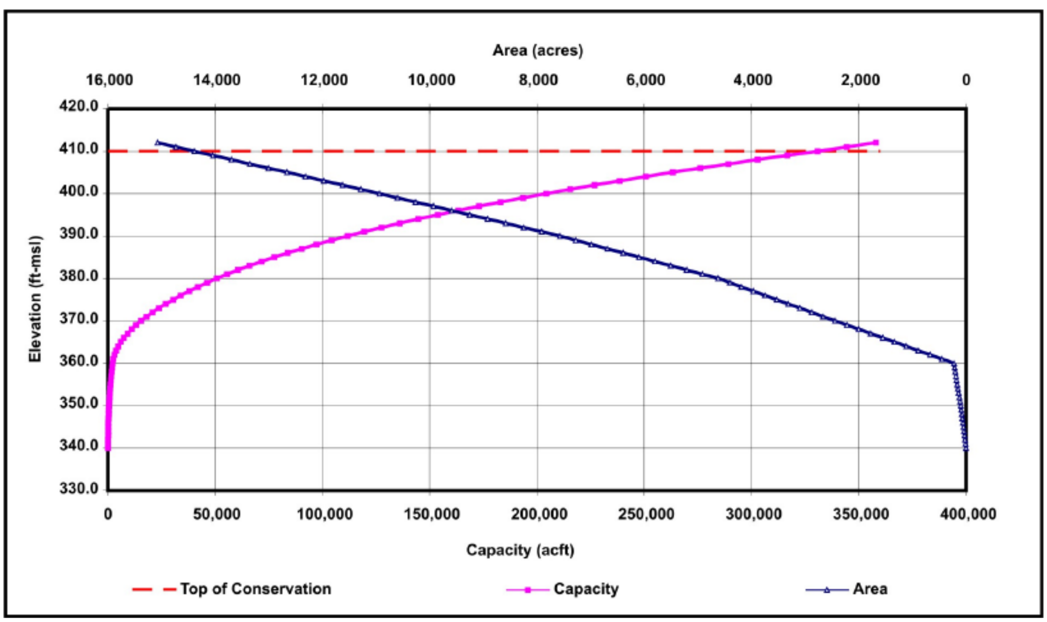


Figure 5-78. Elevation-area-capacity relationship for Parkhouse II Lake.
ft-msl=feet above mean sea level; acft=acre-feet

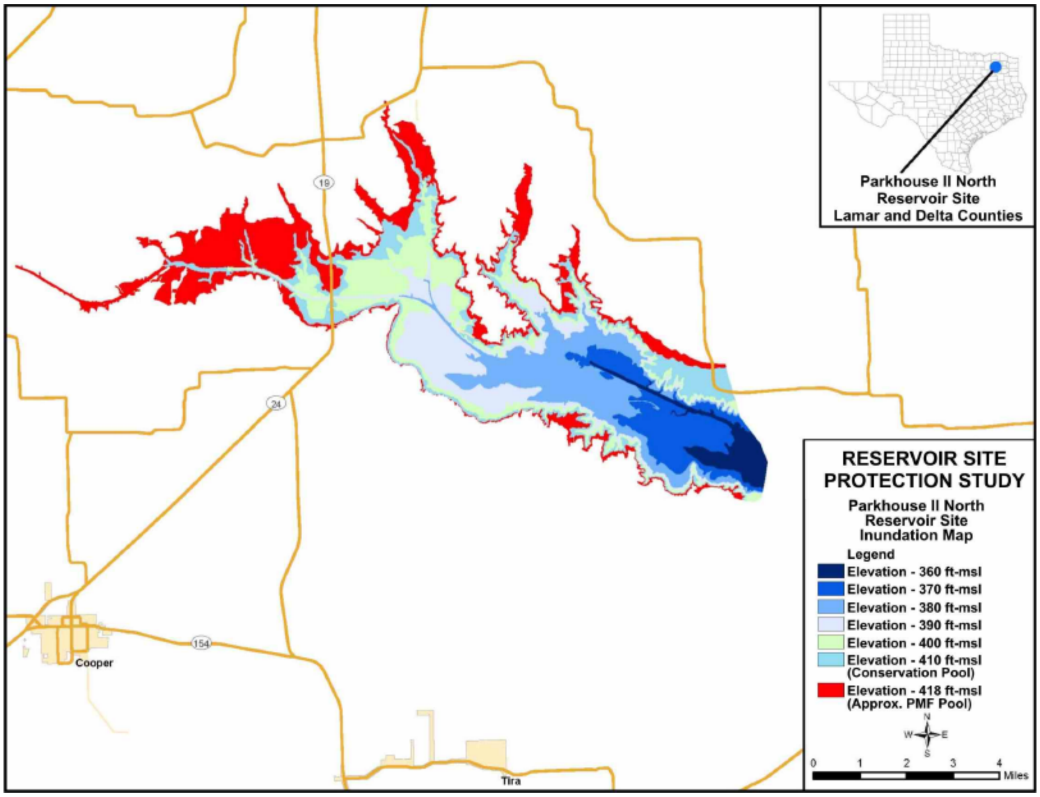


Figure 5-79. Inundation map for Parkhouse II Lake.
ft-msl=feet above mean sea level; PMF=probable maximum flood

Table 5-53. Consensus Criteria for Environmental Flow Needs for Parkhouse II Lake.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | 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 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per square inch

(Ralph Hall, Parkhouse I, and/or Marvin Nichols IA) are built and Parkhouse II Lake has a junior priority to any of these reservoirs. Because the U.S. Army Corps of Engineers Section 404 permit for Lake Ralph Hall was submitted in October 2006, that reservoir will likely be senior to Parkhouse II. Yield analysis determined that Lake Ralph Hall will reduce the firm yield of Parkhouse II by 26,900 acre-feet per year, 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 will be 32,100 acre-feet per year, which is 112,200 acre-feet per year less than the stand-alone yield (or a reduction of 78 percent). Appendix A is a memorandum describing the sensitivity of firm yield in the Sulphur Basin to the development of

Table 5-54. Firm yield versus conservation storage for Parkhouse II Lake.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 390 | 111,707 | CCEFN[d] | 71,900 | 8/77–12/78 |
| 396 | 163,196 | CCEFN | 98,600 | 5/77–12/78 |
| 402 | 226,816 | CCEFN | 120,100 | 5/54–1/57 |
| 410* | 330,871 | CCEFN | 144,300 | 6/51–1/57 |
| | | None | 146,800 | |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre-feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

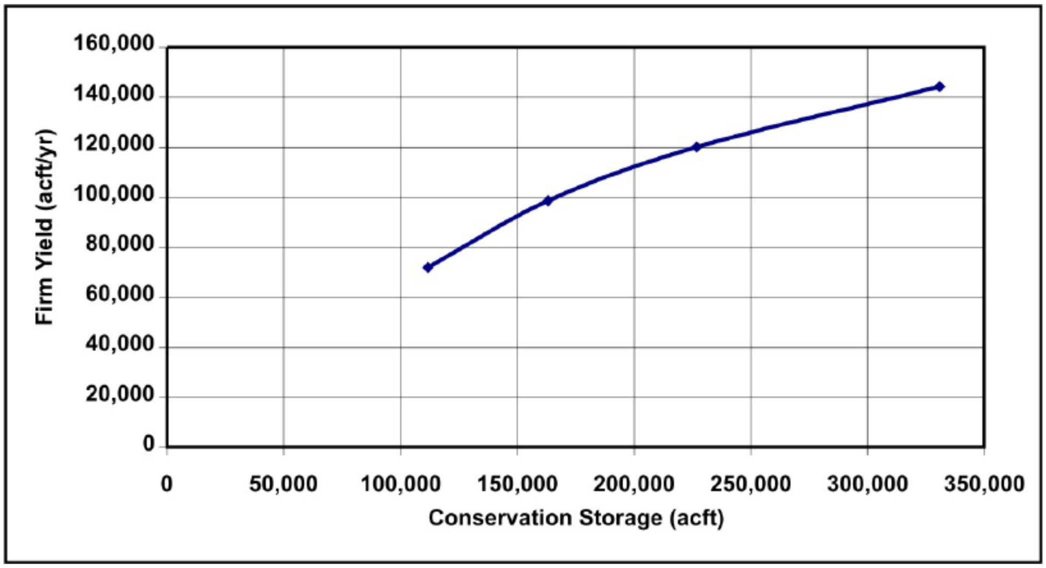


Figure 5-80. Firm yield versus conservation storage for Parkhouse II Lake.
acft/yr=acre-feet per year

other reservoirs.

Freese and Nichols (1990, 1996, 2000, and 2006) have performed previous evaluations of this reservoir. The 2000 study shows that the firm yield (without restrictions due to environmental flows) is 152,500 acre-feet per year. The 2006 Region C Regional Water Plan shows that the yield of Parkhouse II is 148,700 acre-feet per year, which is 4,400 (or 3 percent) more than the yield of this study. The Region C estimate and this study differ because of assumptions for drainage areas for estimating flow. The Region C yield used the Sulphur water availability model methodology for calculating drainage areas, but this study used calculations from U.S. Geological Survey data. The 2000 study shows a higher yield because it does not consider environmental flows.

Figure 5-81 shows the simulated storage trace and storage frequency curve for Parkhouse II Lake with an annual diversion of 144,300 acre-feet. At the conservation pool of 410 feet, assuming full diversion, the reservoir will be full about 23 percent of the time and will be below 50 percent of the conservation storage about 8 percent of the time.

### *5.12.2*
### *Reservoir Costs*

The quantities used for the costs for the Parkhouse II Dam are based on data developed from previous studies (Freese and Nichols, 2000). The dam and spillway costs assume a zoned earthen

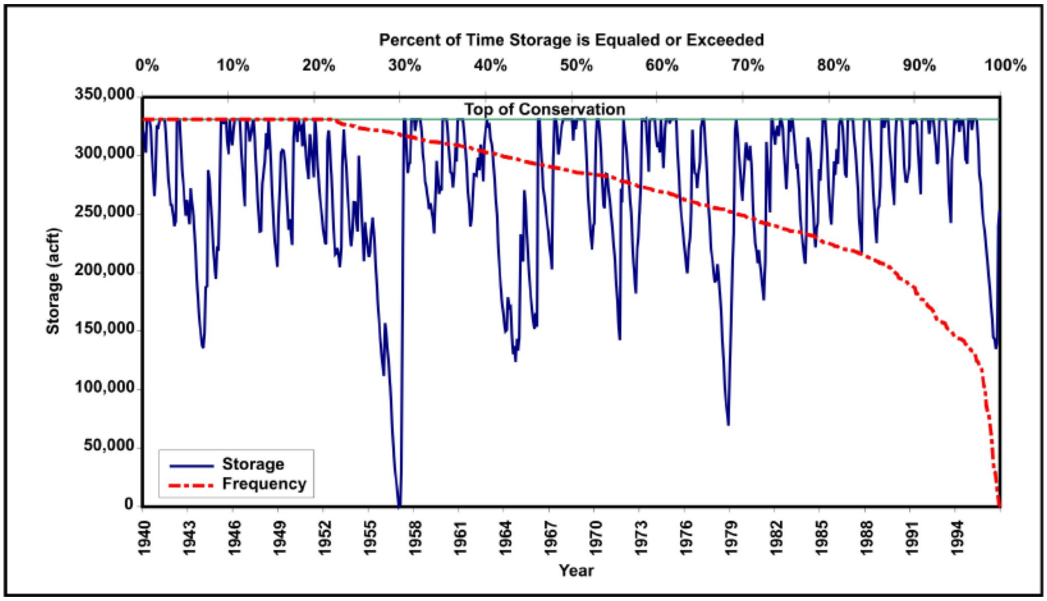


Figure 5-81. Simulated storage in Parkhouse II Lake (conservation elevation=410 feet; diversion=144,300 acre-feet per year).
acft=acre-feet

embankment with a gated spillway structure. The length of the dam is estimated at 24,760 feet with a maximum elevation of 420 feet. The service spillway includes a gated, concrete ogee-type weir, 10 tainter gates, a stilling basin, and a 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 (Figure 5-82). Costs for these conflict resolutions are based on data obtained from the Railroad Commission of Texas and the Texas Natural Resources Information System.

Table 5-55 shows the estimated capital costs for the Parkhouse II Lake Project, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, raw water from the project will cost approximately $107 per acre-foot ($0.33 per 1,000 gallons) during the debt service period.

### *5.12.3 Environmental Considerations*

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 their 2006 Regional 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).

Parkhouse II Lake will inundate approximately 14,400 acres of land at conservation storage capacity. Table 5-56 and Figure 5-83 summarize existing landcover for the Parkhouse II Lake site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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.

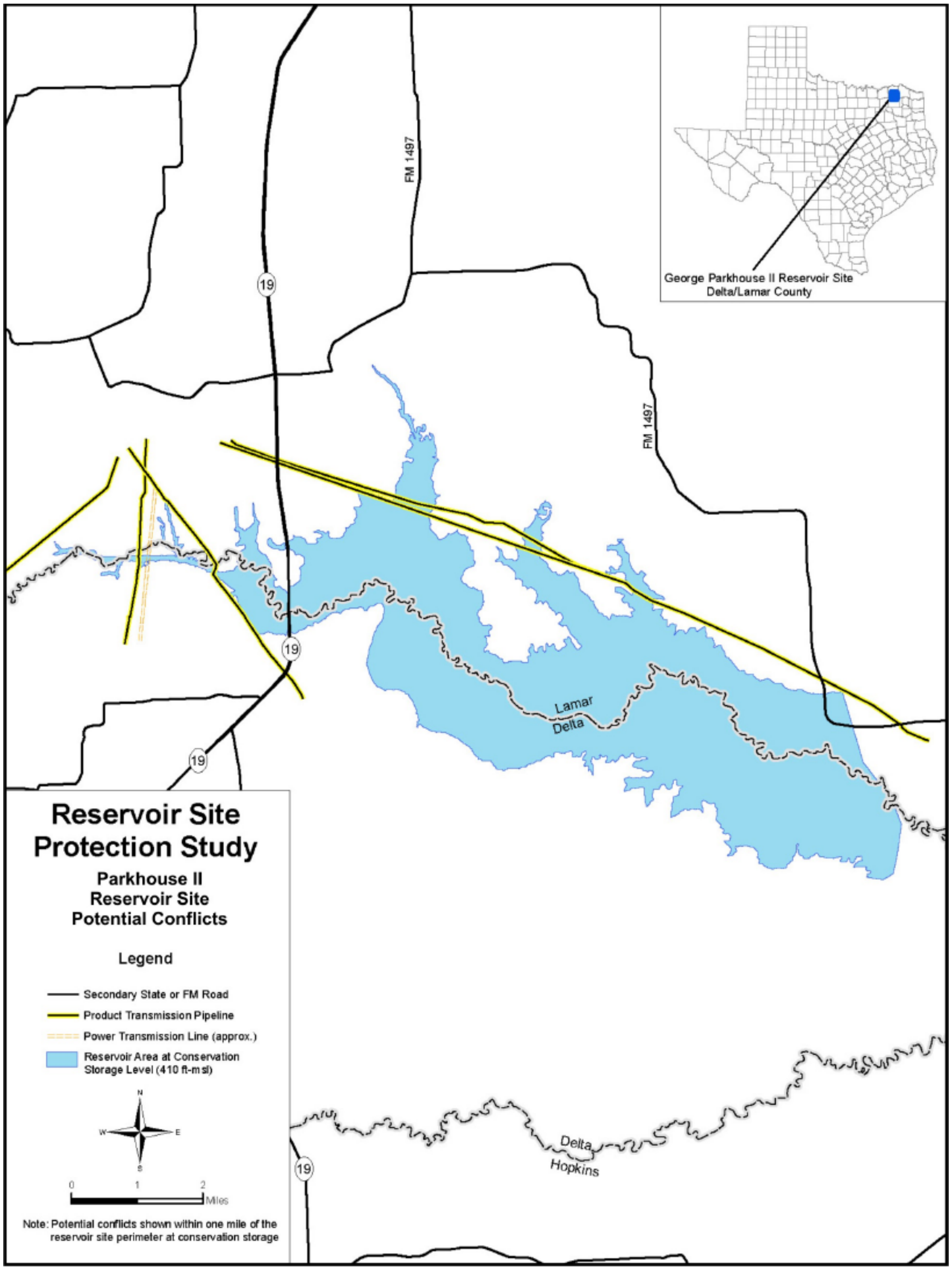


Figure 5-82. Potential major conflicts for Parkhouse II Lake (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Table 5-55. Cost estimate—Parkhouse II Reservoir at elevation 410 feet.

| | Quantity | Unit | Unit Cost | 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 | $35.00 | $10,370,500 |
| Bridge | 490 | LF | $1,300.00 | $637,000 |
| Roadway | 60,520 | SY | $20.00 | $1,210,400 |
| Slurry trench | 1,078,000 | SF | $15.00 | $16,170,000 |
| Soil cement | 208,100 | CY | $65.00 | $13,526,500 |
| Barrier warning system | 490 | LF | $100.00 | $49,000 |
| Gates | | | | |
| Gate & anchor | 10,000 | SF | $275.00 | $2,750,000 |
| Stop gate & lift | 490 | LF | $2,000.00 | $980,000 |
| Hoist | 10 | EA | $250,000.00 | $2,500,000 |
| Electrical | 1 | LS | $550,000.00 | $550,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Spillway low-flow system | 1 | LS | $400,000.00 | $400,000 |
| Stop gate monorail system | 490 | LF | $1,000.00 | $490,000 |
| Guardrail | 780 | LF | $30.00 | $23,400 |
| Grassing | 100 | AC | $4,500 | $450,000 |
| Concrete (mass) | 79,700 | CY | $150.00 | $11,955,000 |
| Concrete (reinforced) | 24,100 | CY | $475.00 | $11,447,500 |
| **Subtotal** | | | | **$86,158,800** |
| Mobilization (5% of subtotal) | | | | $4,307,900 |
| Care of water (3% of subtotal) | | | | $2,584,800 |
| Clearing & grubbing | 150 | AC | $4,000.00 | $600,000 |
| Land clearing | 3,600 | AC | $1,000.00 | $3,600,000 |
| Engineering & contingencies (35%) | | | | $34,038,000 |
| **Subtotal for Dam & Reservoir** | | | | **$131,289,500** |
| **Conflicts** | | | | |
| Highways | | | | |
| State highways (S.H. 19) | 8,400 | LF | $900.00 | $7,560,000 |
| F.M. | 11,100 | LF | $150.00 | $1,665,000 |
| Gas pipelines | | | | |
| 30-inch (2 pipelines) | 33,800 | LF | $98.00 | $3,312,000 |
| Oil & gas wells | 9 | EA | $25,000.00 | $225,000 |
| Water wells | 1 | EA | $49,000.00 | $49,000 |
| Power transmission lines | 610 | LF | $450.00 | $275,000 |
| Engineering & contingencies (35%) | | | | $4,580,000 |
| **Subtotal of Conflicts** | | | | **$17,666,000** |
| **Land acquisition** | 15,826 | AC | $1,201.00 | **$19,007,000** |
| **Environmental studies & mitigation** | | | | **$19,007,000** |
| **Total Reservoir Construction Cost** | | | | **$186,969,500** |
| **Interest during Construction (36 months)** | | | | **$22,749,000** |
| **Total Cost** | | | | **$209,718,500** |
| **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; SY=Square Yard.

Table 5-56. Acreage and percent landcover for Parkhouse II Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

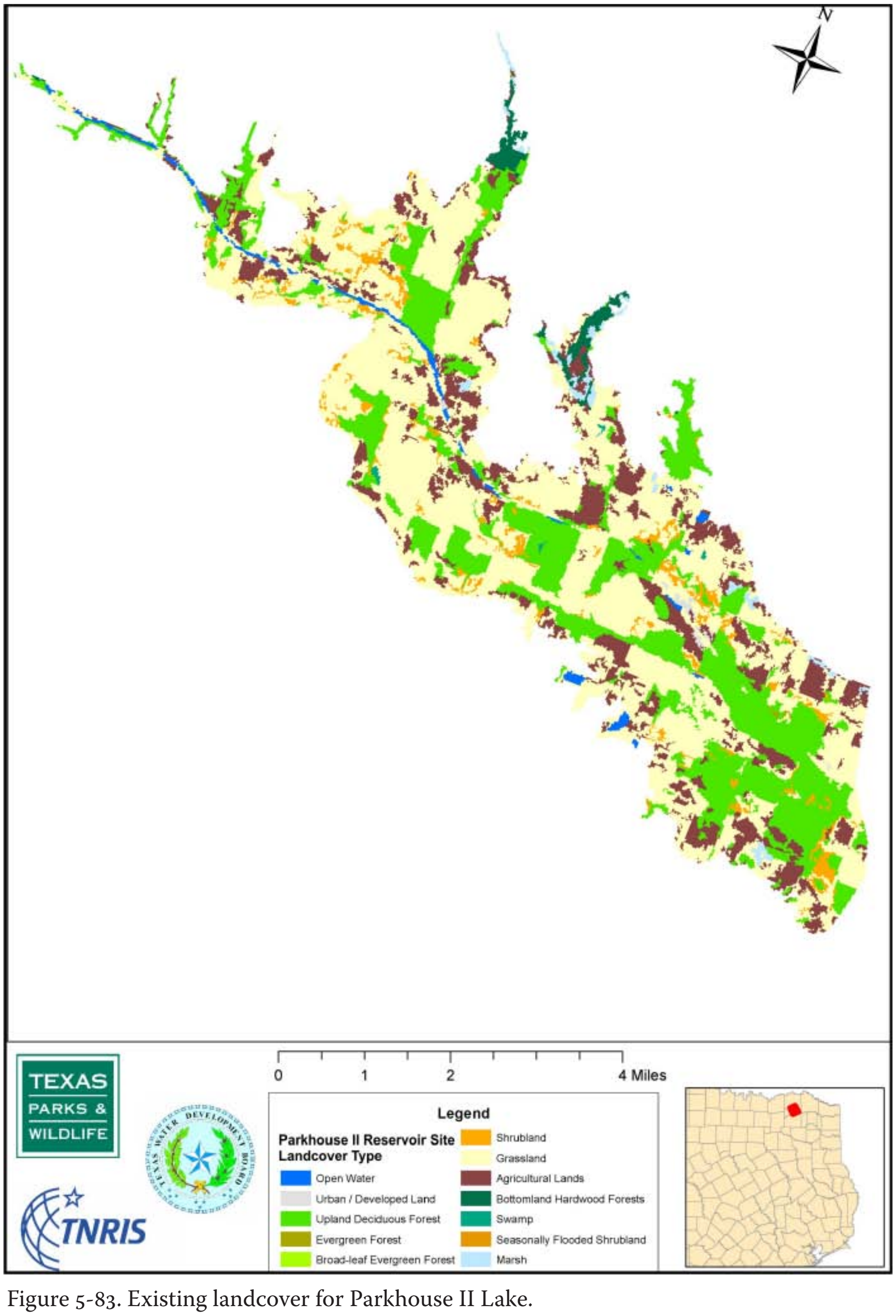


Figure 5-83. Existing landcover for Parkhouse II Lake.

## 5.13
## Lake Ralph Hall

Lake Ralph Hall, proposed by the Upper Trinity Regional Water District, will be located on the North Sulphur River in the Sulphur River Basin in Fannin County (Figure 5-84). The reservoir is recommended as a water management strategy in the 2006 Region C Regional Water Plan and the 2007 State Water Plan. The primary purpose of the project is to provide a municipal water supply source to meet future water demands within the portion of Fannin County that lies within the Sulphur Basin and within the service area of the Upper Trinity Regional Water District in the Trinity River Basin. A water right permit application for the project is pending review and approval at the Texas Commission on Environmental Quality. An application for a Section 404 permit has also been submitted to the U. S. Army Corps of Engineers.

The maximum storage capacity of the project is proposed to be 160,235 acre-feet at an elevation of 551 feet. The reservoir will inundate 7,605 acres at conservation pool elevation. The firm yield is estimated to be approximately 32,940 acre-feet per year; however, annual withdrawals from the reservoir may be as much as 45,000 acre-feet per year, as the project is operated in a systems mode with other Upper Trinity Regional Water District sources of water in order to maximize the overall available water supply. The projected water needs within 50 miles of the proposed reservoir site by 2060 are approximately 419,000 acre-feet per year. The nearest major demand center is the Dallas-Fort Worth metroplex, 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

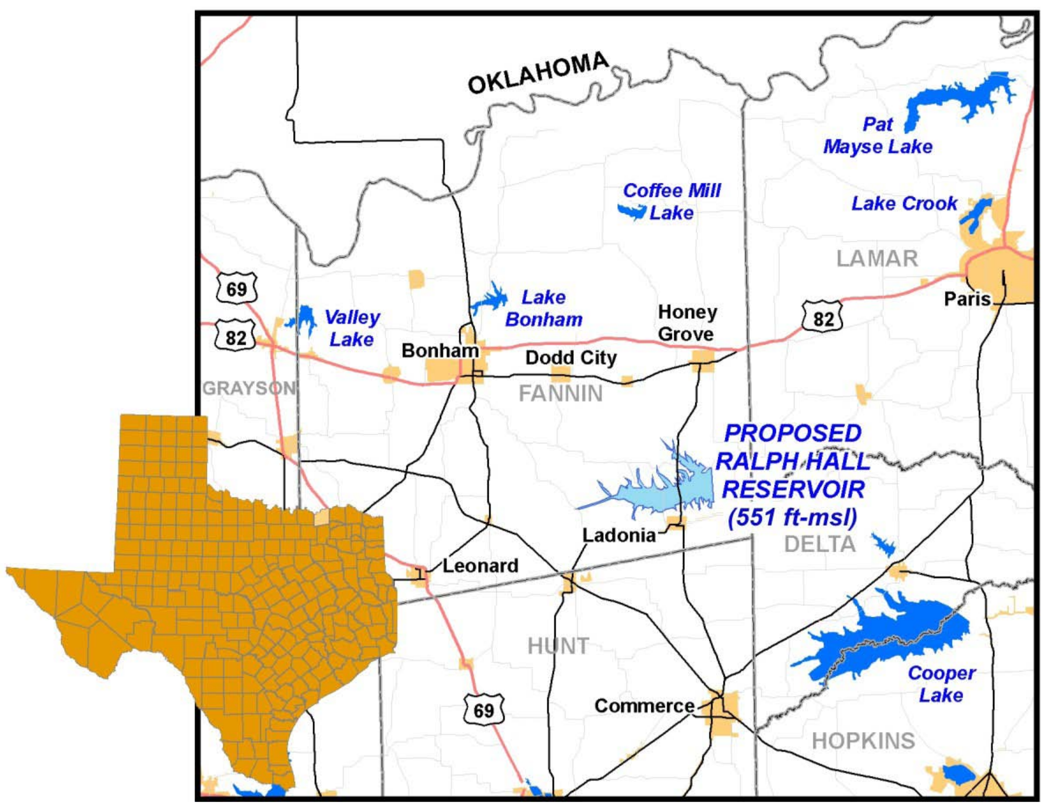


Figure 5-84. Location map of Lake Ralph Hall.
ft-msl=feet above mean sea level

because of the deep, incised, and eroded river channel that lies within a fairly broad, flat floodplain. Although 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 manmade drainage ditch that was constructed in the late 1920s and early 1930s 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.

### *5.13.1 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 right permit application that has been submitted to the Texas Commission on Environmental Quality. 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.

Table 5-57. Elevation-area-capacity relationship for Lake Ralph Hall.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 460 | 0 | 0 |
| 470 | 18 | 57 |
| 480 | 50 | 397 |
| 500 | 208 | 2,357 |
| 510 | 941 | 7,521 |
| 520 | 2,003 | 21,849 |
| 530 | 3,307 | 47,989 |
| 540 | 5,189 | 90,104 |
| 550 | 7,345 | 152,630 |
| 551 | 7,605 | 160,235 |
| 560 | 9,914 | 238,693 |
| 564 | 10,985 | 280,506 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

The elevation-area-capacity relationship and the corresponding conservation storage capacity for the proposed reservoir, as determined from a 2-foot contour map of the reservoir site prepared specifically for the project, are presented in Table 5-57 and Figure 5-85. Figure 5-86 shows the reservoir inundation area at different water surface elevations.

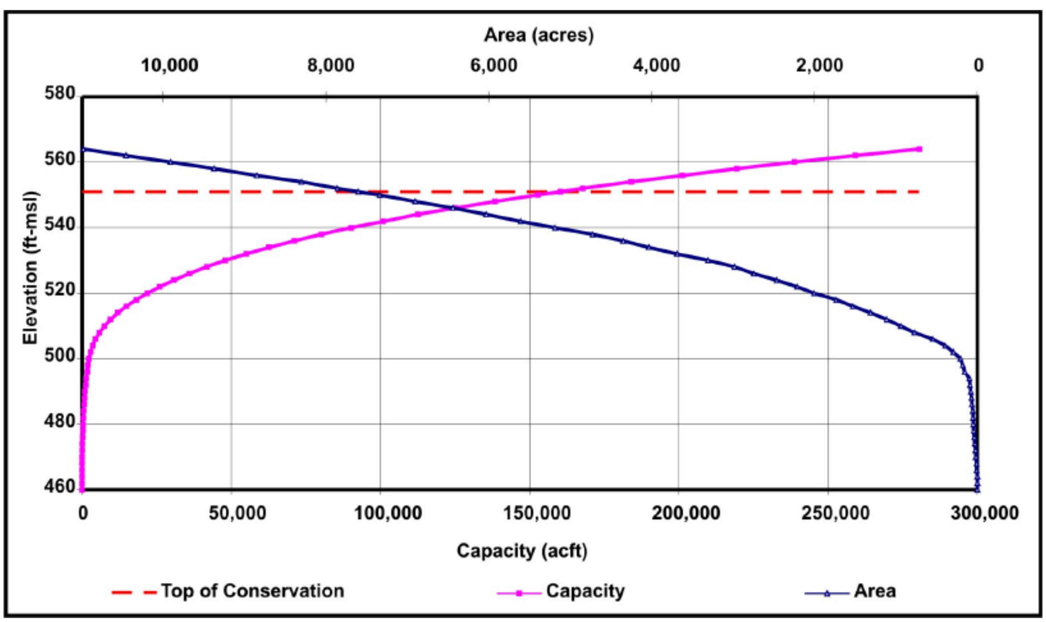


Figure 5-85. Elevation-area-capacity relationship for Lake Ralph Hall.
ft-msl=feet above mean sea level; acft=acre-feet

For purposes of the pending water right permit application for Lake Ralph Hall, the Lyons Method was used for estimating environmental flow requirements. These estimates serve as a placeholder until field studies provide a more scientific basis for establishing appropriate river flows for protecting downstream biological resources. This method 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,

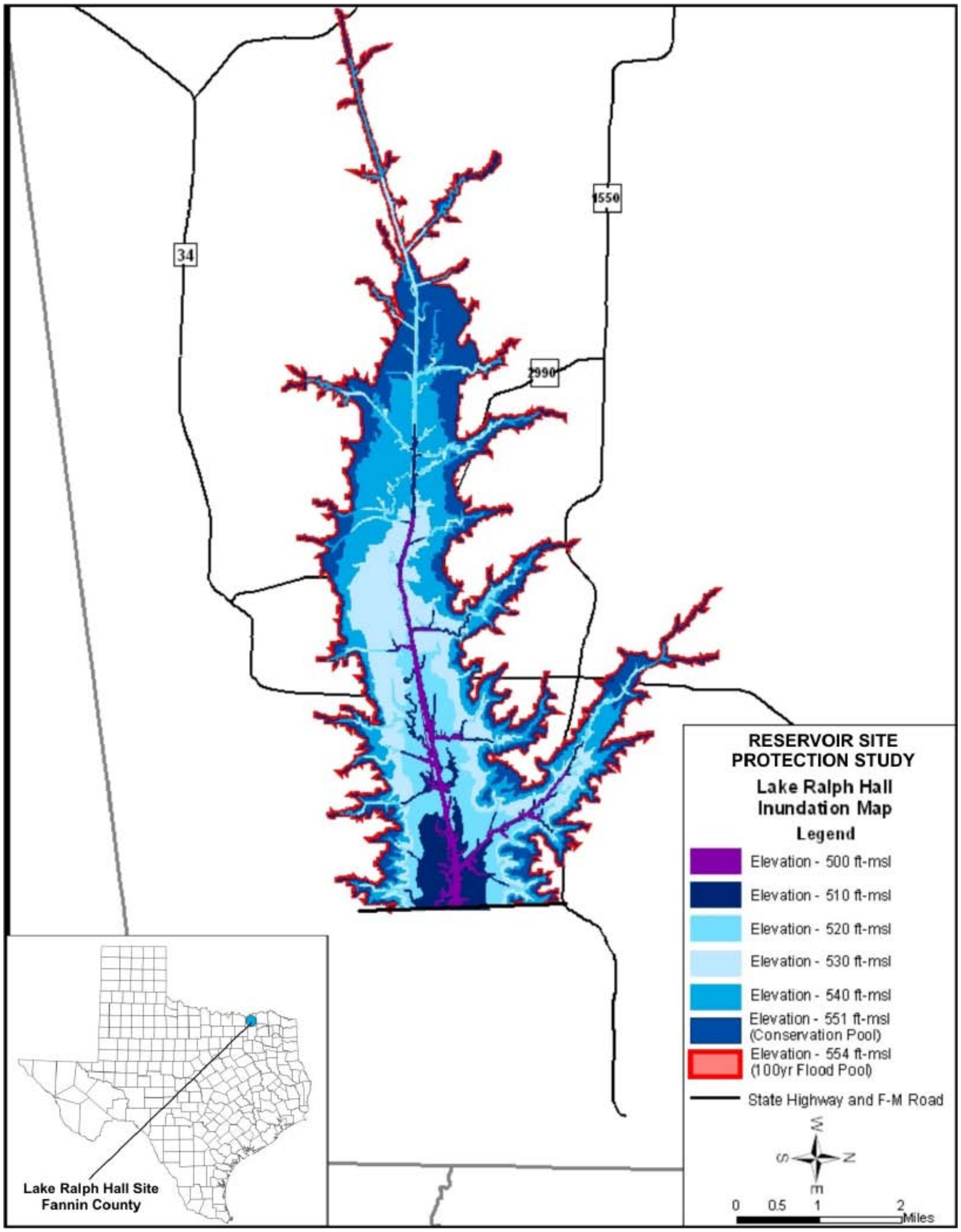


Figure 5-86. Inundation map for Lake Ralph Hall.
ft-msl=feet above mean sea level

Table 5-58. Lyons criteria for environmental flow needs for Lake Ralph Hall.

| Month | Median | | Lyons | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 584 | 9.5 | 211 | 3.4 | 6 | 0.1 |
| Feb | 818 | 14.6 | 325 | 5.8 | 6 | 0.1 |
| Mar | 812 | 13.2 | 486 | 7.9 | 6 | 0.1 |
| Apr | 607 | 10.2 | 365 | 6.1 | 6 | 0.1 |
| May | 541 | 8.8 | 324 | 5.3 | 6 | 0.1 |
| Jun | 238 | 4.0 | 144 | 2.4 | 6 | 0.1 |
| Jul | 37 | 0.6 | 22 | 0.4 | 6 | 0.1 |
| Aug | 6 | 0.1 | 6 | 0.1 | 6 | 0.1 |
| Sep | 12 | 0.2 | 7 | 0.1 | 6 | 0.1 |
| Oct | 37 | 0.6 | 14 | 0.2 | 6 | 0.1 |
| Nov | 202 | 3.4 | 81 | 1.4 | 6 | 0.1 |
| Dec | 449 | 7.3 | 180 | 2.9 | 6 | 0.1 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

or 0.1 cubic feet per second for this reach of the North Sulphur River. The resulting environmental flow values used in the original yield analyses are presented in Table 5-58.

During the initial planning investigations, we obtained the Sulphur water availability model from the Texas Commission on Environmental Quality and modified it to incorporate Lake Ralph Hall and its environmental flow requirements. This model was used to evaluate the reservoir's 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 an elevation of 551 feet, which provided the adopted total conservation storage capacity of 160,235 acre-feet. We determined the firm yield at this reservoir capacity to be 32,940 acre-feet per year. As noted previously, Lake Ralph Hall is to be operated as part of the overall water supply system for the Upper Trinity Regional Water District; therefore, the pending water right permit application stipulates that up to 45,000 acre-feet per year may be withdrawn from the reservoir. Figure 5-87 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.

### *5.13.2 Reservoir Costs*

The projected costs for the Lake Ralph Hall dam assume a zoned earthen embankment with an impervious core that will have a maximum height of 100 feet. It will extend across the valley of the North Sulphur River. 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 an elevation of 562 feet. Internal drains will be provided to remove any seepage that may accumulate within the downstream slope of the embankment. As planned, an ungated, five-cycle labyrinth weir will act as the principal spillway, with a total spillway width of 300 feet. A concrete-capped 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.

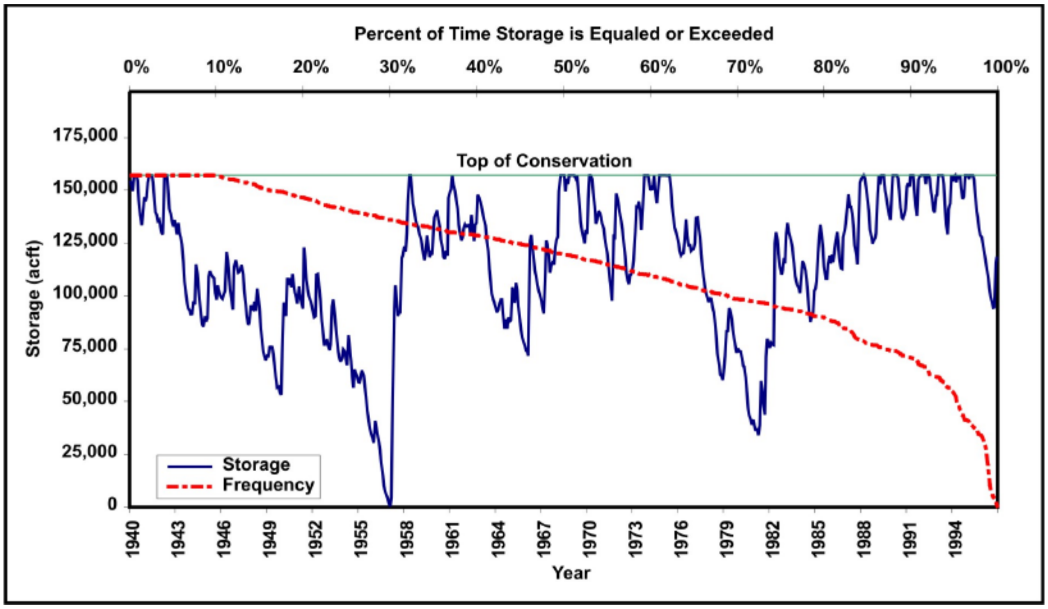


Figure 5-87. Simulated storage in Lake Ralph Hall (conservation elevation=551 feet; diversion=32,940 acre-feet per year).
acft=acre feet

The conflicts identified at the site include roadways, bridges, utilities, and miscellaneous relocations (Figure 5-88). The conflict costs represent less than 18 percent of the total construction cost of the reservoir project.

Table 5-59 summarizes the estimated capital costs for the Lake Ralph Hall dam and reservoir project, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, raw water from the project will cost approximately $430 per acre-foot ($1.32 per 1,000 gallons) during the debt service period.

### *5.13.3 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. 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 Upper Trinity Regional Water District 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 5-60 and Figure 5-89 summarize existing landcover for the Lake Ralph Hall site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is dominated by grassland (48 percent) with sizeable, but fragmented, areas of upland deciduous forest (23 percent) and agricultural land (18 percent). The Texas Parks and Wildlife Department did not classify any of the reservoir site as bottomland hardwood forest.

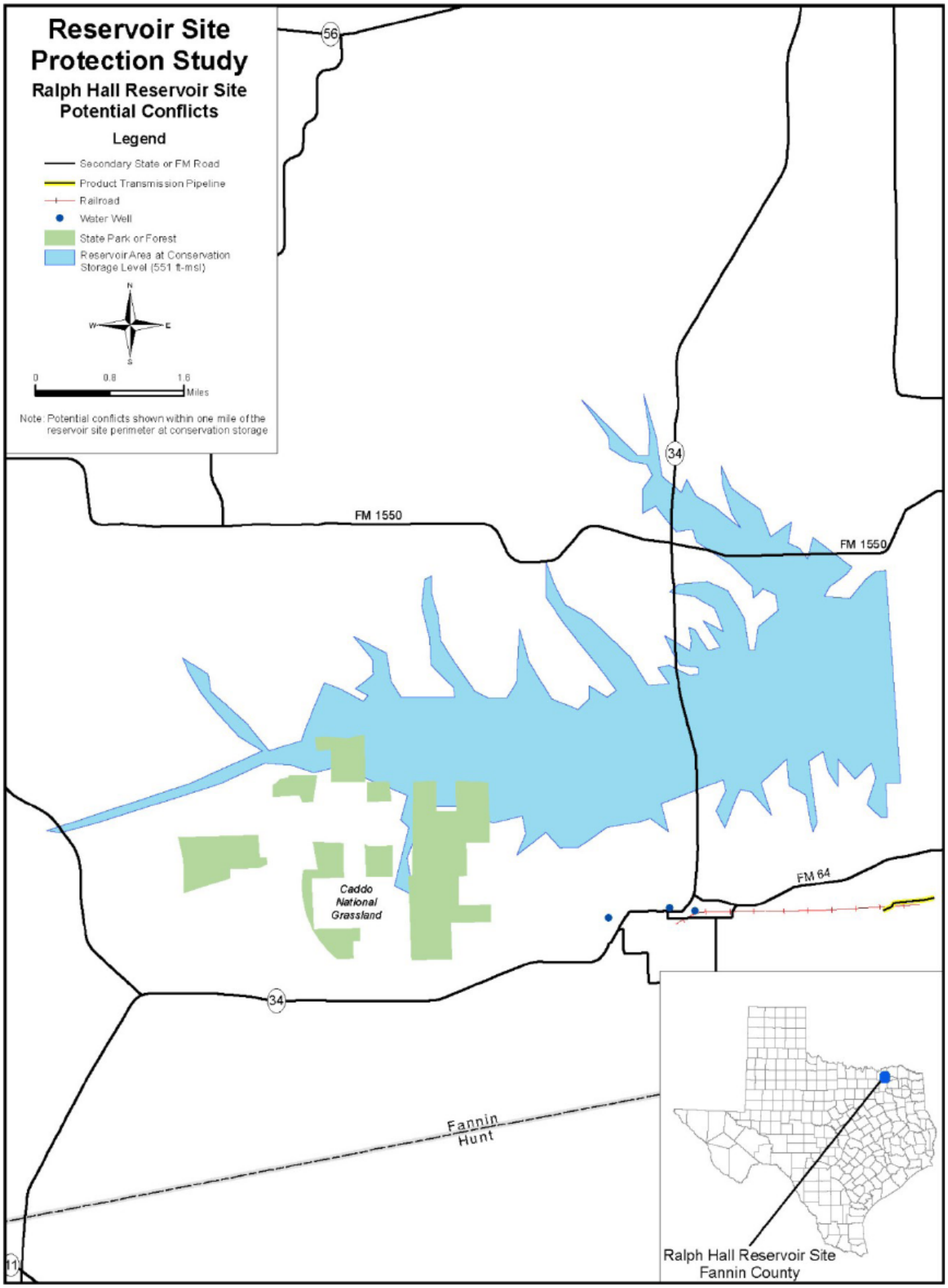


Figure 5-88. Potential major conflicts for Lake Ralph Hall (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

Table 5-59. Cost estimate—Lake Ralph Hall at elevation 551 feet.

| | Quantity | Unit | Unit Cost | Cost |
|---|---|---|---|---|
| **Mobilization and Demobilization (5%)** | 1 | LS | $4,306,387 | **$4,306,387** |
| **Dam & Reservoir** | | | | |
| Stormwater prevention | 1 | LS | $897,711 | $897,711 |
| Clearing & gubbing | 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 reinforced concrete | 38,034 | CY | $320 | $12,170,880 |
| Emergency spillway mass/reinforced concrete | 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 | $201,000 |
| **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 | $2,000,000 |
| **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** | | | | **$30,227,500** |
| **Construction Total** | | | | **$187,164,295** |
| **Interest during Construction (24 months)** | | | | **$11,314,064** |
| **Total Cost** | | | | **$198,478,359** |
| **Annual Costs** | | | | |
| Debt service (6% for 40 years) | | | | $13,191,000 |
| Operation & maintenance | | | | $956,975 |
| **Total Annual Costs** | | | | **$14,147,975** |
| **Firm Yield (acre-feet per year)** | | | | **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; SY=Square Yard.

Table 5-60. Acreage and percent landcover for Lake Ralph Hall.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

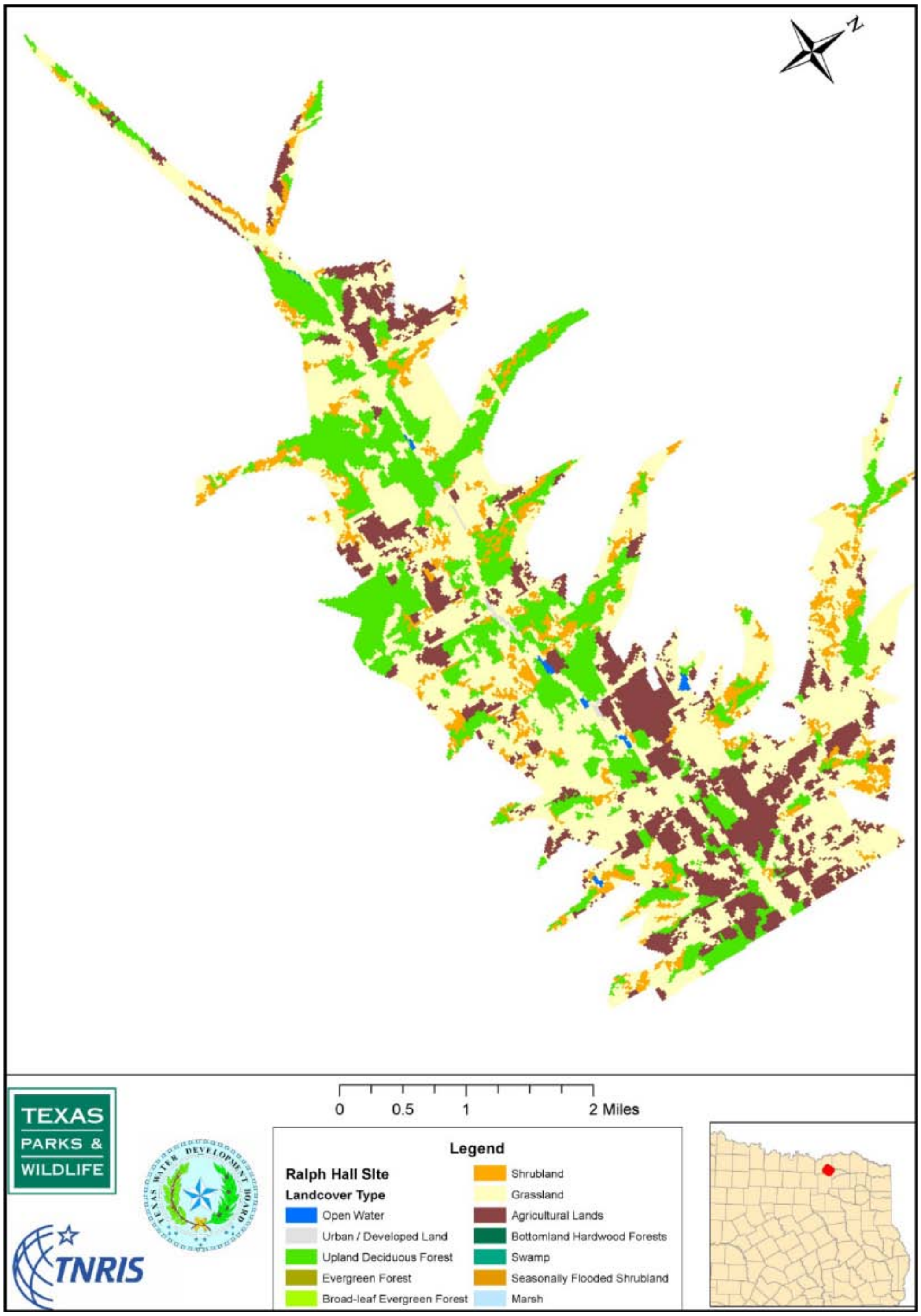


Figure 5-89. Existing landcover for Lake Ralph Hall.

## 5.14 Ringgold Reservoir

Ringgold Reservoir is a proposed reservoir that will be located on the Little Wichita River east of Henrietta, just upstream of the confluence with the Red River in Clay County (Figure 5-90). The proposed conservation pool will be at an elevation of 844 feet, with a conservation capacity of 271,600 acre-feet. The inundated area at the top of the conservation pool will be 14,980 acres. The reservoir has a total contributing drainage area of 1,475 square miles, of which 822 are controlled by Lake Arrowhead.

This reservoir has been previously studied by Freese and Nichols (1958, 1981). It was a recommended water management strategy for the City of Wichita Falls in the 2001 Region B Regional Water Plan and is an alternate water management strategy in the 2006 Region B Regional Water Plan.

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 chose not to recommend designation as a unique reservoir site until additional information is made available to them. The reservoir has historically been included as part of the long-term water supply plans for 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 acre-feet per year by 2060. Much of this need is associated with Region C, located east and south of the proposed reservoir site. The nearest major demand center, the Dallas-Fort Worth metroplex, is located approximately 96 miles southeast of the reservoir site.

### *5.14.1 Reservoir Yield Analysis*

The elevation-area-capacity relationship

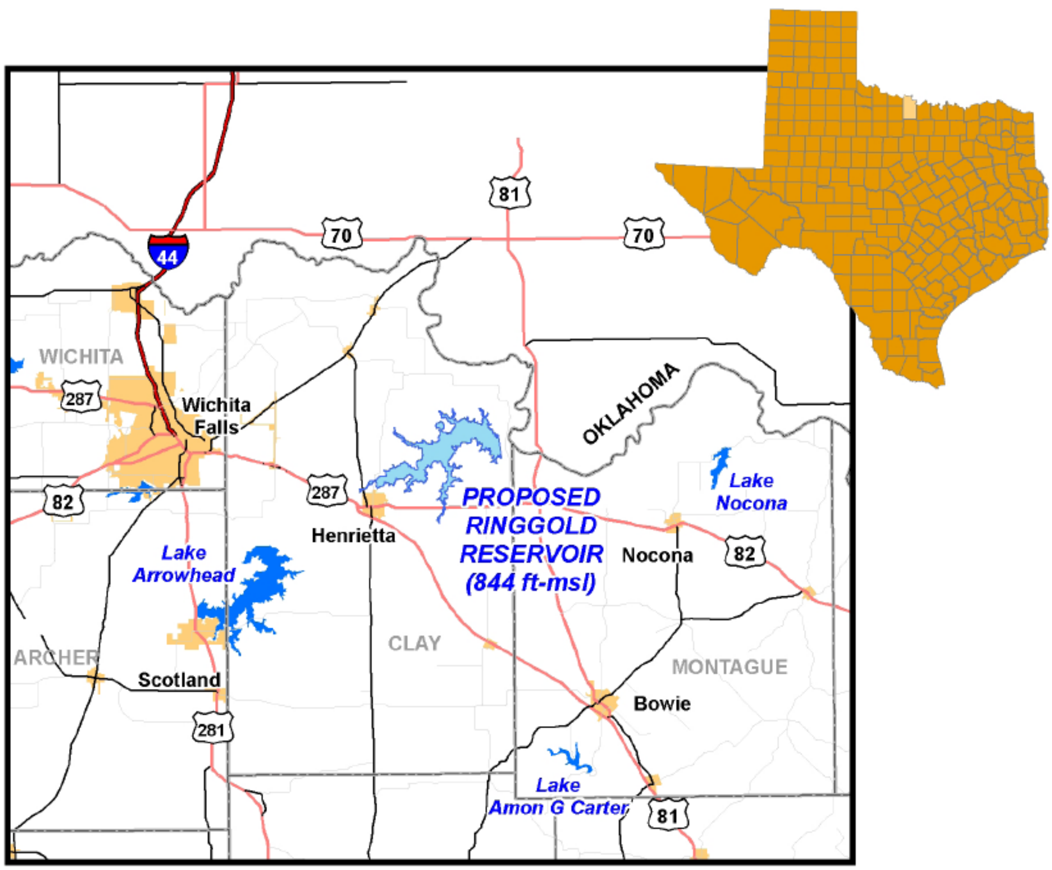


Figure 5-90. Location map of Ringgold Reservoir.
ft-msl=feet above mean sea level

is included in Table 5-61 and Figure 5-91. Freese and Nichols (1981) derived the data from the 1:24,000 scale U.S. Geological Survey topographic quadrangle maps. Figure 5-92 shows the inundation map at different elevations in 10-foot intervals. The map also shows the inundation of the reservoir at an elevation of 847 feet, which is the estimated maximum elevation before the emergency spillway starts operating in a flood event.

The reservoir will be subject to regulatory bypass to meet environmental needs. For this study, we used the Consensus Criteria for Environmental Flow Needs. The reservoir will have to pass the lesser of the inflow and the values in Table 5-62.

The firm yield of Ringgold Reservoir was calculated with the full authorization scenario (Run 3) of the Red River Basin water availability model. 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 the primary control point with calculated inflow.

The Red River water availability model 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

Table 5-61. Elevation-area-capacity relationship for Ringgold Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 783 | 5 | 4 |
| 785 | 14 | 22 |
| 790 | 64 | 198 |
| 795 | 170 | 754 |
| 800 | 330 | 1,954 |
| 805 | 820 | 4,499 |
| 810 | 1,920 | 11,259 |
| 815 | 3,270 | 24,194 |
| 820 | 4,850 | 44,344 |
| 820 | 6,610 | 72,904 |
| 830 | 8,480 | 110,629 |
| 835 | 10,510 | 158,014 |
| 840 | 12,800 | 216,189 |
| 844 | 14,980 | 271,600 |
| 845 | 15,620 | 286,900 |
| 847 | 16,990 | 319,500 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

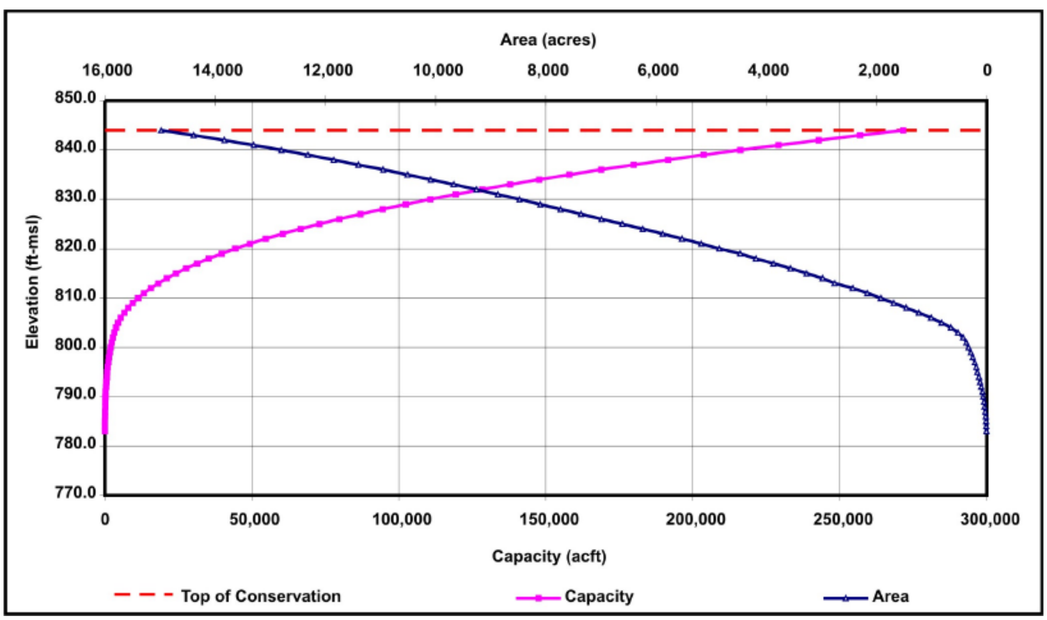


Figure 5-91. Elevation-area-capacity relationship for Ringgold Reservoir.
ft-msl=feet above mean sea level; acft=acre feet

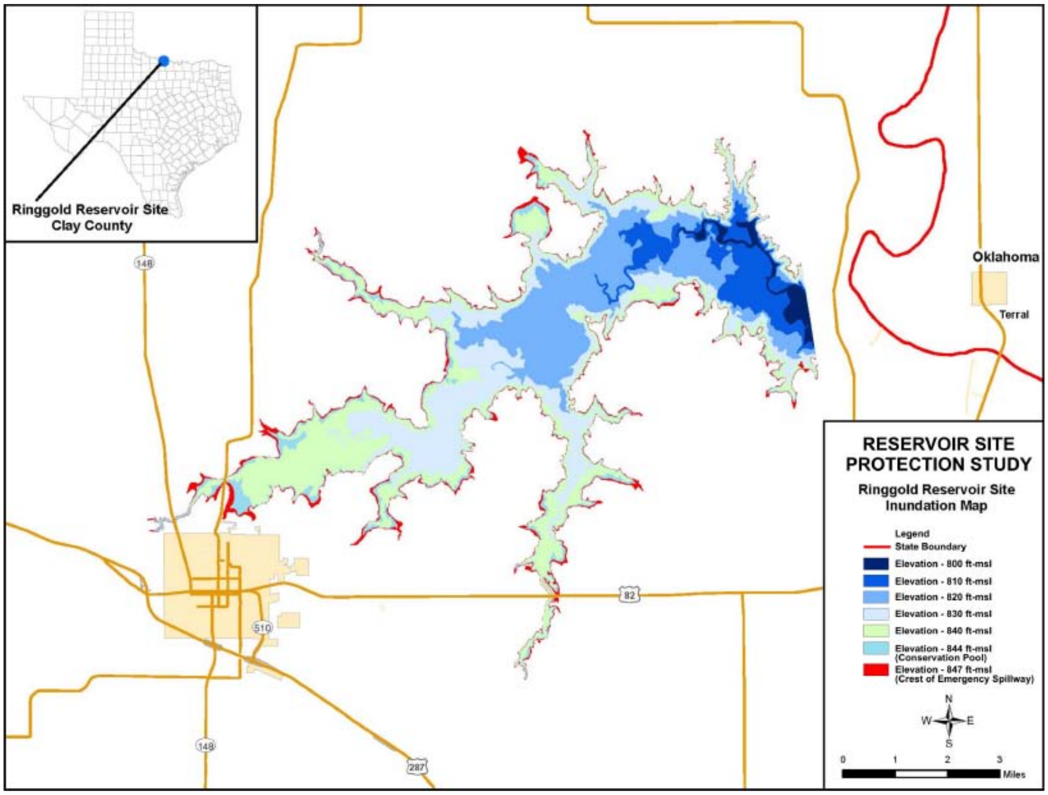


Figure 5-92. Inundation map for Ringgold Reservoir.
ft-msl=feet above mean sea level

Table 5-62. Consensus Criteria for Environmental Flow Needs for Ringgold Reservoir.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | 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 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

at the Wichita River at Charlie, the Red River near Burkburnett, and the Red River near Terral, Oklahoma. However, the model's 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 sub-basin. We entered the reservoir location as a primary control point (with known naturalized flows) in the water availability 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.

Yields were calculated for elevations

Table 5-63. Firm yield versus conservation storage for Ringgold Reservoir.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield (acft/yr[c]) | Critical Period |
|---|---|---|---|---|
| 830 | 110,629 | CCEFN[d] | 23,700 | 8/75–2/81 |
| 835 | 158,014 | CCEFN | 29,300 | 7/75–2/81 |
| 840 | 216,189 | CCEFN | 31,900 | 5/58–2/81 |
| 844* | 271,600 | CCEFN | 32,800 | 11/57–2/81 |
| | | None | 33,200 | 11/57–2/81 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]acft/yr=acre feet per year
[d]CCEFN=Consensus Criteria for Environmental Flow Needs

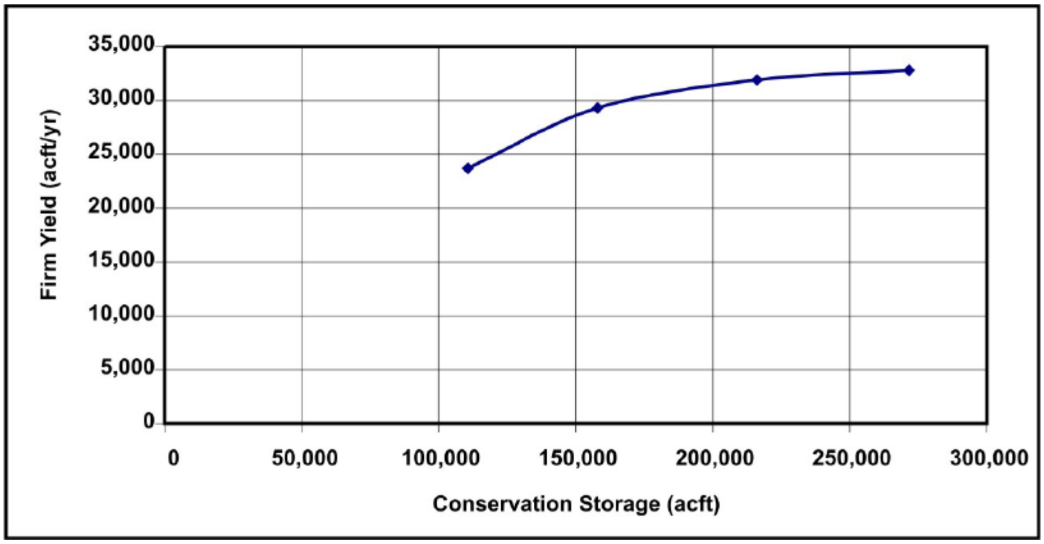


Figure 5-93. Firm yield versus conservation storage for Ringgold Reservoir.
acft/yr=acre-feet per year

of 844, 840, 835, and 830 feet, subject to environmental flow needs and assuming stand-alone reservoir operations with no minimum reserve content (Table 5-63 and Figure 5-93). At the conservation pool level of 844 feet, the firm yield is 32,800 acre-feet per year. Assuming no environmental flow releases, the yield of the reservoir increases by 400 acre-feet per year at the recommended conservation pool elevation.

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. They determined a net gain of 27,640 acre-feet per year, which is lower than the firm yield determined in this report because the 1981 study assumes that Ringgold Reservoir has a minimum reservoir reserve at an elevation of 805 feet. This leaves about 4,500 acre-feet in storage. The 1981 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 previous study determined that runoff depletions will reduce the firm yield of Ringgold Reservoir by 1,800 acre-feet per year. The water availability model hydrology, however, does not account for changes in land use or future small impoundments.

Figure 5-94 presents a simulated storage trace and storage frequency curve derived from the Red River water availability model as modified for this study.

At the conservation pool of 844 feet and assuming full diversion, the reservoir will be full about 5 percent of the time and will be below 50 percent of the conservation storage about 33 percent of the time.

### *5.14.2*
### *Reservoir Costs*

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 an elevation of 871 feet. The service spillway is designed as a control structure with five tainter gates, each 40 feet wide by 25 feet high. The reservoir will also include an emergency spillway, approximately 900 feet wide, at an elevation of 847 feet.

The conflicts identified at the site include electrical lines, minor roads, oil and gas lines, and one oil and gas well (Figure 5-95). Costs for these conflict resolutions were developed from data provided by the Texas Natural Resources Information System. The conflict costs represent 6 percent of the total construction cost of the reservoir project.

Table 5-64 shows the estimated capital costs for the Ringgold Reservoir project, including construction, engineering, permitting, and mitigation costs. Costs for the dam and reservoir are based on the unit cost assumptions used in this study. Quantities are taken from Freese and Nichols (1981). The total estimated cost of the project is $119 million (2005 prices). Assuming a yield of 32,800 acre-feet per year, raw water from the project will cost approximately $273 per acre-foot ($0.84 per 1,000 gallons) during the debt service period.

### *5.14.3*
### *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. The reservoir will inundate approximately 15,000 acres of land at conservation storage capacity. Table 5-65 and Figure 5-96 summarize existing landcover for the Ringgold Reservoir site as determined by the Texas Parks and Wildlife Department using methods described

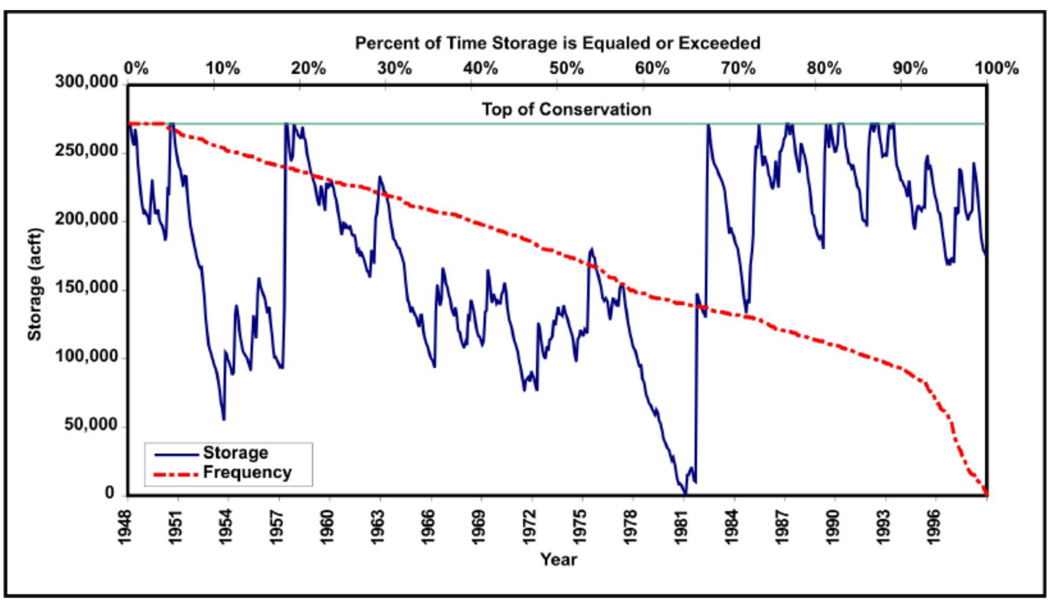


Figure 5-94. Simulated storage in Ringgold Reservoir (conservation elevation=844 feet; diversion=32,800 acre-feet per year).
acft=acre-feet

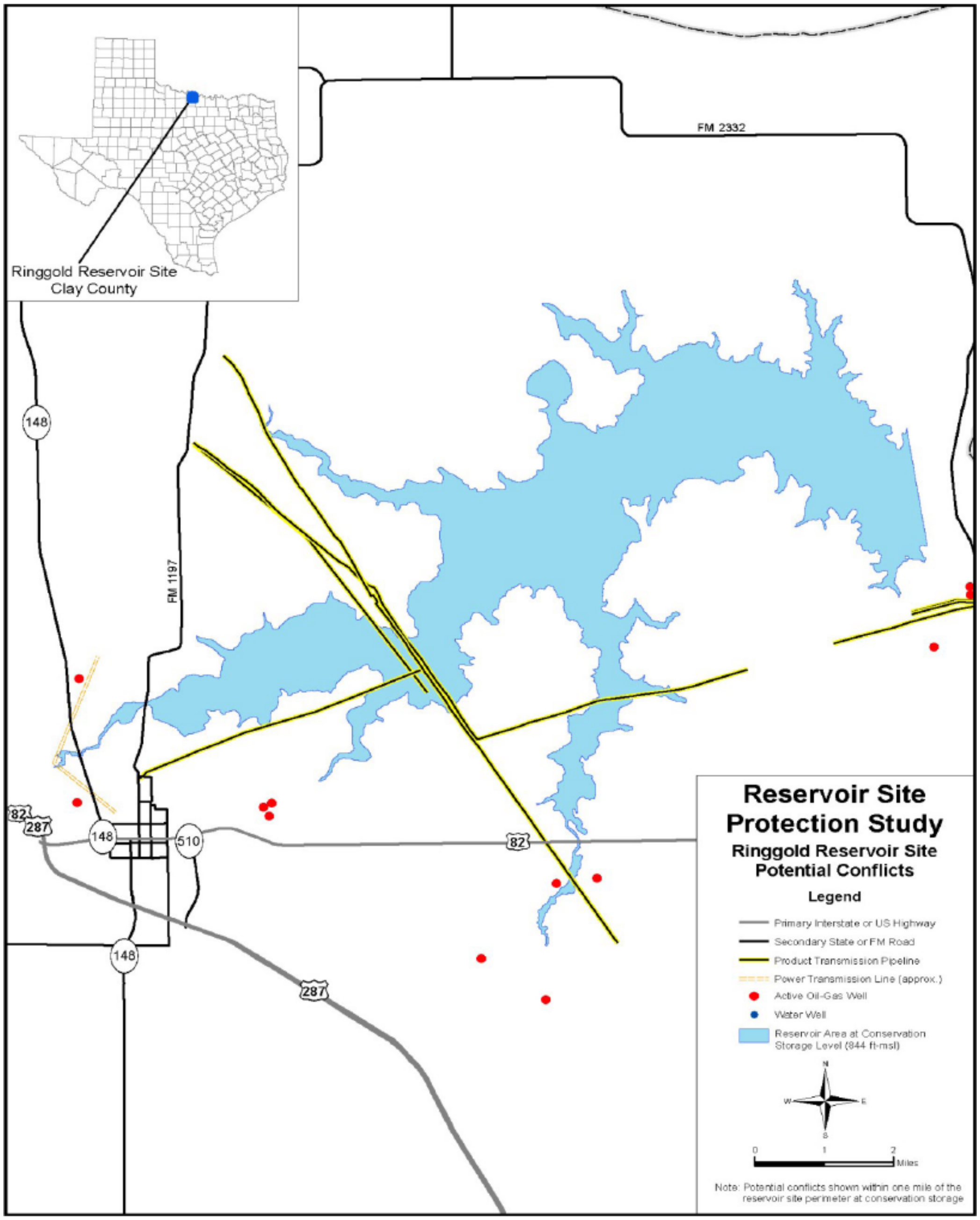


Figure 5-95. Potential major conflicts for Ringgold Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

in Appendix C. Landcover 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 constitute about 13 percent of the inundated area.

Table 5-65. Acreage and percent landcover for Ringgold Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship

Table 5-64. Cost estimate—Ringgold Reservoir at elevation 844 feet.

| | Quantity | Unit | Unit Cost | 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 | $35.00 | $11,795,000 |
| Bridge | 240 | LF | $1,300.00 | $312,000 |
| Roadway | 23,333 | SY | $20.00 | $467,000 |
| Slurry trench | 118,000 | SF | $15.00 | $1,770,000 |
| Soil cement | 121,000 | CY | $65.00 | $7,865,000 |
| Gates | | | | |
| Gate & anchor | 5,000 | SF | $275.00 | $1,375,000 |
| Stop gate & lift | 200 | LF | $2,000.00 | $400,000 |
| Hoist | 5 | Ea | $250,000.00 | $1,250,000 |
| Electrical | 1 | LS | $550,000.00 | $550,000 |
| Power drop | 1 | LS | $250,000.00 | $250,000 |
| Spillway low-flow system | 1 | LS | $400,000.00 | $400,000 |
| Embankment internal drainage | 15,400 | LF | $60.00 | $924,000 |
| Guardrail | 480 | LF | $30.00 | $14,000 |
| Grassing | 50 | AC | $4,500.00 | $225,000 |
| Concrete (mass) | 54,747 | CY | $150.00 | $8,212,000 |
| Reinforced concrete (formed) | 14,160 | CY | $475.00 | $6,726,000 |
| Mobilization (5% of subtotal) | | | | $2,928,000 |
| Care of water (1% of subtotal) | | | | $586,000 |
| Clearing & grubbing | 150 | AC | $4,000.00 | $600,000 |
| Land clearing | 425 | AC | $1,000.00 | $425,000 |
| Engineering & contingencies (35%) | | | | $22,086,000 |
| **Subtotal for Dam & Reservoir** | | | | **$85,190,000** |
| | | | | |
| **Conflicts** | | | | |
| Highways | 6650 | LF | $150.00 | $998,000 |
| Pipelines | | | | |
| 4.5-inch crude oil | 58,900 | LF | $17.00 | $1,001,000 |
| 16-inch gas | 55,800 | LF | $42.00 | $2,344,000 |
| 8.63-inch crude oil | 23,800 | LF | $25.00 | $595,000 |
| Oil & gas well (plug & abandon) | 1 | EA | $25,000.00 | $25,000 |
| Power lines | 240 | LF | $450.00 | $108,000 |
| Engineering & contingencies (35%) | | | | $1,388,000 |
| **Subtotal of Conflicts** | | | | **$6,459,000** |
| | | | | |
| **Land acquisition** | 17,000 | AC | $850.00 | **$14,450,000** |
| **Environmental studies & mitigation** | | | | **$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 | | | | $1,054,000 |
| **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; SY=Square Yard.

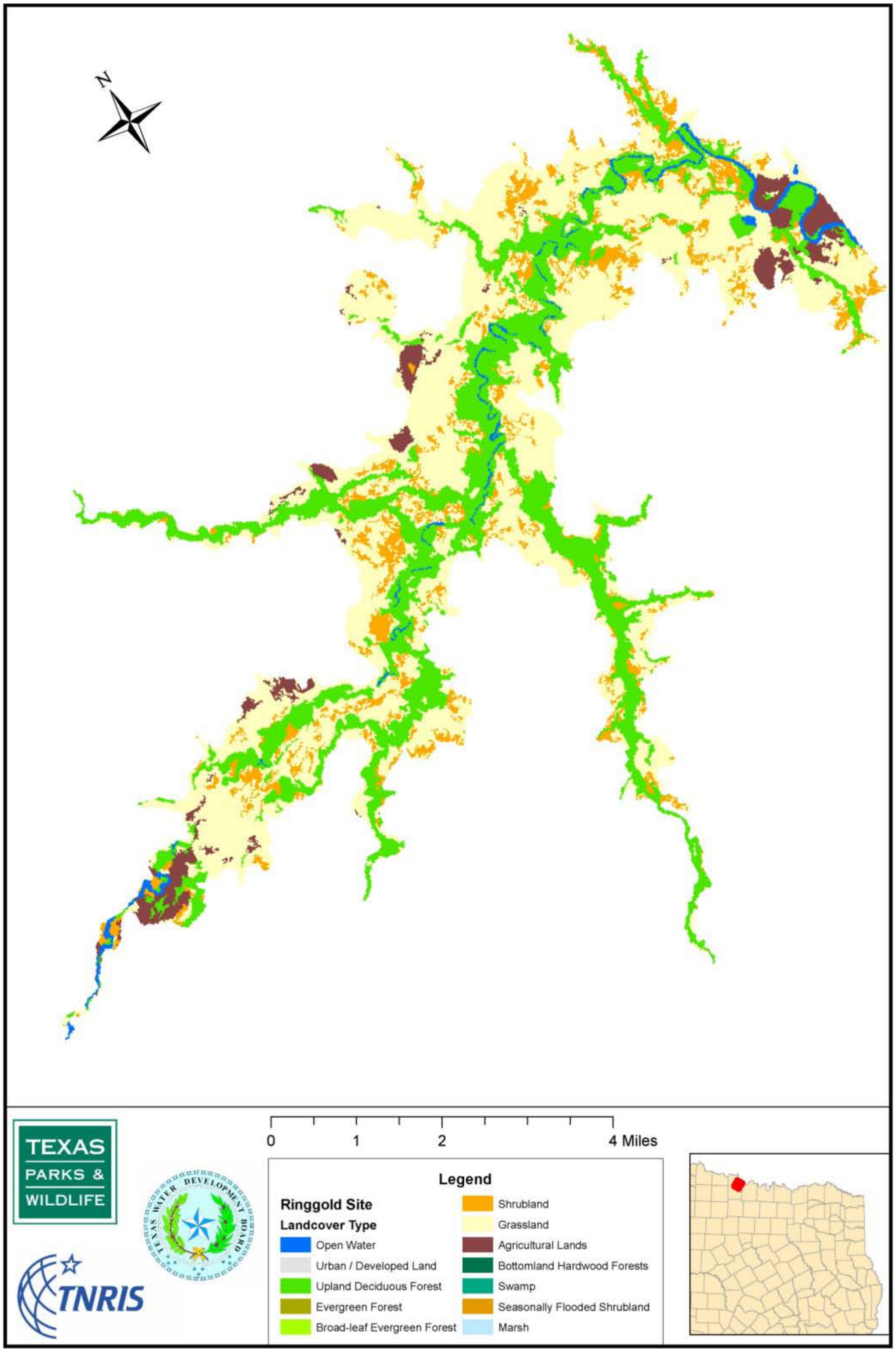


Figure 5-96. Existing landcover for Ringgold Reservoir.

## 5.15 TEHUACANA RESERVOIR

Tehuacana Reservoir is a proposed water supply project on Tehuacana Creek within the Trinity River Basin (Figure 5-97). 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 will likely be sponsored by the Tarrant Regional Water District, will connect to the water district's Richland-Chambers Reservoir by a 9,000-foot channel and be operated as an integrated extension of that reservoir. The project will inundate approximately 15,000 acres adjacent to Richland-Chambers Reservoir.

Tehuacana Reservoir has been a part of the Tarrant Regional Water District's long-term planning since the project was first proposed in the late 1950s. It is included as an alternative strategy for the water district in the 2001 and 2006 Region C Regional Water Plans 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 acre-feet per year. The nearest major demand center is the greater Dallas-Fort Worth area, 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 can function as merely an extension of Richland-Chambers Reservoir. Developing this site will require obtaining a new water right, constructing the dam and reservoir, and upsizing the Tarrant Regional Water District's pipelines to deliver water to Tarrant County.

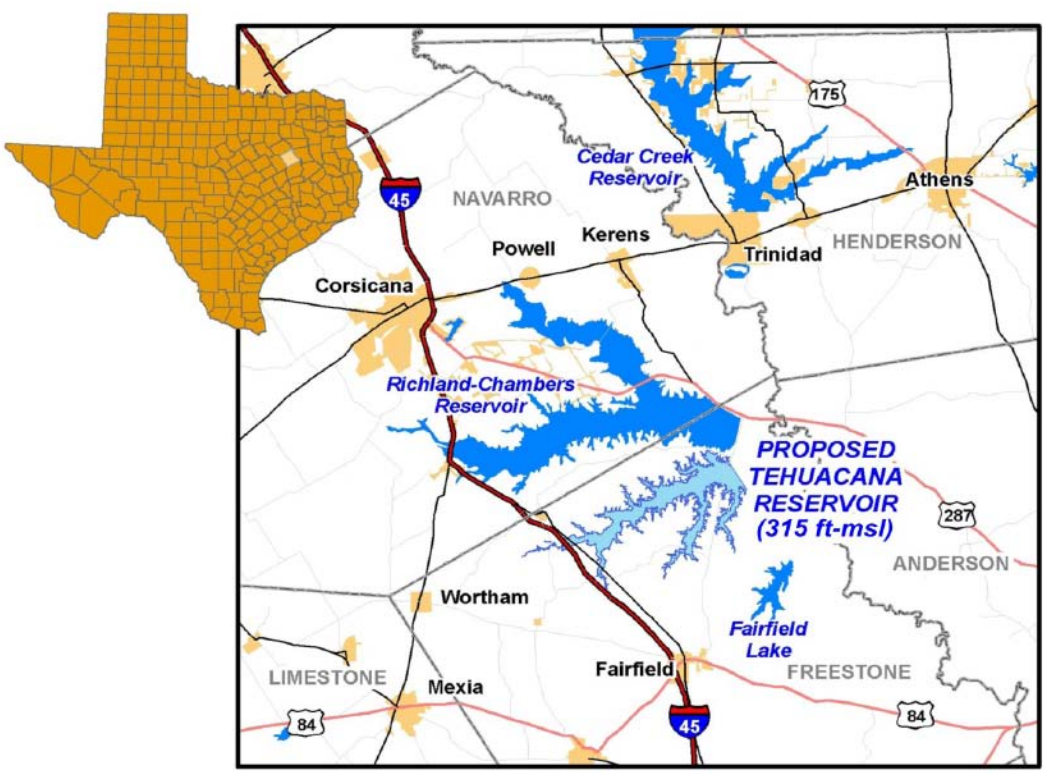


Figure 5-97. Location map of Tehuacana Reservoir.
ft-msl=feet above mean sea level

### 5.15.1 *Reservoir Yield Analysis*

Freese and Nichols (2006) studied the Tehuacana Reservoir as part of the Region C water supply planning process. Their analysis treated this reservoir as an extension of the existing Richland-Chambers Reservoir.

For this report, we calculated the firm yield of Tehuacana Reservoir using a version of the Trinity River Basin water availability model with Run 3 assumptions. The monthly water availability model simulations were performed using the Water Rights Analysis Package. This version of the model, 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 water availability model. 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 (315 feet).

Table 5-66. Elevation-area-capacity relationship for Tehuacana Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 250 | 20 | 10 |
| 255 | 286 | 775 |
| 260 | 552 | 2,870 |
| 265 | 1,168 | 7,170 |
| 270 | 1,784 | 14,550 |
| 275 | 2,586 | 25,474 |
| 280 | 3,387 | 40,406 |
| 285 | 4,701 | 60,625 |
| 290 | 6,014 | 87,411 |
| 295 | 7,551 | 121,323 |
| 300 | 9,087 | 162,917 |
| 305 | 10,694 | 212,368 |
| 310 | 12,300 | 269,852 |
| 315 | 14,938 | 337,947 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

The elevation-area-capacity relationship for Tehuacana Reservoir is presented in Table 5-66 and Figure 5-98 (Freese and Nichols, 1990). The combined elevation-area-capacity relationship for the Richland-Chambers and Tehuacana Reservoir system is presented in Table 5-67 and Figure 5-99. Figure 5-100 shows the reservoir inundation at 10-foot contours.

For purposes of this yield study, it is assumed that inflows to Tehuacana Reservoir will have to be passed downstream to provide environmental flows

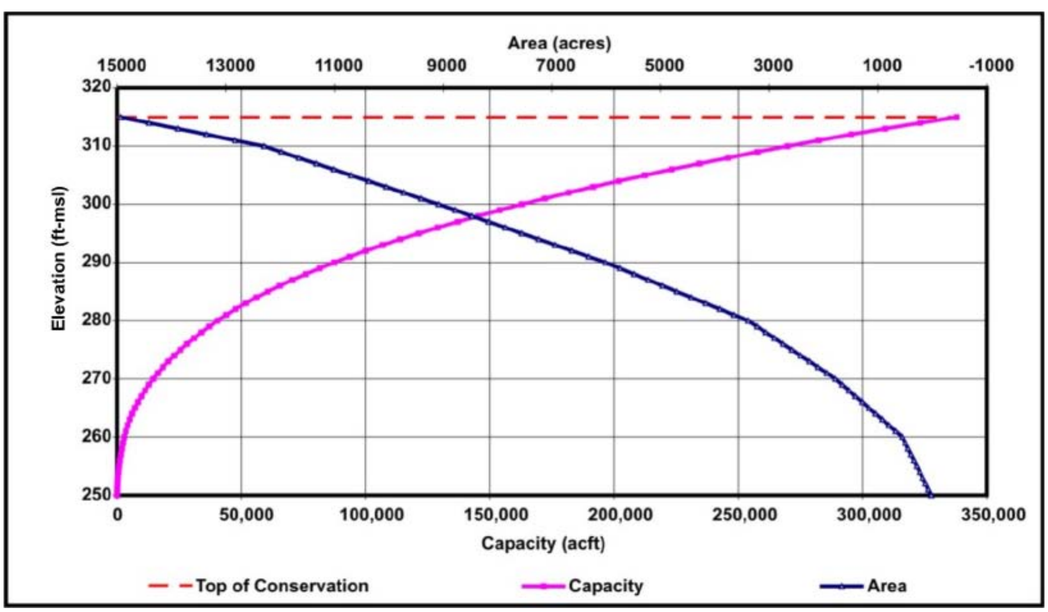


Figure 5-98. Elevation-area-capacity relationship for Tehuacana Reservoir.
ft-msl=feet above mean sea level; acft=acre feet

for Tehuacana Creek. These minimum environmental flow requirements are based on the Consensus Criteria for Environmental Flow Needs. The reservoir has to pass the lesser of the inflow and the values the table in Table 5-68.

As stated in Certificate of Adjudication No. 4248, Lake Livingston, even though it is senior in priority, will be subordinate to Tehuacana Reservoir when and if the reservoir is issued a water right permit by the Texas Commission on Environmental Quality. The Lake Livingston subordination to Tehuacana Reservoir is recognized and modeled in this yield study.

Water availability model simulations were made for firm annual yield determinations with the top of the conservation pool of the combined Richland-Chambers and Tehuacana reservoirs assumed to be at elevations of 312, 313, 314, and 315 feet. For these simulations, the minimum content of the combined reservoirs was set at 116,975 acre-feet, which is the minimum simulated for Richland-Chambers as a stand-alone reservoir, with its demand equal to its own authorized diversion amount (210,000 acre-feet per year). Maintaining this minimum amount during the drought of record is consistent with the Tarrant Regional Water District'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. At the conservation pool level of 315 feet, or 1,447,257 acre-feet of total combined

Table 5-67. Elevation-area-capacity relationship for Tehuacana and Richland-Chambers reservoirs combined.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 250 | 20 | 10 |
| 255 | 674 | 1,294 |
| 260 | 2,522 | 9,290 |
| 265 | 5,677 | 29,674 |
| 270 | 9,035 | 65,213 |
| 275 | 12,861 | 121,065 |
| 280 | 16,825 | 194,794 |
| 285 | 21,947 | 290,422 |
| 290 | 27,162 | 413,626 |
| 295 | 32,253 | 561,859 |
| 300 | 37,445 | 736,215 |
| 305 | 43,885 | 938,794 |
| 310 | 50,517 | 1,176,219 |
| 315 | 58,559 | 1,447,257 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

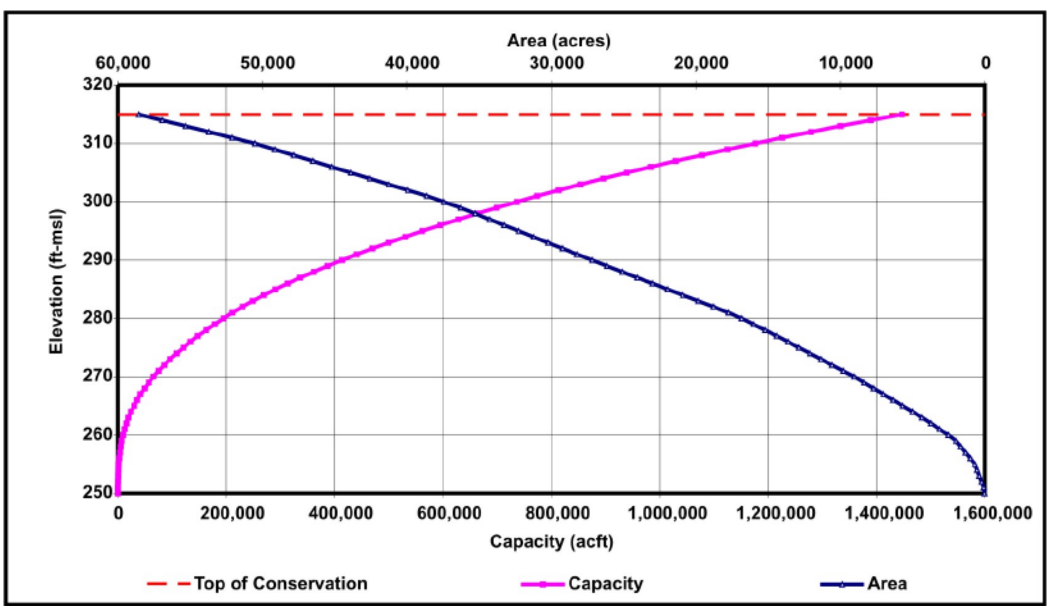


Figure 5-99. Elevation-area-capacity relationship for Tehuacana and Richland-Chambers reservoirs combined.
ft-msl=feet above mean sea level; acft=acre-feet

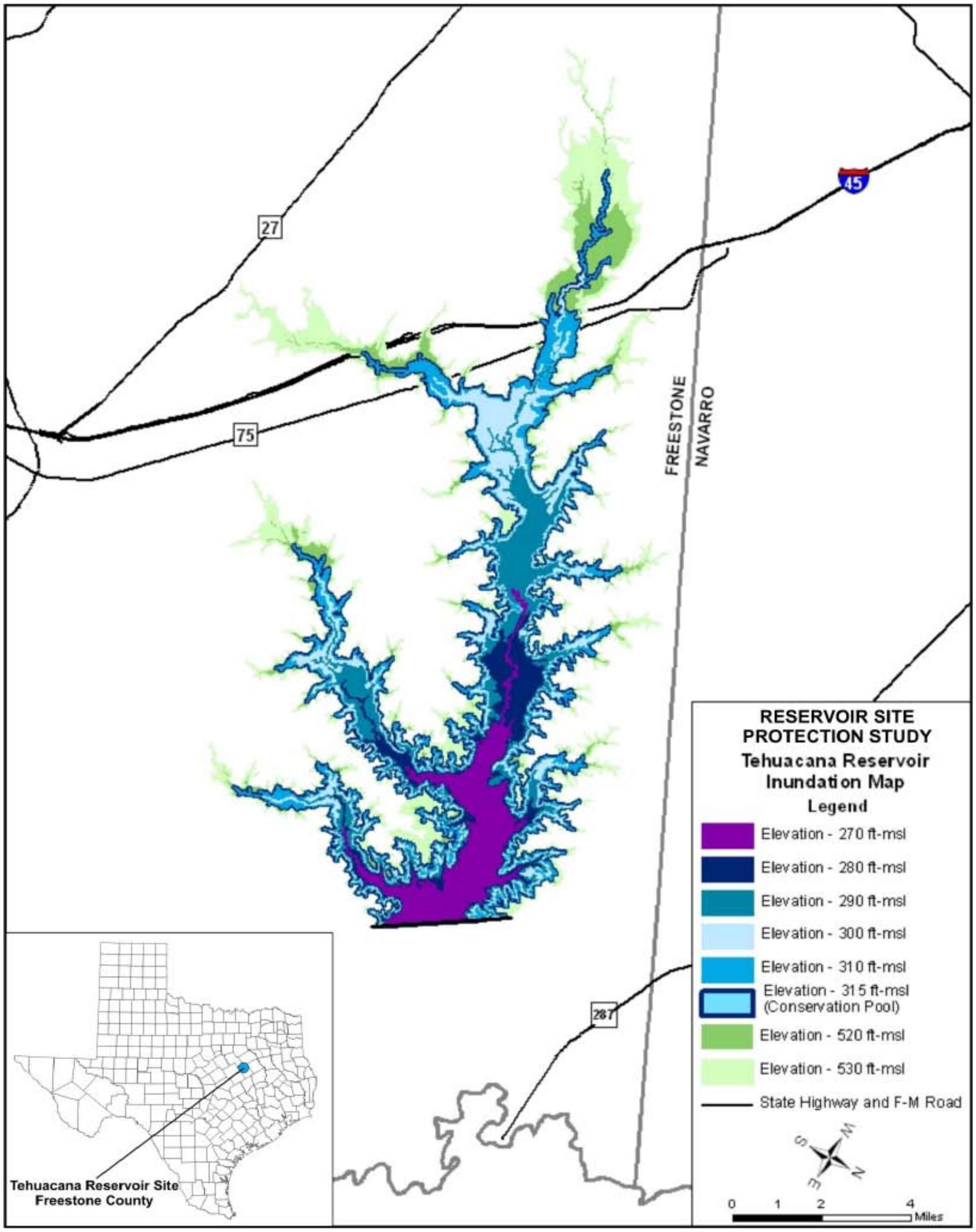


Figure 5-100. Inundation map for Tehuacana Reservoir.
ft-msl=feet above mean sea level

storage capacity, the incremental firm yield of Tehuacana Reservoir is 41,900 acre-feet per year (Table 5-69 and Figure 5-101). The Consensus Critieria for Environmental Flow Needs reduce the yield of the reservoir by about 2,200 acre-feet per year.

Figure 5-102 presents a simulated storage trace and storage frequency curve for the combined Tehuacana-Richland-Chambers Reservoir with a conservation storage capacity of 1,447,257 acre-feet (elevation 315 feet) and an incremental firm yield diversion of 41,900 acre-feet per year attributable to Tehuacana Reservoir. Based on the 1940-1996 monthly water availability model simulations, at the conservation pool level of 315 feet the combined reservoir will be full about 26 percent of the time and will be below 50

Table 5-68. Consensus Criteria for Environmental Flow Needs for Tehuacana and Richland-Chambers reservoirs combined.

| Month | Median | | 25th Percentile | | 7Q2 | |
|---|---|---|---|---|---|---|
| | acft/mo[a] | cfs[b] | acft/mo | cfs | acft/mo | cfs |
| Jan | 694 | 11.3 | 74 | 1.2 | 6 | 0.1 |
| Feb | 1,054 | 18.8 | 267 | 4.8 | 6 | 0.1 |
| Mar | 1,215 | 19.8 | 329 | 5.3 | 6 | 0.1 |
| Apr | 934 | 15.7 | 243 | 4.1 | 6 | 0.1 |
| May | 1,218 | 19.8 | 251 | 4.1 | 6 | 0.1 |
| Jun | 505 | 8.5 | 69 | 1.2 | 6 | 0.1 |
| Jul | 68 | 1.1 | 6 | 0.1 | 6 | 0.1 |
| Aug | 6 | 0.1 | 6 | 0.1 | 6 | 0.1 |
| Sep | 6 | 0.1 | 6 | 0.1 | 6 | 0.1 |
| Oct | 12 | 0.2 | 6 | 0.1 | 6 | 0.1 |
| Nov | 138 | 2.3 | 6 | 0.1 | 6 | 0.1 |
| Dec | 465 | 7.6 | 22 | 0.4 | 6 | 0.1 |

[a]acft/mo=acre-feet per month
[b]cfs=cubic feet per second

Table 5-69. Firm yield versus conservation storage for Tehuacana and Richland-Chambers reservoirs combined.

| Conservation Pool Elevation (ft-msl[a]) | Conservation Storage (acft[b]) | Environmental Bypass Criteria | Firm Yield[c] (acft/yr[d]) | Critical Period |
|---|---|---|---|---|
| 312 | 1,279,413 | CCEFN[e] | 26,300 | 5/48–6/57 |
| 313 | 1,333,378 | CCEFN | 32,100 | 5/48–6/57 |
| 314 | 1,389,508 | CCEFN | 34,400 | 5/48–6/57 |
| 315* | 1,447,257 | CCEFN | 41,900 | 5/48–6/57 |
| | | None | 44,100 | 5/48–6/57 |

*Proposed conservation storage
[a]ft-msl=feet above mean sea level
[b]acft=acre-feet
[c]incremental firm yield attributable to Tehuacana Reservoir
[d]acft/yr=acre-feet per year
[e]CCEFN=Consensus Criteria for Environmental Flow Needs

percent of its capacity about 6 percent of the time.

### *5.15.2*
### *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 (Figure 5-103). The conflict costs represent less than 10 percent of the total construction cost of the reservoir project.

Table 5-70 presents the estimated capital costs for the Tehuacana Reservoir dam, including construction, engineering, permitting, and mitigation costs. 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 acre-feet per year, raw water from the project will cost approximately $320 per acre-foot ($0.98 per 1,000 gallons) during the debt service period.

### *5.15.3*
### *Environmental Considerations*

The Tehuacana Reservoir site is not located on an ecologically significant stream segment as identified by the Texas Parks and Wildlife Department, nor is it identified as ecologically unique in the 2007 State Water Plan. It is, how-

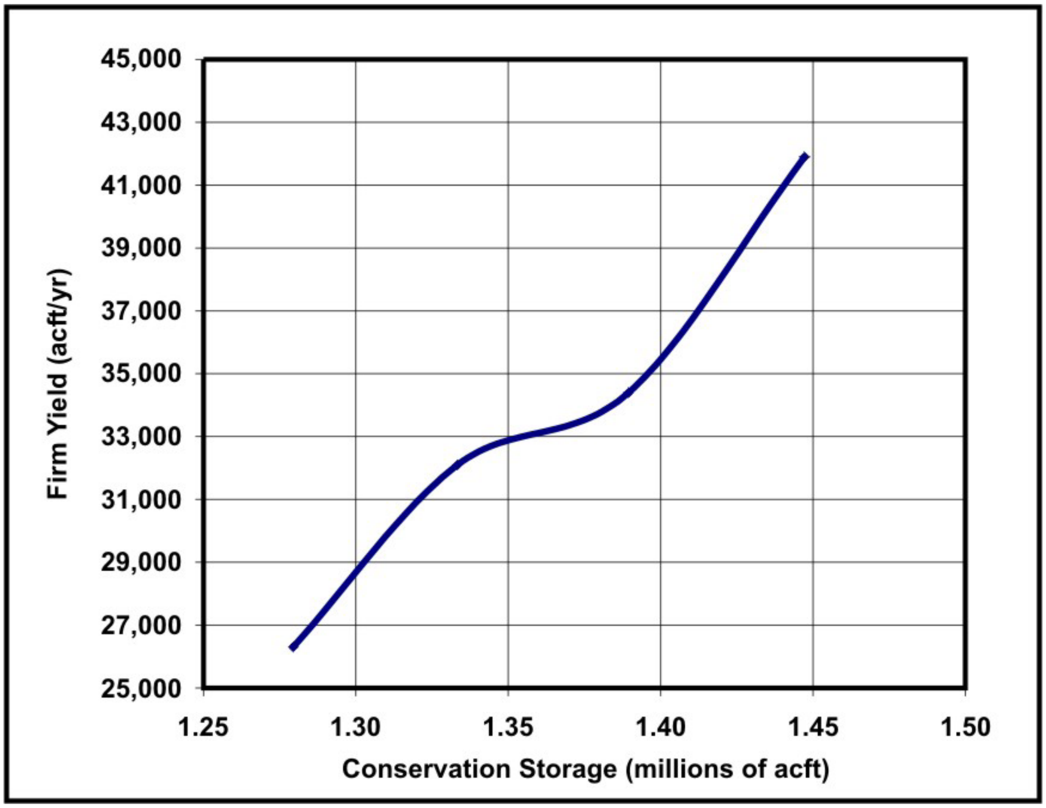


Figure 5-101. System yield versus conservation storage for Tehuacana and Richland-Chambers reservoirs combined.
acft/yr=acre-feet per year

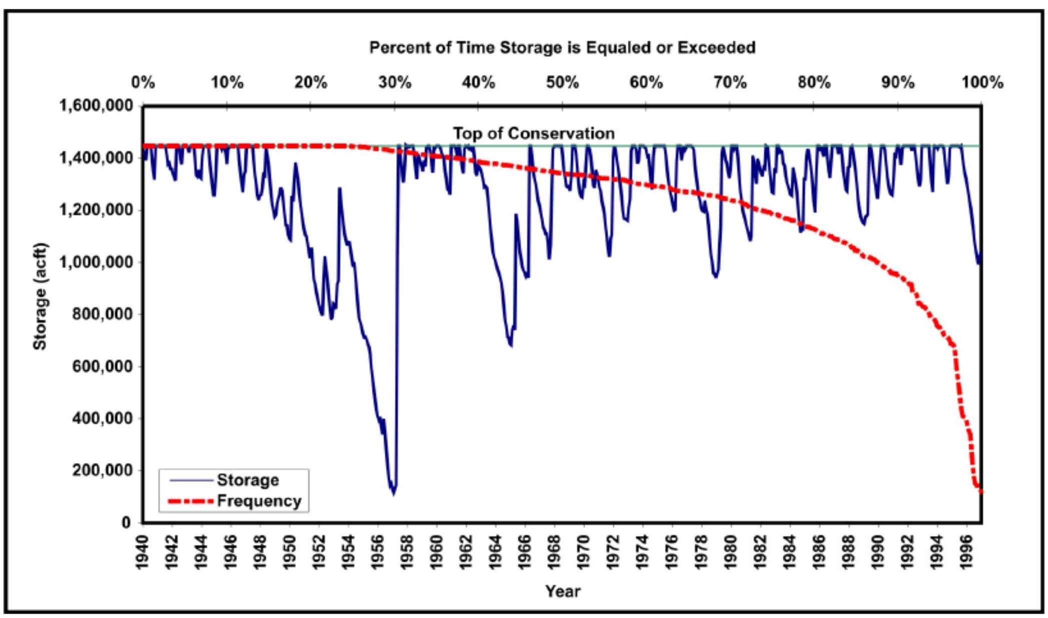


Figure 5-102. Simulated storage in Tehuacana and Richland-Chambers reservoirs (conservation elevation=315 feet; incremental yield=41,900 acre-feet per year).
acft=acre-feet

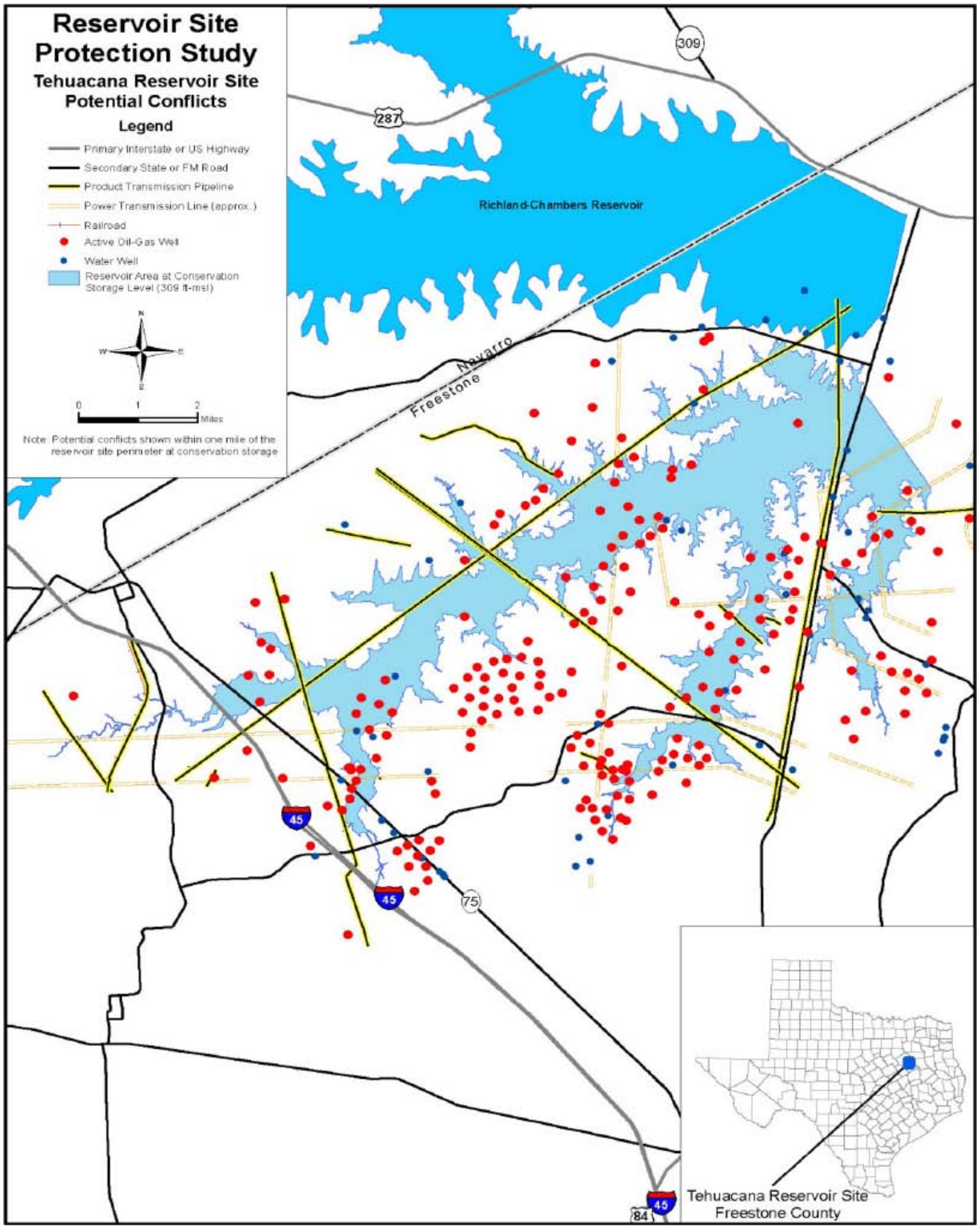


Figure 5-103. Potential major conflicts for Tehuacana Reservoir (map from Texas Natural Resources Information System).
ft-msl=feet above mean sea level

ever, located just upstream of a segment of the Trinity River identified by the Texas Parks and Wildlife Department as ecologically significant due to a population of rare endemic Texas heelsplitter freshwater mussels (TPWD, 1999). 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 will be very comparable to existing water supply sources. This indicates that no significant changes to

Table 5-70. Cost estimate—Tehuacana Reservoir at elevation 315 feet.

| | 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** | AC | 14,938 | $2,009.00 | **$30,010,442** |
| **Environmental Studies & Mitigation** | | | | **$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 (acre-feet per year)** | | | | **41,900** |
| **Unit Cost of Water (during Amortization)** | | | | |
| Per acre-foot | | | | **$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; SY=Square Yard.

the existing treatment processes will be necessary for this reservoir. The project will 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.

Table 5-71 and Figure 5-104 summarize existing landcover for the Tehuacana Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover 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 constitutes about 8 percent of the inundated area. Approximately 2.7 percent of the site is presently classified as marsh or open water.

Table 5-71. Acreage and percent landcover for Tehuacana Reservoir.

| Landcover Classification | Acreage[a] | 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%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship

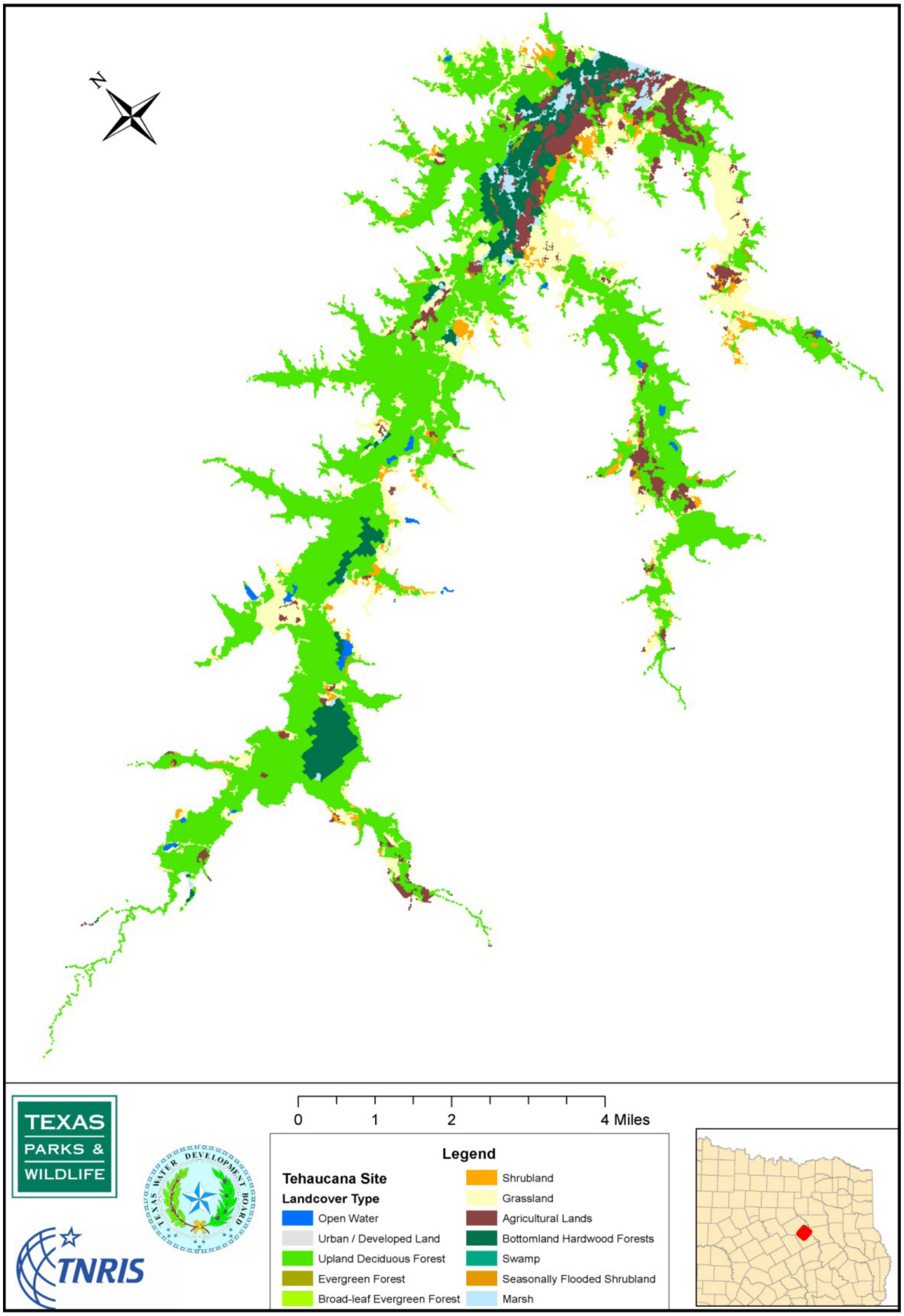


Figure 5-104. Existing landcover for Tehuacana Reservoir.

## 5.16 WILSON HOLLOW RESERVOIR

In 1986, HDR Engineering performed a volumetric survey to determine the capacity of Lake Palo Pinto (HDR, 1986). The survey indicated the capacity of the lake to be 27,650 acre-feet or about 16,450 acre-feet less than the authorized capacity of 44,100 acre-feet. This lesser capacity for Lake Palo Pinto was subsequently verified by TWDB 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, 2005). The proposed off-channel reservoir will be located approximately 1.6 miles north of Lake Palo Pinto at Wilson Hollow (Figure 5-105). The dam will be an earthfill embankment that will provide a conservation storage capacity of 22,000 acre-feet at an elevation of 1,077 feet and inundate 333 surface acres.

The Wilson Hollow Reservoir will 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 will 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 feet and 867 feet, respectively, the combined storage capacity in 2060 will be approximately 44,100 acre-feet, 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 also identified Turkey Peak Reservoir as an alternative water management strategy to Wilson Hollow Reservoir for recovering authorized Lake

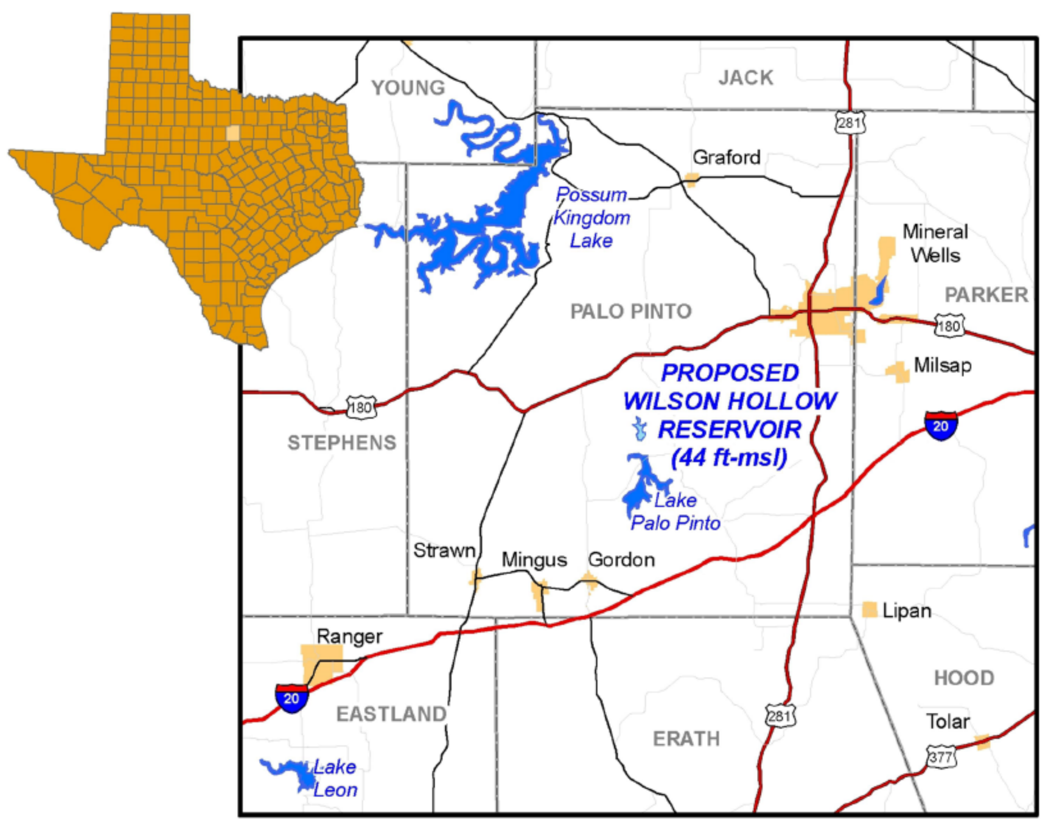


Figure 5-105. Location map of Wilson Hollow Reservoir.
ft-msl=feet above mean sea level

Palo Pinto storage capacity.

Projected municipal, industrial (including manufacturing), and steam-electric needs for additional water supply by year 2060 total 511,124 acre-feet per year 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).

### *5.16.1 Reservoir Yield Analysis*

The elevation-area-capacity relationship for Wilson Hollow Reservoir is presented in Figure 5-106 and Table 5-72 and was developed from 10-foot contour, digital hypsography data from the Texas Natural Resources Information System. These data are derived from the 1:24,000-scale (7.5-minute) quadrangle maps developed by the U.S. Geological Survey. The total area inundated at each 10-foot elevation contour is shown in Figure 5-107. Surface areas and capacities associated with an elevation of 1,077 feet are computed by linear interpolation between values for 1,070

Table 5-72. Elevation-area-capacity relationship for Wilson Hollow Reservoir.

| Elevation (ft-msl[a]) | Area (acres) | Capacity (acft[b]) |
|---|---|---|
| 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 |

[a]ft-msl=feet above mean sea level
[b]acft=acre-feet

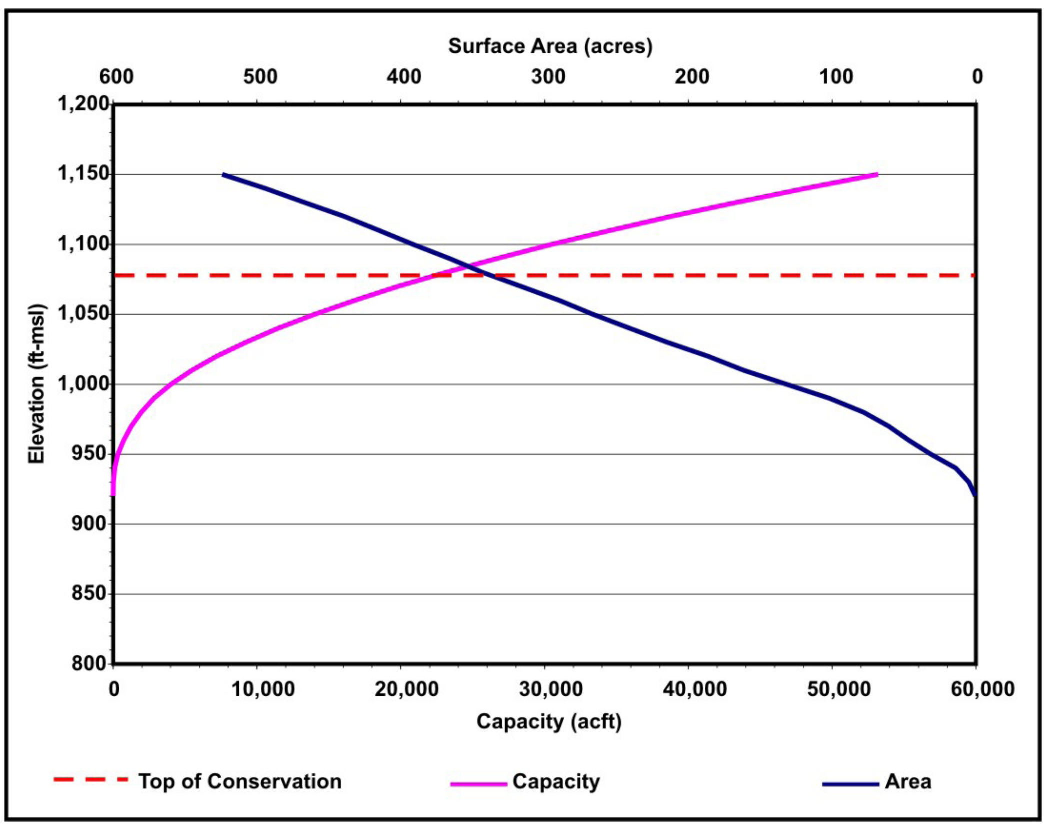


Figure 5-106. Elevation-area-capacity relationship for Wilson Hollow Reservoir.
ft-msl=feet above mean sea level; acft=acre-feet

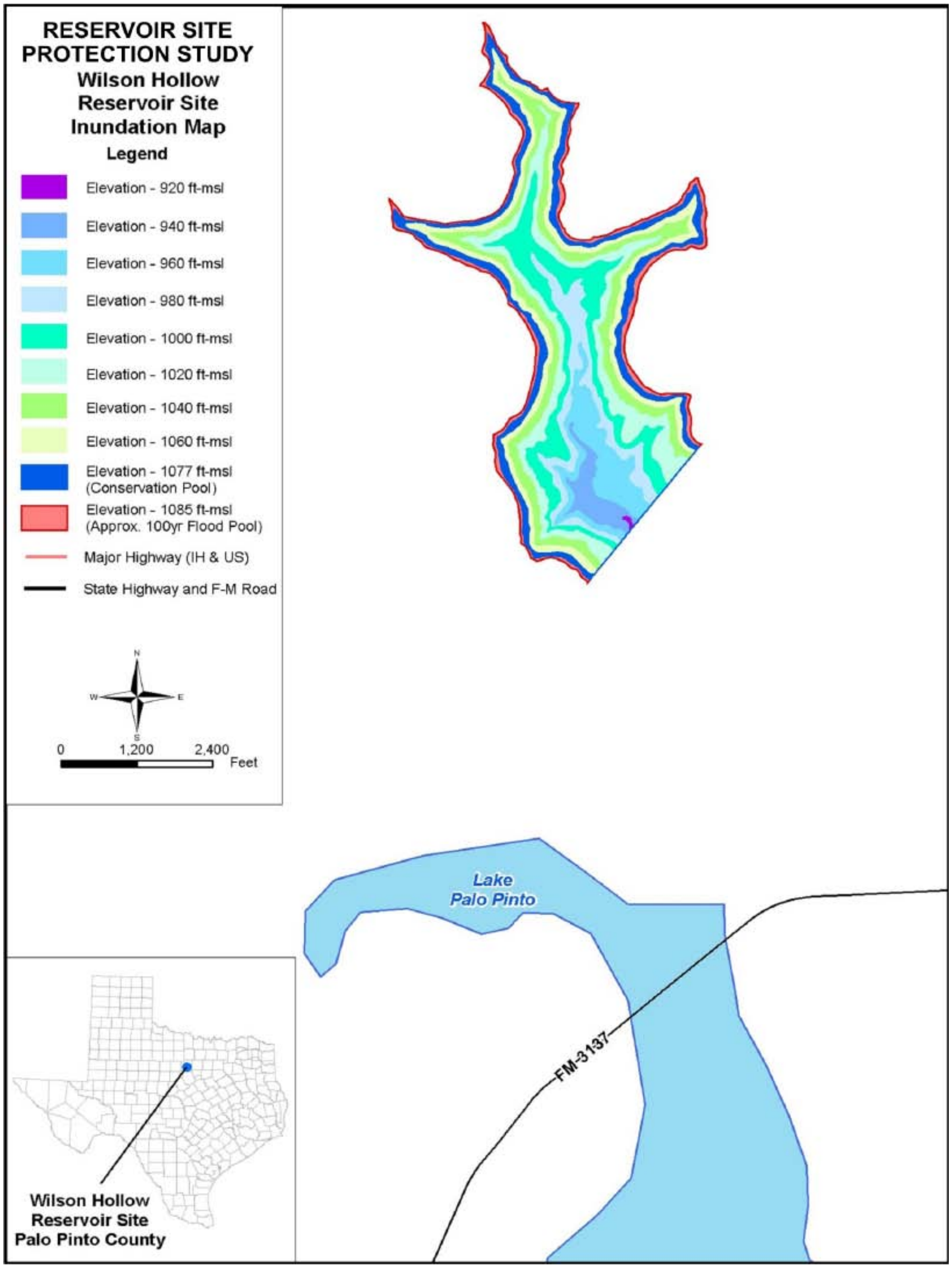


Figure 5-107. Inundation map for Wilson Hollow Reservoir.
ft-msl=feet above mean sea level

and 1,080 feet and are subject to future refinement based on more detailed topographic information. At the conservation storage pool elevation of 1,077 feet, Wilson Hollow Reservoir will inundate 333 acres and have a capacity of 22,000 acre-feet.

The firm yield of Wilson Hollow Reservoir is estimated using the Texas Commission on Environmental Quality Brazos River Basin water availability model data sets and the Water Rights Analysis Package. The Brazos model 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 and 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 subordinate 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 were modeled for Wilson Hollow Reservoir. These conservation storage capacities are 10,000, 15,000, 20,000, and 22,000 acre-feet (Table 5-73). Wilson Hollow Reservoir was simulated with the priority date of Lake Palo Pinto since it is envisioned as a project to recover "lost" storage in Lake Palo Pinto. Current planning initiatives envision a conservation elevation of 1,077 feet for Wilson Hollow Reservoir, thereby yielding an additional water supply of 5,873 acre-feet per year above the 2060 Lake Palo Pinto firm yield of 11,340 acre-feet per year. Figure 5-108 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 million gallon-per-day diversion intake, pump station, and pipeline were assumed to pump water up from Lake Palo Pinto to Wilson Hollow Reservoir.

Wilson Hollow Reservoir was most recently studied by Region G and identified as a recommended water management strategy in their 2006 Regional

Table 5-73. Firm yield versus conservation storage for Wilson Hollow Reservoir.

| Wilson Hollow Conservation Capacity (acft[a]) | Lake Palo Pinto/Wilson Hollow System Yield (acft/yr[b]) | 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
[a]acft=acre-feet
[b]acft/yr=acre-feet per year

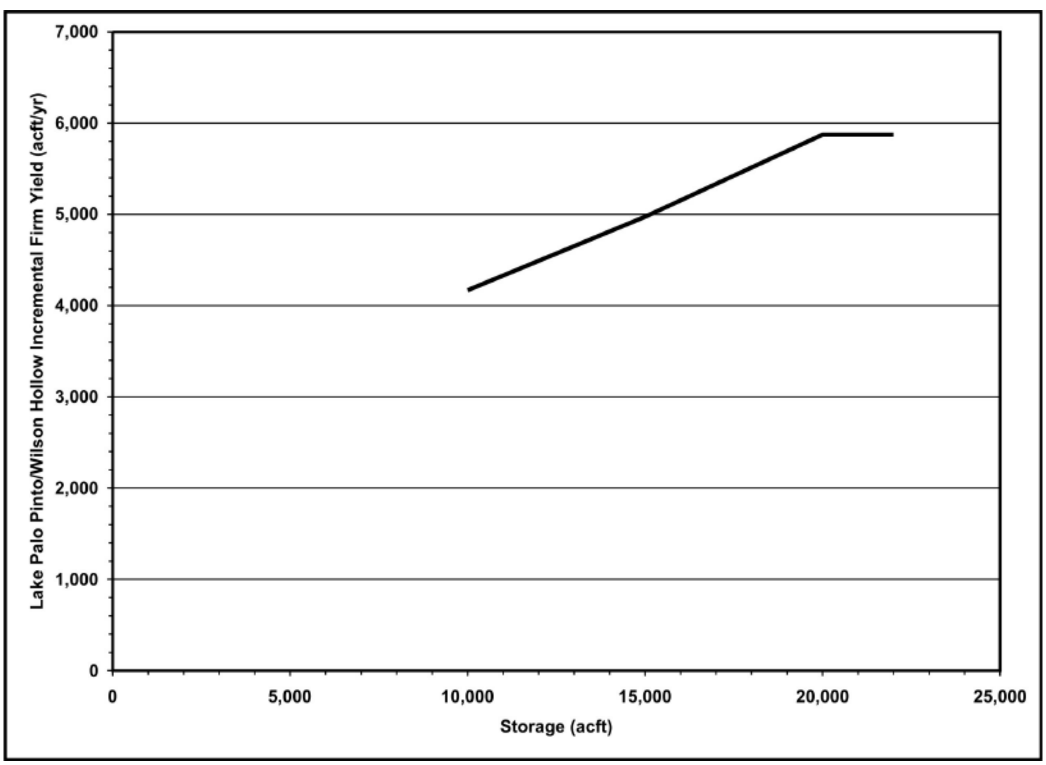

Figure 5-108. Firm yield versus conservation storage for Wilson Hollow Reservoir.
acft/yr=acre-feet per year

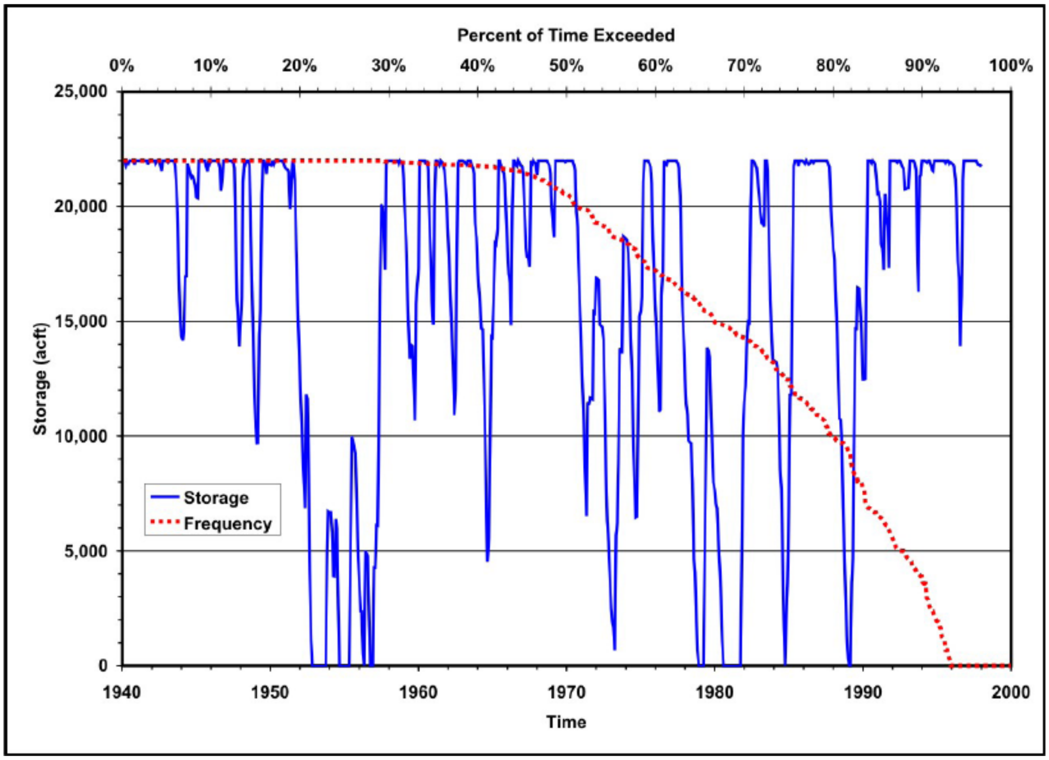


Figure 5-109. Simulated storage in Wilson Hollow Reservoir (conservation elevation=1,077 feet; incremental diversion=873 acre-feet per year).
acft=acre-feet

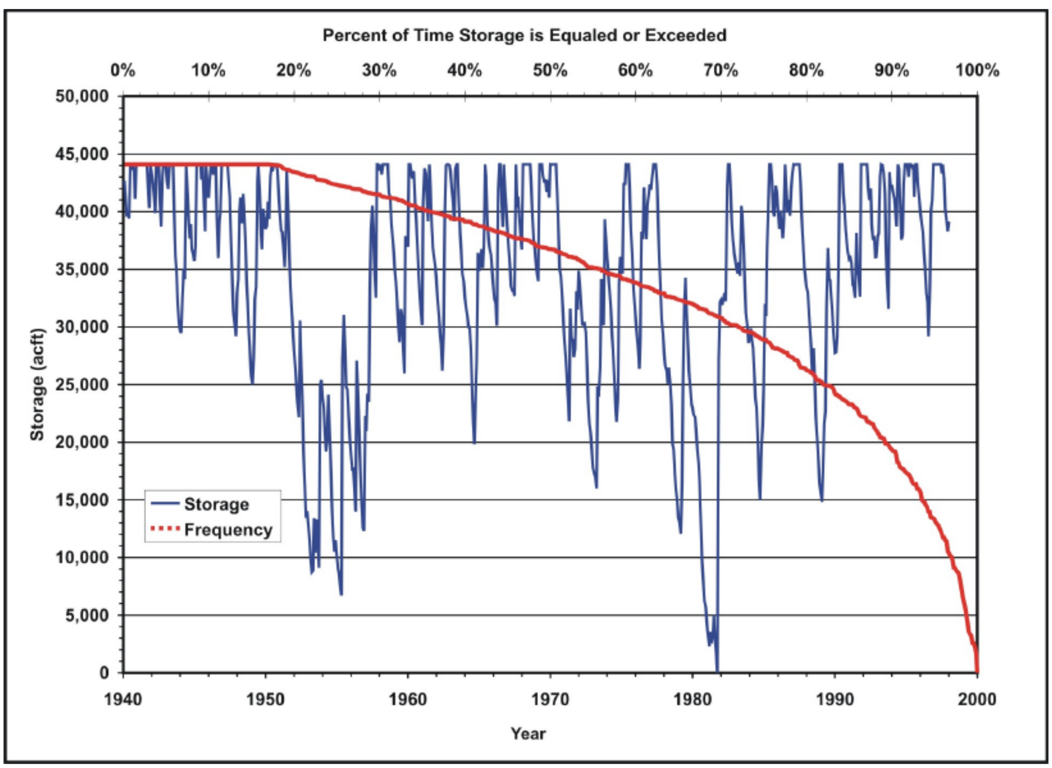


Figure 5-110. Simulated system storage for Lake Palo Pinto and Wilson Hollow reservoirs (system diversion=17,213 acre-feet per year).
acft=acre-feet

Water Plan. In that plan, Wilson Hollow Reservoir was evaluated at a location slightly upstream and at a smaller size (10,000 acre-feet). In addition, the Lake Palo Pinto/Wilson Hollow System was evaluated on a safe yield basis.

Figure 5-109 illustrates storage fluctuations through time for Wilson Hollow Reservoir, and Figure 5-110 shows combined system storage in Lake Palo Pinto and Wilson Hollow Reservoir. The storage frequency curve in Figure 5-109 indicates that the reservoir will 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. However, the system of reservoirs will be above 50 percent of capacity about 90 percent of the time.

### *5.16.2*
### *Reservoir Costs*

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 million gallon-per-day intake and pump station, a 1.5-mile, 54-inch pipeline, and a stilling basin.

Potential conflicts for Wilson Hollow Reservoir are limited to existing gas infrastructure (Figure 5-111). Resolving facility conflicts represents less than 1 percent of the total construction cost.

A summary cost estimate for Wilson Hollow Reservoir at an elevation of 1,077 feet is shown in Table 5-74. Dam and reservoir costs total about $47 million, and relocations total another $540,000. Land, including 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 per acre-foot ($2.82 per 1,000 gallons).

### *5.16.3*
### *Environmental Considerations*

Wilson Hollow Reservoir is not located on or immediately upstream of any ecologically significant stream segments as recommended by the Texas Parks and Wildlife Department (TPWD, 1999). The reservoir will inundate 333 acres of land. Table 5-75 and Figure 5-112 summarize existing landcover for the Wilson Hollow Reservoir site as determined by the Texas Parks and Wildlife Department using methods described in Appendix C. Landcover is 96 percent upland deciduous forest, with one small homestead near the dam site.

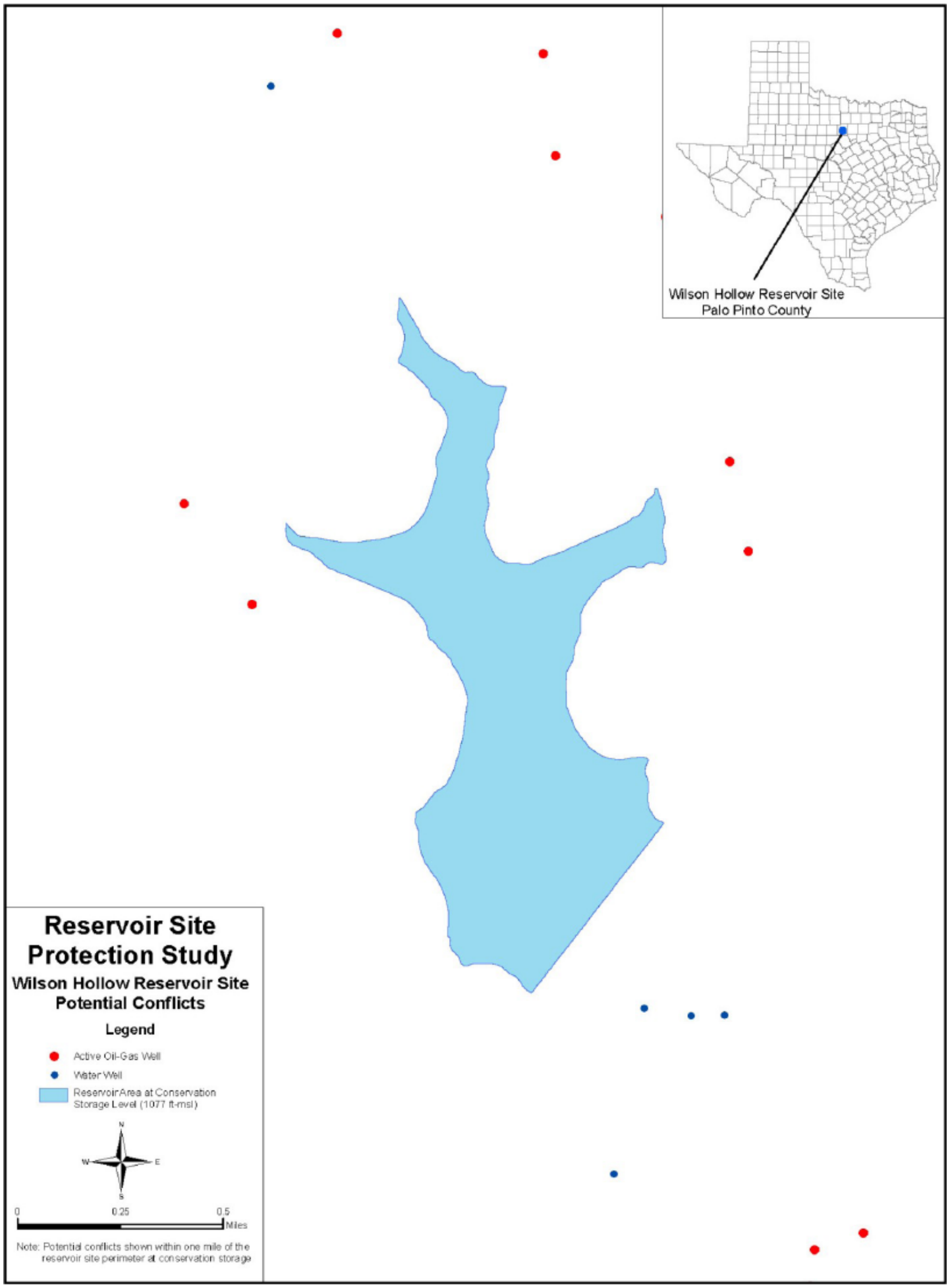


Figure 5-111. Potential major conflicts for Wilson Hollow Reservoir (map from Texas Natural Resouces Information System).
ft-msl=feet above mean sea level

Table 5-74. Cost estimate—Wilson Hollow Reservoir at elevation 1,077 feet.

| | Quantity | Unit | Unit Cost | 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 & foundation preparation | 1 | LS | $494,517 | $494,517 |
| Geocomposite liner/riprap | 1 | LS | $4,313,025 | $4,313,025 |
| Outlet works tower & 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) | 7,794 | 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 & mitigation | | | | $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** | | | | **$5,403,829** |
| **Firm Yield (acre-feet/per year)** | | | | **5,873** |
| **Unit Costs of Water ($/acre-foot)** | | | | **$920** |

Units: AC=Acre; CY=Cubic Yard; EA=Each; LB=Pound; LF=Linear Foot; LS=Lump Sum; SF=Square Foot; SY=Square Yard; MGD=Million Gallons per Day; cfs=cubic feet per second.

Table 5-75. Acreage and percent landcover for Wilson Hollow Reservoir.

| Landcover Classification | Acreage[a] | Percent |
|---|---|---|
| Upland deciduous forest | 330 | 96.0% |
| Urban/developed land | 14 | 4.0% |
| **Total** | **344** | **100.0%** |

[a]Acreage based on approximate GIS coverage rather than calculated elevation-area-capacity relationship.

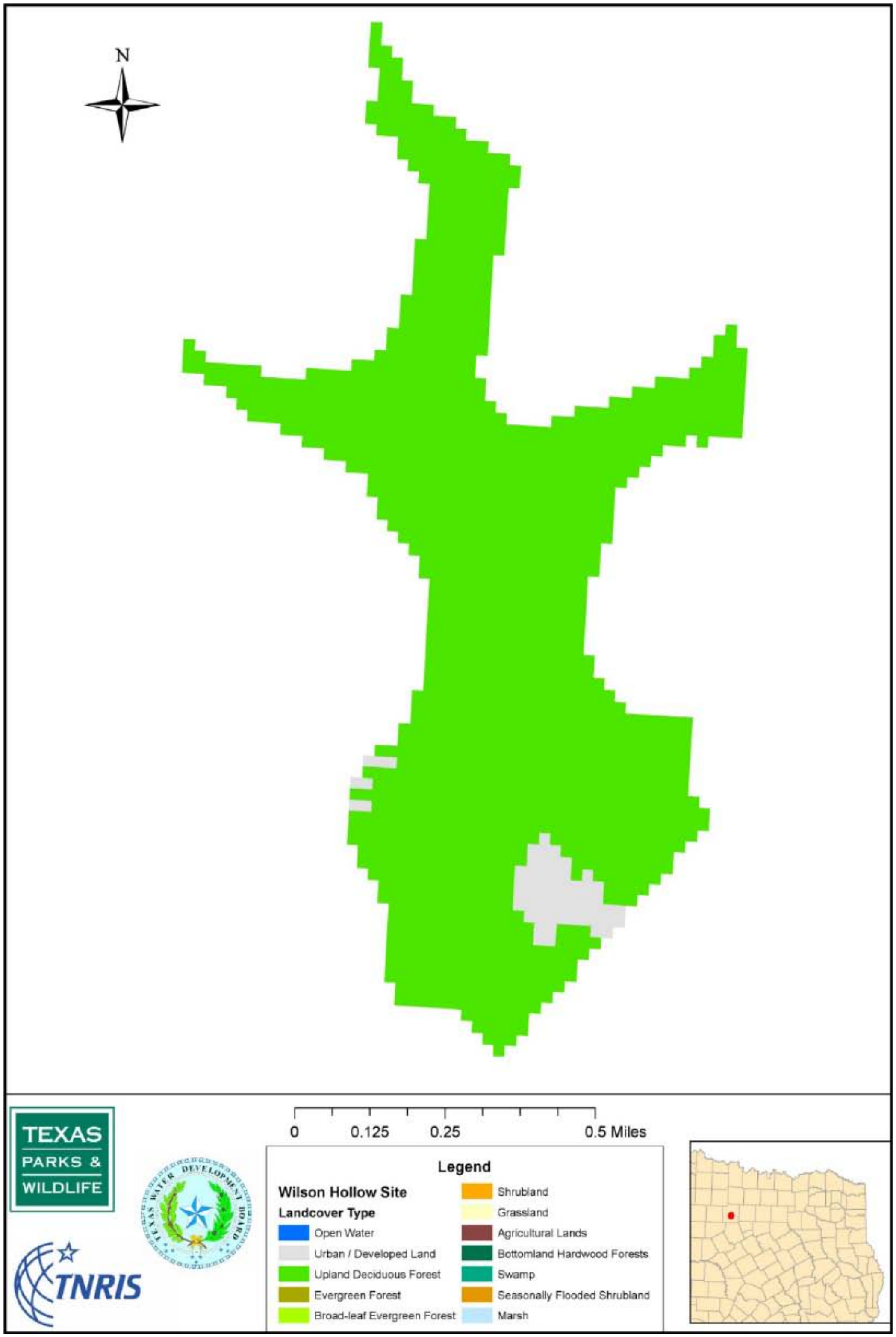


Figure 5-112. Existing landcover for Wilson Hollow Reservoir.

# 6 *Summary*

## 6.1 Comparison of Reservoir Sites Recommended for Protection

Using the technical evaluations of the 16 reservoirs included in this report, we summarized their information in light of the screening criteria (Table 6-1). Observations and comparisons are presented in the following paragraphs in the order of relative importance for the screening process.

### *6.1.1 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), Parkhouse I and II, and Wilson Hollow, are recommended water management strategies and/or are recommended for designation as unique reservoir sites in the 2007 State Water Plan (and subsequently designated by the legislature). The Parkhouse I and II reservoirs are identified as alternative water management strategies for several major water suppliers in the 2006 Region C Regional Water Plan. The Cuero II Reservoir site is not explicitly mentioned in the 2006 Region L Regional Water Plan though it might be considered additional storage, which is referenced as a water management strategy in need of further study and funding prior to implementation.

### *6.1.2 Firm Yield*

The largest firm yield or dependable supply during a drought of record (602,000 acre-feet per year) can be provided by the Marvin Nichols IA Reservoir site. However, depending upon the ultimate development of other sites recommended for protection in the Sulphur River Basin (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 acre-feet per year (Appendix A). The Brushy Creek Reservoir site provides the least firm yield (1,380 acre-feet per year) among the sites recommended for protection; however, it is the recommended water supply strategy for the City of Marlin.

### *6.1.3 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 will 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.

### *6.1.4 Special Considerations*

The Texas Commission on Environmental Quality or a predecessor regulatory agency has issued permits for reservoirs at the Brownsville Weir, Brushy Creek, and Palmetto Bend II sites. A water right application is pending 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.

Table 6-1. Comparison of reservoir sites recommended for protection.

| Reservoir Site | River Basin | Region | Recommended Water Management Strategy or Unique Reservoir Site (2007 SWP[a]) | Firm Yield (acft/yr[b]) | 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 | 41,437 | $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 | Inundating (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 |

[a]SWP=State Water Plan
[b]acft/yr=acre-feet per year

### *6.1.5*
### *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 and Wildlife Department. The Brownsville Weir, Fastrill, and Lower Bois d'Arc Creek sites will affect recommended segments by inundation, and 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.

### *6.1.6*
### *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 and Wildlife Service. The Fastrill, Lower Bois d'Arc Creek, and Marvin Nichols IA sites will affect such bottomland hardwood preservation sites by inundation, and the Bedias and Tehuacana sites will be located immediately upstream of potential preservation sites. Although the Parkhouse I and II sites will be located some distance upstream of a prioritized bottomland hardwood preservation site, detailed hydrological and biological studies will likely be required to assess potential reservoir impacts. Developing reservoir projects at all 16 of the sites recommended for protection in this study will significantly affect only two of 14 Priority 1 bottomland hardwood preservation sites in Texas. Since 1985, when the U.S. Fish and Wildlife Service published the prioritized bottomland hardwood preservation sites, no major reservoirs have been constructed that consequentially affect any of the 14 Priority 1 sites.

### *6.1.7*
### *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 by 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 near the reservoir sites. However, projected needs near the Cedar Ridge site could be underestimated because the recent drought in north central Texas appears to be worse than the drought of record captured by the water availability models; thus, the firm yield of the reservoirs in the vicinity might be lower than is currently being planned for.

### *6.1.8*
### *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, and the Cedar Ridge, Fastrill, and Marvin Nichols IA sites are the most distant.

### *6.1.9*
### *System Operations Opportunity*

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

### *6.1.10*
### *Water Quality Concerns*

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

#### *6.1.11*
#### *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.

## 6.2
## Reservoir Site Acquisition Program

Table 6-2 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. Acquiring all sites up to the conservation storage level will entail purchasing about 244,000 acres at an estimated capital cost of about $428 million for land only. This capital cost equates to an annual cost of about $28 million, assuming a 40-year debt service period and an annual interest rate of 6 percent.

Additional acreage for project facilities and land 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 sites studied. There will also be additional costs for title research, negotiations, land surveying, and legal proceedings.

As an important part of this reservoir site protection study, the Texas Parks and Wildlife Department 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 are included in Appendix C. Figure 6-1 summarizes landcover classification for the 16 potential reservoir sites up to their conservation storage levels. 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.

Table 6-2. Reservoir site acquisition costs.

| Reservoir | Conservation Pool Elevation (ft-msl[a]) | Conservation Pool Area (acres) | Land Unit Cost[b]($/ac[c]) | Conservation Pool Land Cost[b] ($) |
|---|---|---|---|---|
| Bedias | 210 | 10,000 | $3,288 | $32,880,000 |
| Brownsville Weir | 26 | 600 / 0[d] | $0[d] | $0[d] |
| Brushy Creek | 380.5 | 697 / 0[e] | $0[e] | $0[e] |
| 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[f] | 315 | 10,000 | $1,825 | $18,250,000 |
| Post[f] | 2,420 | 2,283 | $566 | $1,292,278 |
| Allens Creek[f] | 121 | 7,003 | $0[g] | $0[g] |
| **Grand Total** | | **263,452** | | **$447,173,657** |

[a]ft-msl= feet above mean sea level
[b]Land costs in 2005 dollars.
[c]$/ac=dollars per acre
[d]All of the inundated area associated with the Brownsville Weir and 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, purchasing this land will not be necessary.
[e]All of the land to be inundated by Brushy Creek Reservoir has been purchased by the City of Marlin.
[f]The Texas Legislature has designated this site as being of unique value for the construction of a reservoir.
[g]All of the land to be inundated by Allens Creek Reservoir has been jointly purchased by TWDB, the City of Houston, and the Brazos River Authority.

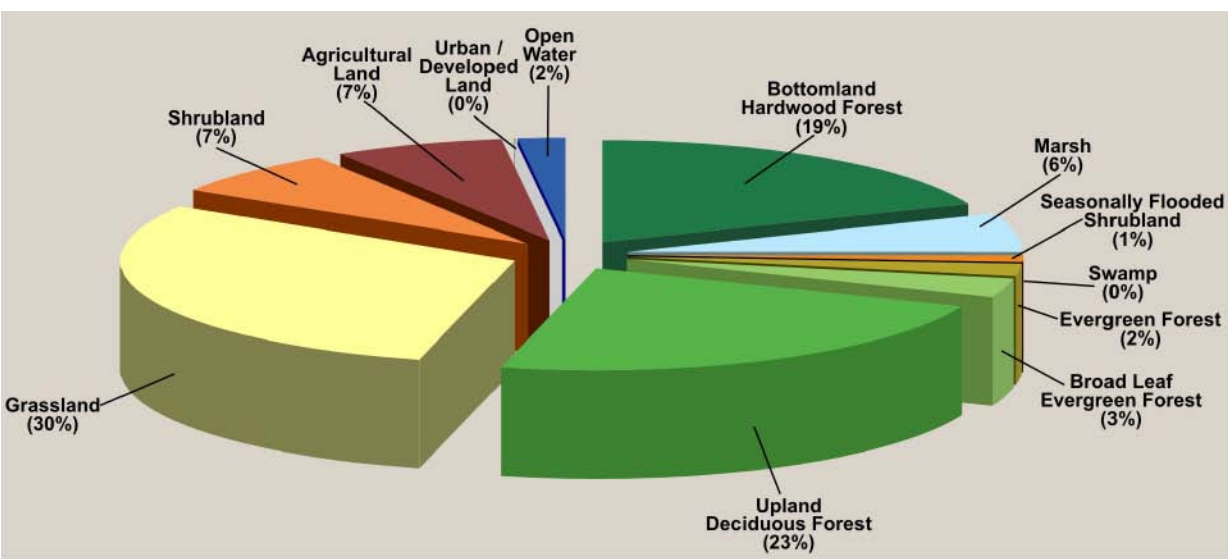


Figure 6-1. Landcover classification for 16 reservoir sites.

# 7 *Acknowledgments*

As authors of this report, we would like to offer our thanks to Kevin Ward, Bill Mullican, and Carolyn Brittin of the Texas Water Development Board (TWDB) for their committed leadership and technical support of this study. Further, we offer our appreciation for the significant technical contributions of key TWDB staff members (Richard Wade, Erik Obrian, Felicia Retiz, Christopher Jurgens, Gene Smith, and Diane Hyatt) and the Texas Parks and Wildlife Department (Kim Ludeke and Duane German) in the compilation of databases and application of advanced Geographic Information Systems techniques. Finally, we appreciate the editorial and formatting refinements of this report provided by Merry Klonower of TWDB and design assistance of JoAnn Estrada.

# 8 *References*


Bauer, J., Frye, R., Spain, B., 1991, A natural resource survey for proposed reservoir sites and selected stream segments in Texas: Texas Parks and Wildlife Department.

BOR (U.S. Bureau of Reclamation), 1965, Texas basins project.

BOR (U.S. Bureau of Reclamation), 2001, Lavaca River Basin, Colorado-Lavaca Coastal Basin, water availability model—final report: Texas Commission on Environmental Quality.

Brown and Root Services, Freese and Nichols, Espey-Padden and Crespo Consultants, 2000, Neches River Basin WAM—final report: Texas Commission on Environmental Quality.

Brown and Root, Inc., and Turner Collie and Braden, Inc., 2001, 2001 Region H Regional Water Plan: Region H Planning Group.

Burns and McDonnell, 1989, Bedias project investigation, Texas: U.S. Bureau of Reclamation Plan Formulation Working Document

Espey Huston and Associates, 1986, Water availability study for the Guadalupe and San Antonio river basins: San Antonio River Authority, Guadalupe-Blanco River Authority, and City of San Antonio.

Forrest and Cotton, Inc., 1961, Report on master plan for water supply reservoirs: Upper Neches River Municipal Water Authority.

Freese and Nichols, Alan Plummer Associates, Chiang Patel & Yerby, and Cooksey Communications, 2006a, 2006 Region C regional water plan: Region C Planning Group.

Freese and Nichols, Inc., 1958, Report on Ringgold Reservoir water supply project: Wichita Water Control and Improvement District Number One.

Freese and Nichols, Inc., 1981, Study of additional surface water supply, phase II: Wichita Falls, Texas and Texas Electric Service Company Engineering Report on Ringgold Reservoir.

Freese and Nichols, Inc., 1984, Report on New Bonham Reservoir: North Texas Municipal Water District and Red River Authority of Texas.

Freese and Nichols, Inc., 1990, Regional water supply plan: Tarrant Regional Water Control and Improvement District Number One.

Freese and Nichols, Inc., 1996, Preliminary studies of additional water supply: North Texas Municipal Water District.

Freese and Nichols, Inc., 2000, Sulphur River Basin Reservoir study summary report: North Texas Municipal Water District.

Freese and Nichols, Inc., 2006, Report supporting an application for a Texas water right for Lower Bois d'Arc Creek Reservoir: North Texas Municipal Water District.

Freese and Nichols, Inc., and Alan Plummer Associates, Inc., 1990, Regional water supply plan volume one: Tarrant County Water Control and Improvement District Number One in conjunction with the Texas Water Development Board.

Freese and Nichols, Inc., Alan Plummer Associates, Inc., Chiang, Patel, and Yerby, Inc., and Cooksey Communications, Inc., 2006, Region C Regional Water Plan: Region C Planning Group

HDR (HDR Engineering, Inc.), 1986, Yield studies of Lake Palo Pinto and Turkey Peak reservoir site: Palo Pinto Municipal Water District.

HDR (HDR Engineering, Inc.), 1991, Regional water planning study cost update for Palmetto Bend Stage 2 and yield enhancement alternative for Lake Texana and Palmetto Bend Stage 2: Lavaca-Navidad River Authority.

HDR (HDR Engineering, Inc.), 2004, Evaluation of Breckenridge Reservoir (Cedar Ridge Site) and other water supply alternatives (Draft).

HDR (HDR Engineering, Inc.), 2005, Reconnaissance report for off-channel reservoir project: Palo Pinto County Municipal Water District No. 1.

HDR (HDR Engineering, Inc.), 2006a, Fastrill Reservoir—Preliminary yield and feasibility study: Upper Neches River Municipal Water Authority and City of Dallas.

HDR (HDR Engineering, Inc.), 2006b, Updates and enhancements to Lower Nueces River Basin Bay and Estuary model and Corpus Christi water supply model: City of Corpus Christi.

Naismith Engineering, Inc., 1999, Strategies to enhance water conservation in the Coastal Bend, Appendix 3.

Red River Compact Commission (Arkansas, Louisiana, Oklahoma, and Texas), 1979, Red River compact with supplemental interpretive comments of legal advisory committee.

TAMU (Texas A&M University), 2005, Rural land values in the southwest: Real estate center, available online at http://recenter.tamu.edu/data/datarl.htm.

TCEQ (Texas Commission on Environmental Quality), 2001, Agreed order amending the operational procedures and continuing an advisory council pertaining to special condition 5.B., Certificate of Adjudication No. 21-3214; Docket No. 2001-0230-WR, Held by City of Corpus Christi and others.

TCEQ (Texas Commission on Environmental Quality), 2006, Input files of the water availability models, http://www.tceq.state.tx.us/permitting/water_supply/water_rights/wam.html.

TNRCC (Texas Natural Resource Conservation Commission), 1994, Certificate of Adjudication No. 16-2095B.

TPWD (Texas Parks and Wildlife Department), 1999, Ecologically significant river and stream segments, http://www.tpwd.state.tx.us/landwater/water/environconcerns/water_issues/sigsegs.

TRA (Trinity River Authority of Texas), 2003, Trinity River Basin Master Plan—2003.

TWDB (Texas Water Development Board), 1966, A summary of the preliminary plan for proposed water resources development in the Guadalupe River Basin.

USDA (U.S. Department of Agriculture), 1984, Final watershed plan and environmental impact statement for the Big Creek watershed for Falls, Limestone, and McLennan counties.

USFWS (U.S. Fish and Wildlife Service), 1985, Texas bottomland hardwood preservation program, Albuquerque, New Mexico.

USFWS (U.S. Fish & Wildlife Service), 2005, North Neches River national wildlife refuge establishment proposal—Proposal, conceptual management plan, and land protection plan: National Wildlife Refuge System, Southwest Region, Albuquerque, New Mexico.

# 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.

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**Figure 1. Location Map**

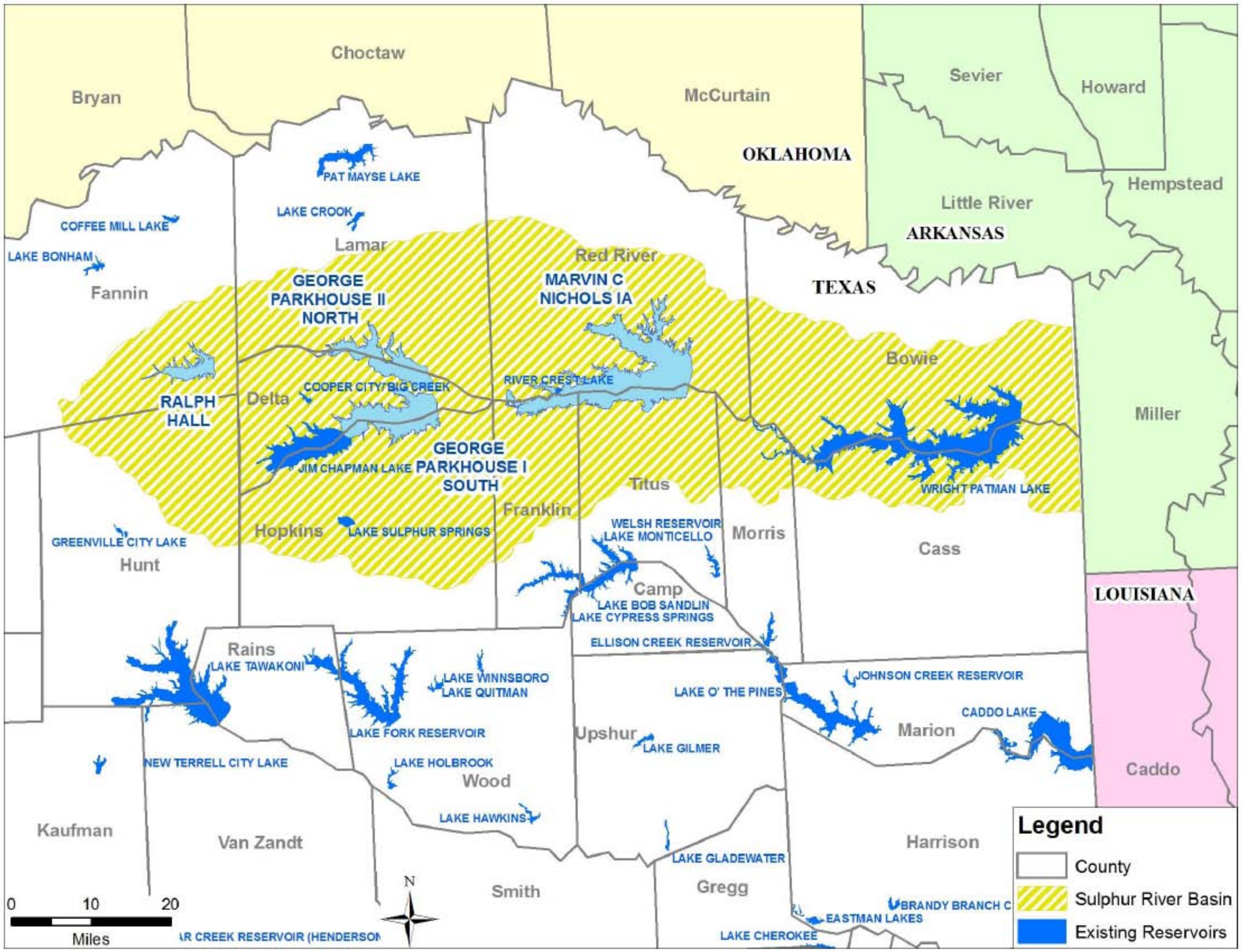

**Table 1**
**Proposed Reservoirs in Sulphur River Basin**

| 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 AcreF eet 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.

**References**

RJ Brandes Company. 1999. *Water Availability Modeling for the Sulphur River Basin.*

Texas Commission on Environmental Quality. 2006. Input File of the Water Availability Models. http://www.tceq.state.tx.us/permitting/water_supply/water_rights/wam.html

Texas Water Development Board. 2006. Evaporation and Precipitation Data for the State of Texas. Available at http://hyper20.twdb.state.tx.us/Evaporation/evap.html

## 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**

Natural Flow (Entered as primary control point)

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

Evaporation

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

**4- Marvin Nichols IA**

Natural Flow (Entered as primary control point)

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

Evaporation

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

# ARCHEOLOGICAL AND CULTURAL SITES RELATING TO RESERVOIR SITE ACQUISITION AND DEVELOPMENT

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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 potentially 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. Judicious 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 archeological 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.

**REFERENCES CITED:**

Collins, Michael B. and C. Britt Bousman
1993 Historic Context: Quaternary Environments and Archeology in Northeastern Texas. In: Nancy A. Kenmotsu and Timothy K. Perttula, *Archeology in the Eastern Planning Region, Texas: A Planning Document,* Section 2.2. Cultural Resources Reports, Number 3. Austin, Texas: Texas Historical Commission, Department of Antiquities Protection.

Guy, Janice A.
1990 Previous Archeological Investigations. In: Dee Ann Story, Janice A. Guy, Barbara A. Burnett, Martha Doty Freeman, Jerome C. Rose, D. Gentry Steele, Ben W. Olive, and Karl J. Reinhard, *The Archeology and Bioarcheology of the Gulf Coast Plain,* volume 1, Chapter 3. Research Series, Number 38. Fayetteville: Arkansas Archeological Survey.

Kenmotsu, Nancy A., and Timothy K. Pertttula
1993 *Archeology in the Eastern Planning Region, Texas: A Planning Document*. Cultural Resources Reports, Number 3. Austin, Texas: Texas Historical Commission, Department of Antiquities Protection.

Mercado-Allinger, Patricia A., Nancy A. Kenmotsu, and Timothy K. Perttula
1996 *Archeology in the Central and Southern Planning Region, Texas: A Planning Document.* Cultural Resources Reports, Number 7, and Office of the State Archeologist, Special Reports, Number 35. Austin, Texas: Texas Historical Commission, Department of Antiquities Protection.

Owens, J. D., T. Myers, C.D. Frederick, R. Clark, A. Peyton, and A.E. Butman
in preparation *Interim Report: Phase Ia Cultural Resource Inventory Survey, Lake Columbia Water Supply Project, Cherokee and Smith Counties, Texas*. Austin, Texas: Horizon Environmental Services, Inc. (Manuscript in possession of Texas Water Development Board)

Parsons, Mark, Martha Doty Freeman, David Shannabrook, and Brian Keeley
1992 Cultural Resources of the Proposed Lake Gilmer Project, Upshur County, Texas. Report Submitted to the U. S. Army Corps of Engineers for Job # 910055. Austin, Texas: Horizon Environmental Services, Inc.

Pertttula, Timothy K., and Nancy A. Kenmotsu
1993 Introduction. In: Nancy A. Kenmotsu and Timothy K. Perttula, *Archeology in the Eastern Planning Region, Texas: A Planning Document,* Section 2.1. Cultural Resources Reports, Number 3. Austin, Texas: Texas Historical Commission, Department of Antiquities Protection.

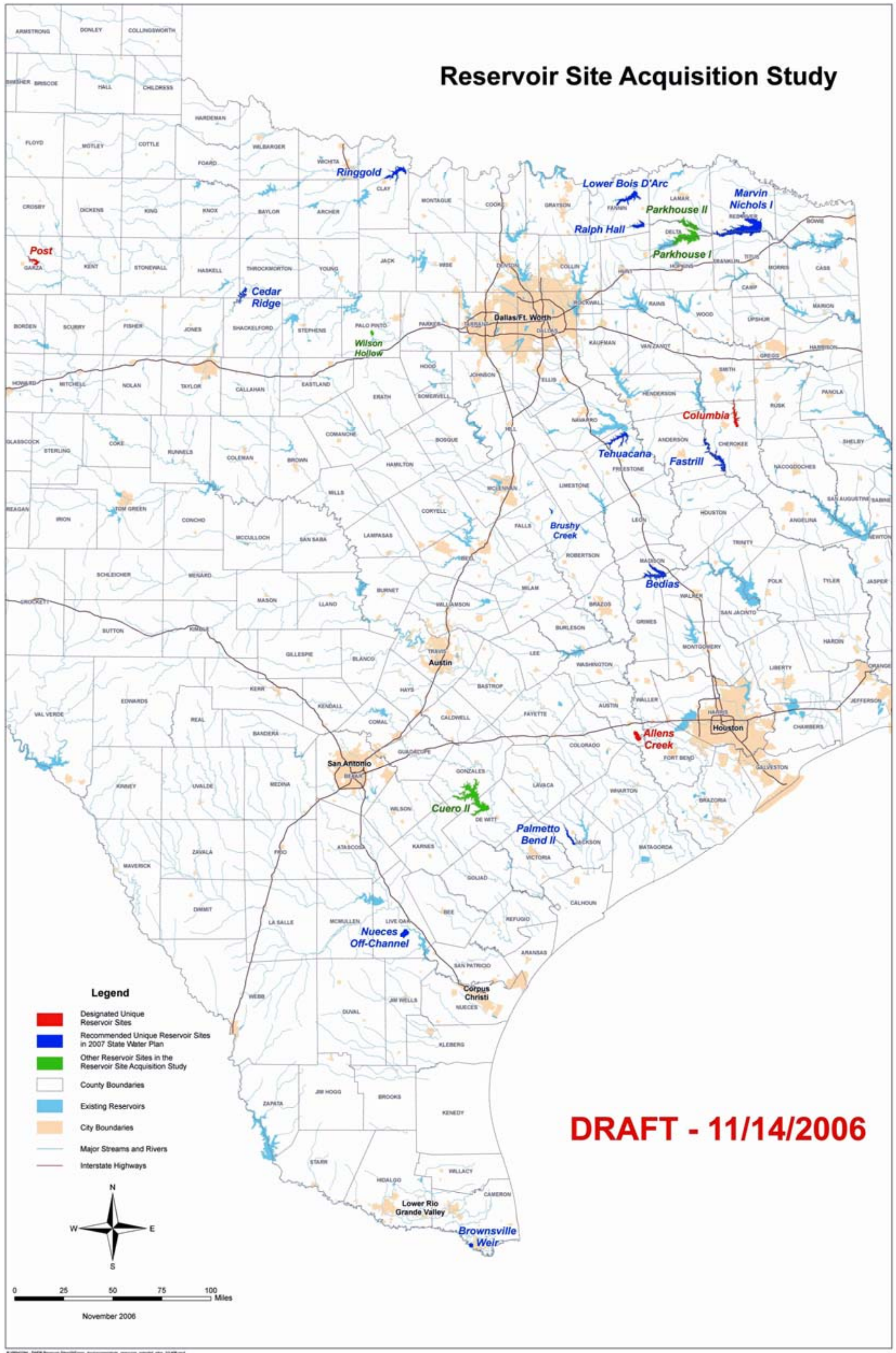


**Figure 1: Location of Proposed Reservoir Sites Considered in the Current Study.**

**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)

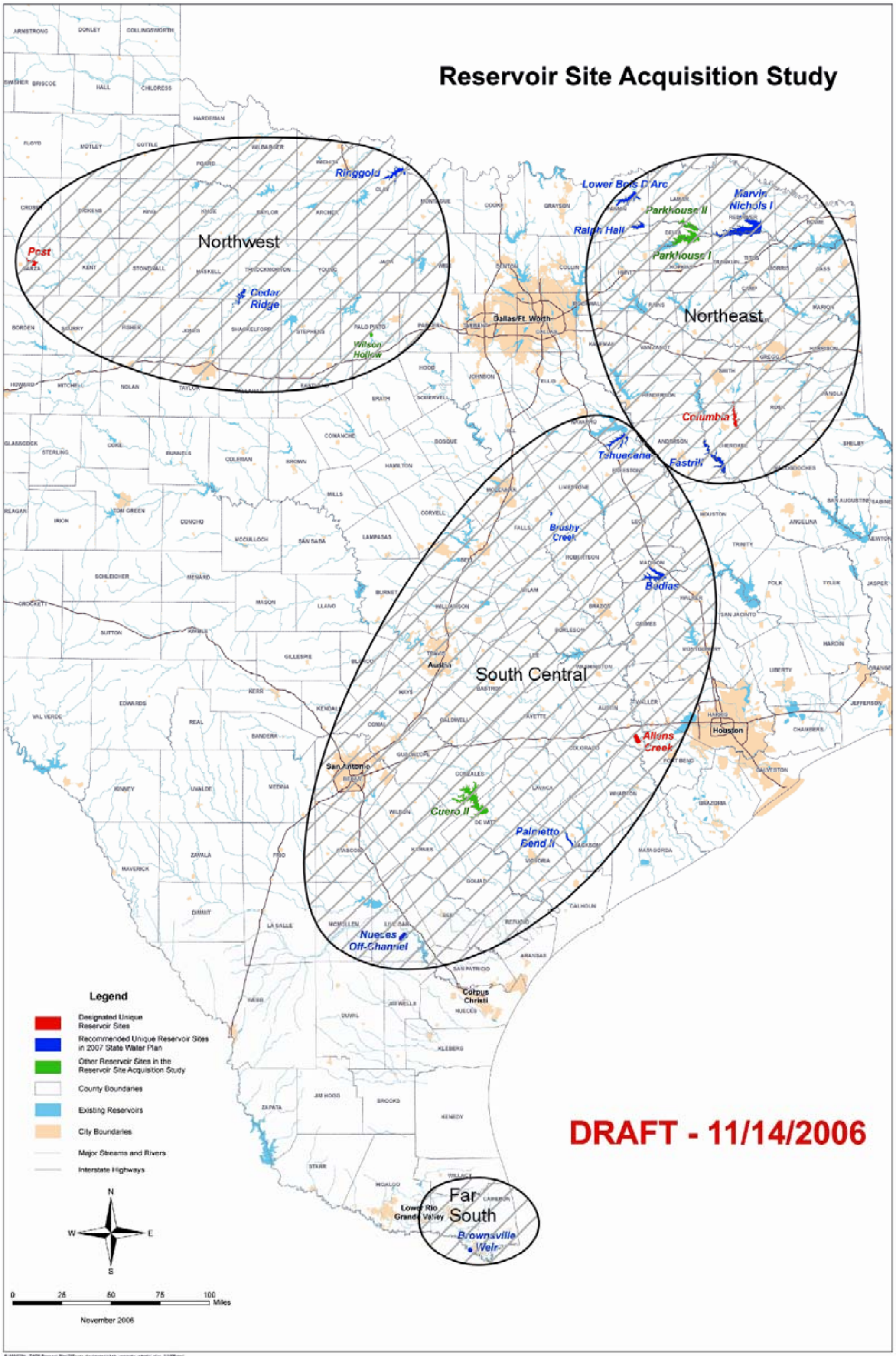


**Figure 2: Location of Regional Groups Used in Study, Aggregated on the Basis of Physiography and Characteristics of Historic Properties.**

**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 |

| 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** | |

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# 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.

[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

## 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.*

February 2007

# 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 | 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 |

## 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.*

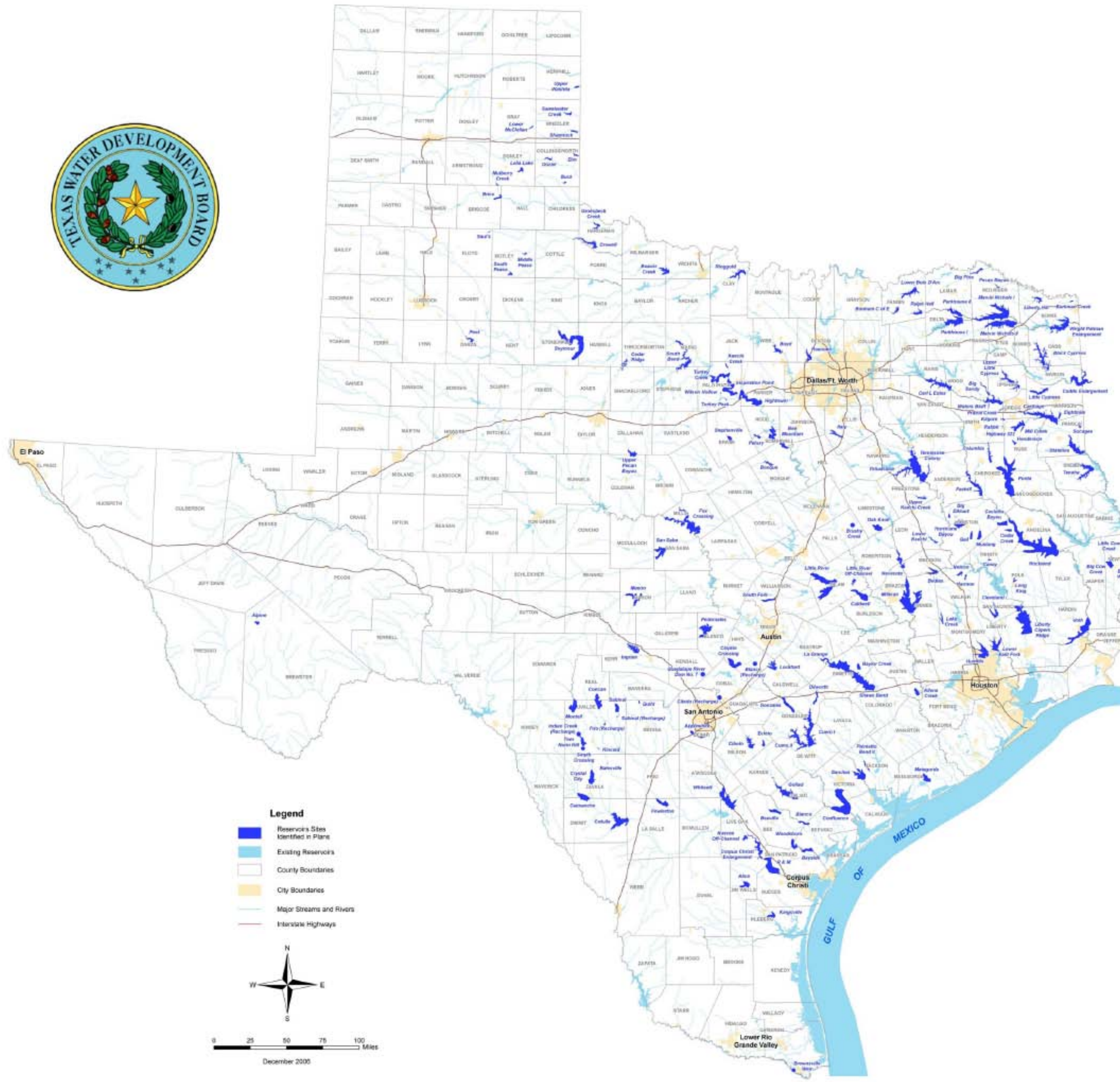


Exhibit 1. Reservoir sites identified in plans.

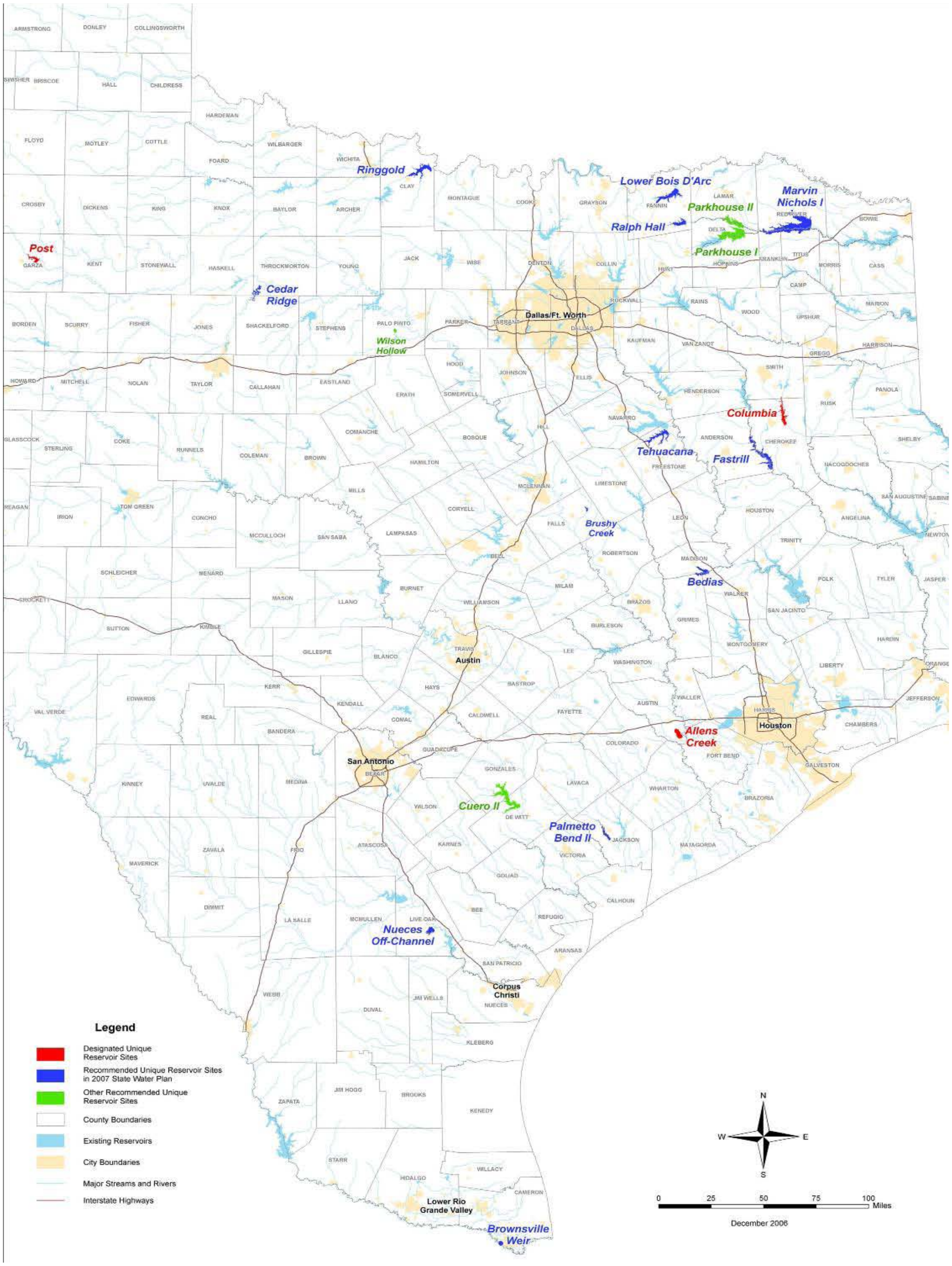


Exhibit 2. Unique reservoir sites.