# FLOOD MITIGATION STUDY

## Canyon, Randall County, Texas



TEXAS WATER DEVELOPMENT BOARD

US Army Corps
of Engineers®
Tulsa District

MAY 2011

city of
CANYON
TEXAS

1004831053_Final Report

# FLOOD MITIGATION STUDY

## Canyon, Randall County, Texas

US Army Corps of Engineers
Tulsa District

MAY 2011

## TABLE OF CONTENTS

# City of Canyon and Randall County, Texas
# Watershed Drainage Study

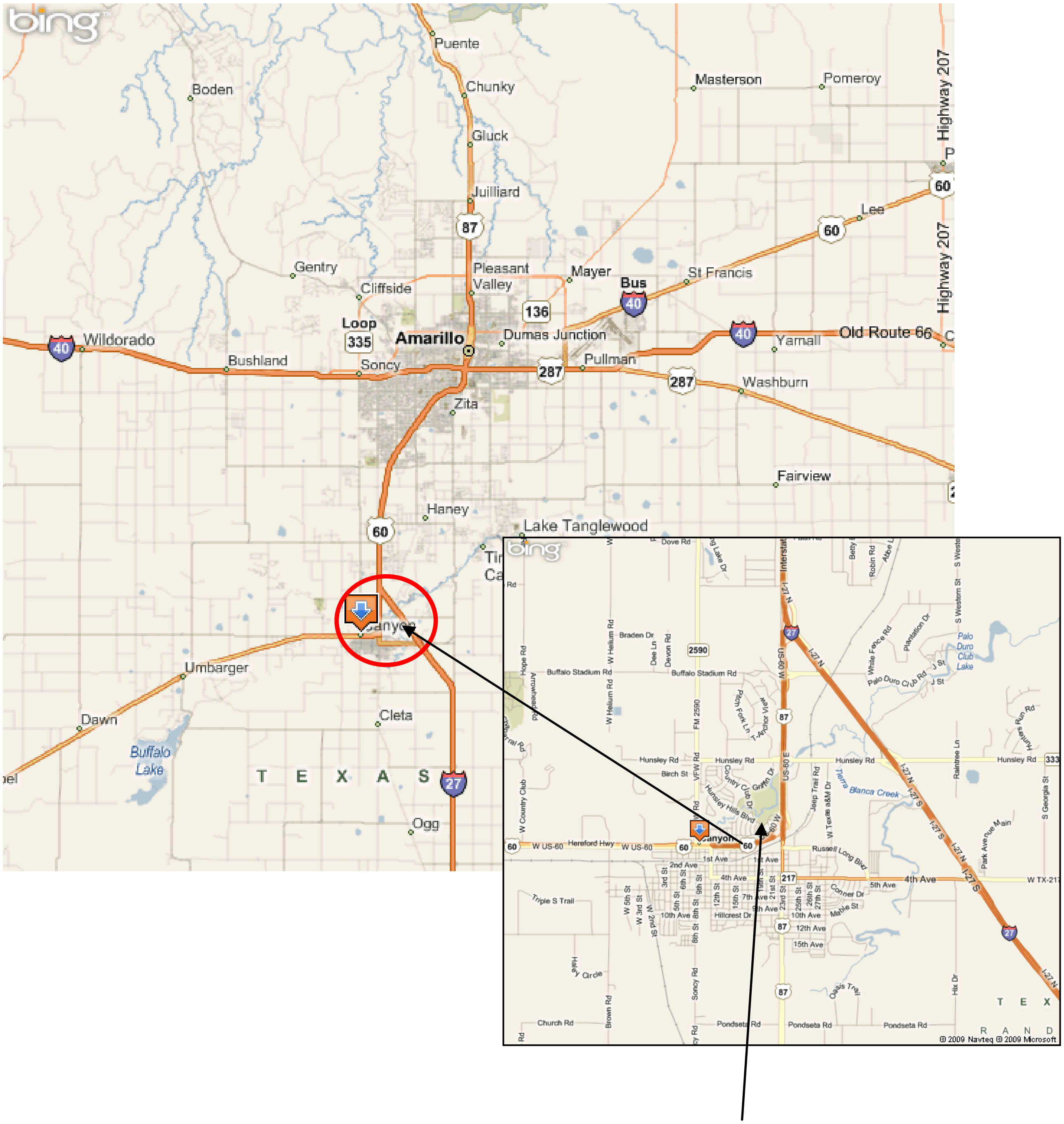
## I. PURPOSE OF STUDY

The City of Canyon, Randall County, Texas, and local citizen groups have requested an investigation into correcting flooding problems. The main focus area was on the Canyon City Golf Course area surrounded by homes. Palo Duro Creek runs through this area which is the source of historical flooding and standing stagnant water. The local residents are interested in recommended methods of reducing flood hazards as well as reducing or eliminating standing water in the Palo Duro Creek bed.

This watershed drainage study report was prepared for the City of Canyon and Randall County Texas, by the U.S. Army Corps of Engineers, Tulsa District. The purpose of the watershed drainage study is to develop detailed hydrologic and hydraulic information, flood boundary maps, and evaluate alternative flood mitigation measures for the City of Canyon and Randall County Texas. The study area is shown on vicinity map Figure 1.

This study contains hydrologic and hydraulic analysis and specific flood mitigation planning recommendations for these watersheds. Included in this report are existing and modified flood boundary maps with mitigation options specific to the watershed. Streams evaluated in this study include Palo Duro Creek, Tierra Blanca Creek, Spring Draw Creek and the Prairie Dog Town Fork of the Red River.

To establish a basis for flood mitigation studies a hydrologic and hydraulic analysis was performed reflecting current watershed conditions and current survey data. All models used are current as of the date of this report. All computations and support files will be furnished to the City of Canyon and maintained in U.S. Army Corps of Engineers files for at least five years.




Canyon Golf Course

**Figure 1 Vicinity Map**

## II. AUTHORITY

Section 206 of the Flood Control Act of 1960 authorizes the U. S. Army Corps of Engineers to use its technical expertise to provide guidance in floodplain management matters to all private, local, State, and Federal entities. The objective is to support comprehensive floodplain management planning. Section 202 of the Water Resources Development Act of 1999 authorizes the U. S. Army Corps of Engineers to accept funds for recovering the cost of providing such services. A Letter of Agreement (LOA) was prepared and signed by the City of Canyon and Tulsa District U.S. Army Corps of Engineers (USACE). That LOA included a Scope of Work and cost estimate for development of this Flood Mitigation Study.

The Texas Water Development Board (TWDB) provided 50 percent of the funding provided to the City of Canyon. That was from a Flood Protection Planning Grant through the TWDB's Research and Planning Fund. The other 50 percent was funded by the City of Canyon with a portion also provided by Randall County, Texas.

The City of Canyon and Randall County, Texas, contracted with the Tulsa District U.S. Army Corps of Engineers to evaluate the floodplains within the city and adjacent areas in the county under existing conditions and make recommendations for mitigation alternatives that would reduce the frequency and depth of flooding. These alternatives would include structural, non structural and policy changes for both the city and the county.

The city and county also have requested studies under Section 205 of the 1948 Flood Control Act as amended. That authority for flood risk reduction has been initiated but federal funding has not been obtained. This study under Section 206 will provide extensive data that can be used to reduce study costs for a future potential Section 205 study. That type study would determine federal interest and select the most cost effective solution. It would require cost sharing from a local sponsor such as the City of Canyon to prepare detailed design and construction. Some other available USACE authorities allow ecosystem restoration alone or in conjunction with flood risk reduction.

## III. COORDINATION

This study effort was coordinated with the City of Canyon, Randall County, Texas Water Development Board and others as well as within the Corps of Engineers. As part of the LOA three public meetings were held at the City of Canyon. The Corps of Engineers as the contractor presented an overview to initiate the study and to solicit input from local stakeholders on August 19, 2008. An interim public meeting was held on May 19, 2009, about halfway through the study efforts. This meeting presented the status and preliminary findings of flood issues. The final public meeting was held at the City of Canyon on December 13, 2010, to present recommendations and options for flood risk reduction. All public meetings had active discussions from attendees who have experienced flooding and /or had concerns of flooding issues. Participants understood the available services from all entities on flood risk reduction, environmental issues etc. Comments on the draft report were made by the TWDB and City of Canyon. Those comments and responses are included in the Executive Summary.

## IV. PROBLEM IDENTIFICATION

The City of Canyon and Randall County Unincorporated areas have experienced severe flooding in various locations with the most concentrated being residential areas around the Canyon City Golf Course in North Canyon. Palo Duro Creek has a drainage area of 193 square miles all of which flows through the Canyon City Golf Course. The existing channel would convey only a one to two year frequency flood event. This area has had multiple floods with significant property damage and loss of life due to flooding. A flood in 1978 killed 10 people and caused 10 million dollars in damages. In 1951 five people lost their lives in a major flood in this area. The existing Canyon City Golf Course channel also has a severe water quality problem with standing water in Palo Duro Creek. A major contributor to this problem is an abundance of cattle feed lots in the watershed.

Other areas in Randall County also have experienced major flooding. Several developments downstream from Canyon exist around various lakes. Lake Tanglewood and Palo Duro Club Lake have also had historic flooding issues. Tierra Blanca Creek is south of the City of Canyon and effects some city park land. Most of that watershed is scattered rural development with wide open spaces. There is a potential for some new development in the adjacent city area. Floodplain data from this study should be used to insure that new structures are above the regulatory flood elevation. The area where most new development is occurring is Spring Creek on the north side of the City of Canyon. There are a few small lakes in the watershed where development is occurring. Although new development is not in flood prone areas, new urbanization increases the flow downstream. It is highly recommended that local communities adopt measures to require retention or other measures to contain increased storm water runoff from new construction.

The Canyon City Golf Course is generally within the Federal Emergency Management Agency (FEMA) Zone AE floodplain and floodway of Palo Duro Creek. Many structures surrounding that golf course are also within the floodplain boundary. The current FEMA Flood Insurance Rate Maps for Randall County and incorporated communities (Reference 1) were revised while this study was underway. Those revised maps were based on a hydrologic study for the City of Canyon done in 1991 (Reference 2). Since that study additional development has occurred in Canyon and the surrounding area due to the proximity to Amarillo. The previous FEMA Flood Insurance Study (FIS) for the unincorporated areas in Randall County was published in 1982 (Reference 3). Studies for the Village of Lake Tanglewood and Timbercreek Canyon were published in 1981 and 1985 respectively (Reference 4 &5). The Canyon City Golf Course area and the adjoining subdivisions are within the corporate limits of the City of Canyon. Other areas in the surrounding County including Lake Tanglewood and Timbercreek Canyon were remapped during this study. The revised mapping will be evaluated to determine if the FEMA Flood Insurance Rate Maps need to be revised.

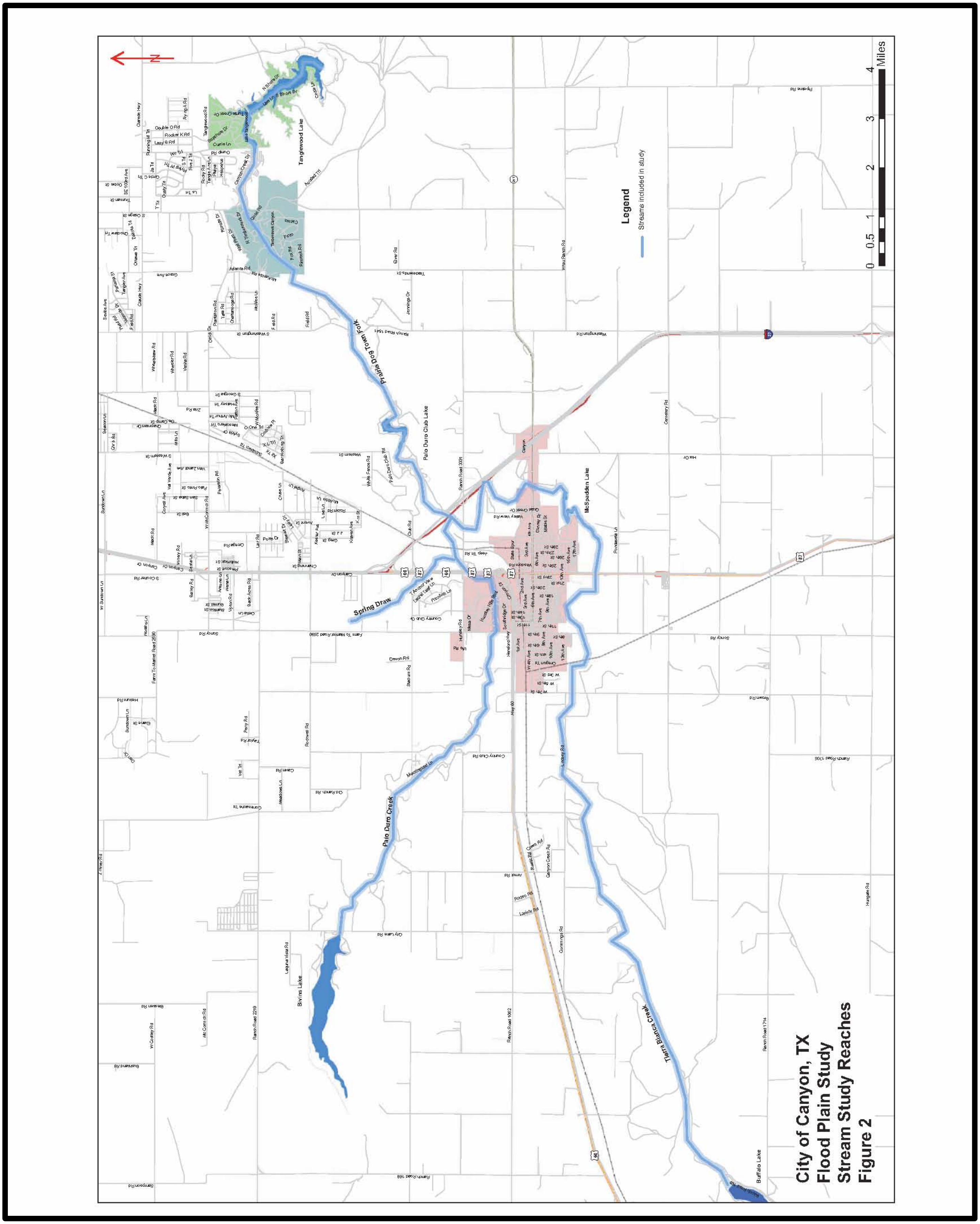
This report contains updated hydrology and hydraulic modeling for Palo Duro Creek, Tierra Blanca Creek, Prairie Dog Town Fork of the Red River and Spring Creek Draw. The stream study reaches are shown in Figure 2.

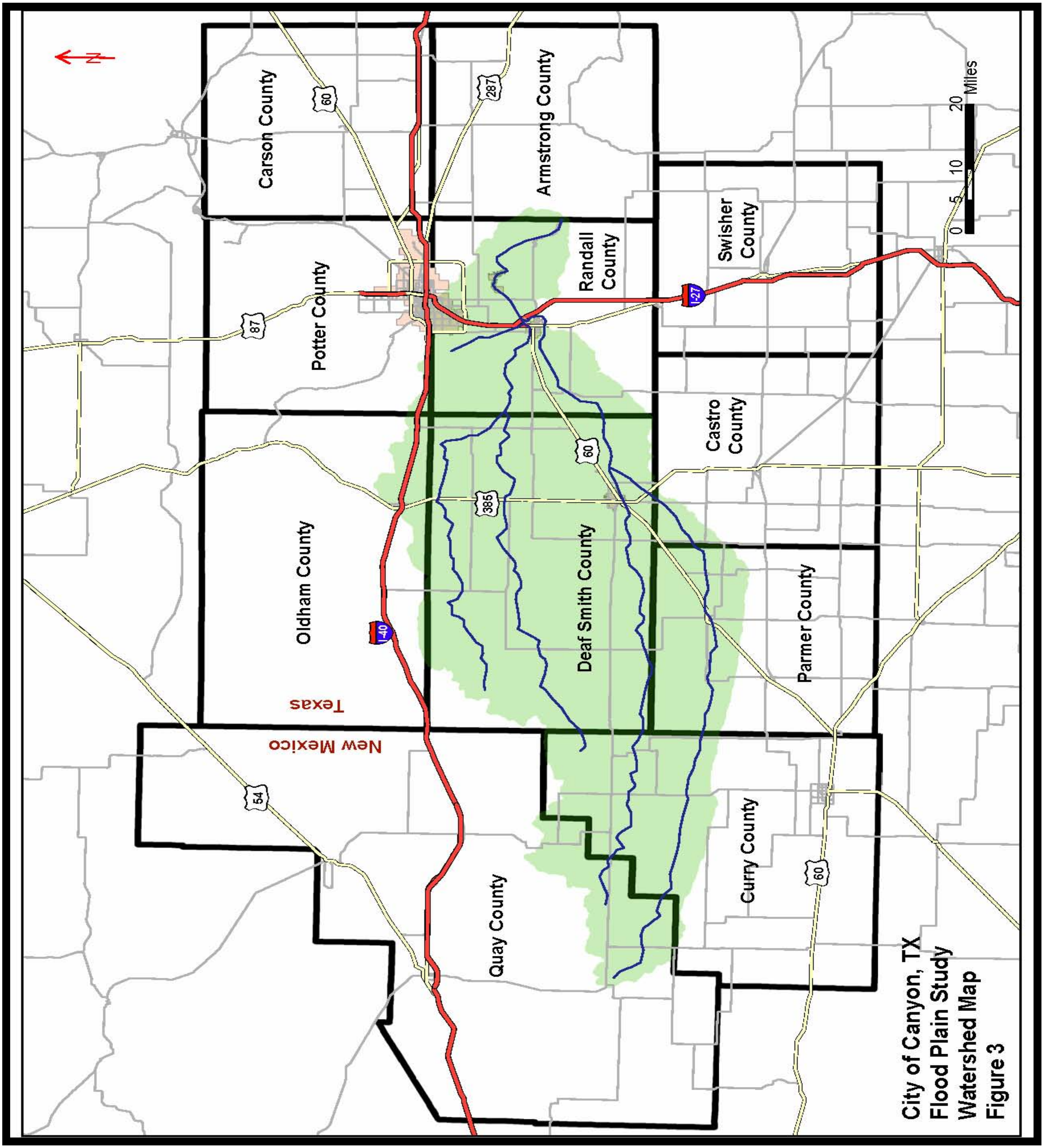
## V. STUDY AREA DESCRIPTION

The City of Canyon, Texas is located approximately 15 miles south of Amarillo, Texas. Canyon and Randall County lie in the drainage basin of the Prairie Dog Town Fork of the Red River. That basin consists of three creeks that merge on the east side of the city to form this river. They are Tierra Blanca on the south, Palo Duro Creek in the center and Spring Draw on the north. The drainage basin for this watershed is unusual due to the numerous playas throughout which effect the amount of contributing drainage to the creeks. Those larger playas store water and are mapped by FEMA as flood hazard areas. The contributing drainage area is normally confined to the channels and creates a very long and narrow basin beginning in eastern New Mexico and flowing eastward through Randall County. Figure 3 shows the watershed basin of the study area. Details such as drainage areas etc. are contained in the Hydrologic and Hydraulics sections of this report.

Spring Draw Creek is a smaller watershed that drains from the north into Palo Duro Creek near highway 87. This is a rapidly developing watershed due to its proximity to Amarillo.

Several large reservoirs are located in the study watershed. They are described in detail in the hydrology section of this report.


City of Canyon, TX
Flood Plain Study
Stream Study Reaches
Figure 2
Legend
Streams included in study
Miles
0 0.5 1 2 3 4
Prairie Dog Town Fork
Palo Duro Creek
Tierra Blanca Creek
Spring Draw
Tanglewood Lake
Palo Duro Club Lake
McSpadden Lake
Bivins Lake
Buffalo Lake


City of Canyon, TX
Flood Plain Study
Watershed Map
Figure 3
Carson County
Armstrong County
Potter County
Randall County
Swisher County
Oldham County
Deaf Smith County
Castro County
Parmer County
Quay County
Curry County
Texas
New Mexico
60
287
87
385
54
I-40
I-27
0
5
10
20
Miles

# VI. TECHNICAL PROJECT BACKGROUND

## A. Topographic and Survey Data

The survey data used in the study is a compilation of several different surveys with differing levels of accuracy. The large background survey data that was used in the areas in the county are United States Geologic Survey (USGS) One Arc-Second Digital Elevation Model (DEM) data which is approximately a 30 meter resolution.

Merged into this data were surveys and topographic maps provided by the City of Canyon. The latest topography covered the entire city and has a two foot contour interval. That mapping was done in March 1998 (reference 6). Also merged into the survey data were the planned contours for the Wal-Mart Supercenter at the intersection of Highway 87 and Hunsley Road (also known as FM 3331). This survey was on a one foot contour interval and dated May 2003 (reference 7). The last three surveys merged into the DEM were areas of specific interest including the south side of the Hunsley Hills Unit 16 Second Amended Subdivision, the area filled between the Canyon City Golf Course and Highway 87 and the park in the southeast corner of the city. Supplemental field survey data was provided by the City of Canyon to better identify various residential development built after the most recent topographic mapping. All of these surveys and topographic maps were merged together to give the greatest accuracy possible within the city limits. The survey data and topography for this study is based on North American Vertical Datum 1988 (NAVD).

## B. Hydrologic Analysis

The hydrologic model was developed for the entire watershed from the furthest upstream point in New Mexico to the eastern edge of Randall County. The Corps of Engineers computer program HEC-HMS Version 3.1.1 (reference 8) and the HEC-1 Computer Program (reference 9) were used. The approach taken to develop the hydrologic model was to subdivide the basin, calculate the Snyder's Unit Hydrograph basin parameters, Calculate the Muskingum Routing parameters and then calibrate the model to two historic storms and the discharges published in the current Flood Insurance Study.

The basin including Palo Duro Creek, Tierra Blanca Creek, and Spring Draw Creek were subdivided based on existing flood control structures (lakes), creek junctions and points of interest. There are 19 sub-basins in the model along with eight reservoirs and 18 reaches. Figure 4 shows sub basins of the study area. Computer program Water Management System (WMS) Version 8.0 (reference 10) was used to delineate sub basins and compute basin and routing parameters. The contributing and non-contributing drainage area for each sub-basin was determined by whether or not there was a defined channel between the playa and the creek. Snyder's Unit Hydrograph and the Initial and Constant Loss Method methods were used in all the models. The basin parameters were calculated using the Tulsa District Rural Method (reference 11). A summary of the basin parameters is shown in Table 1.

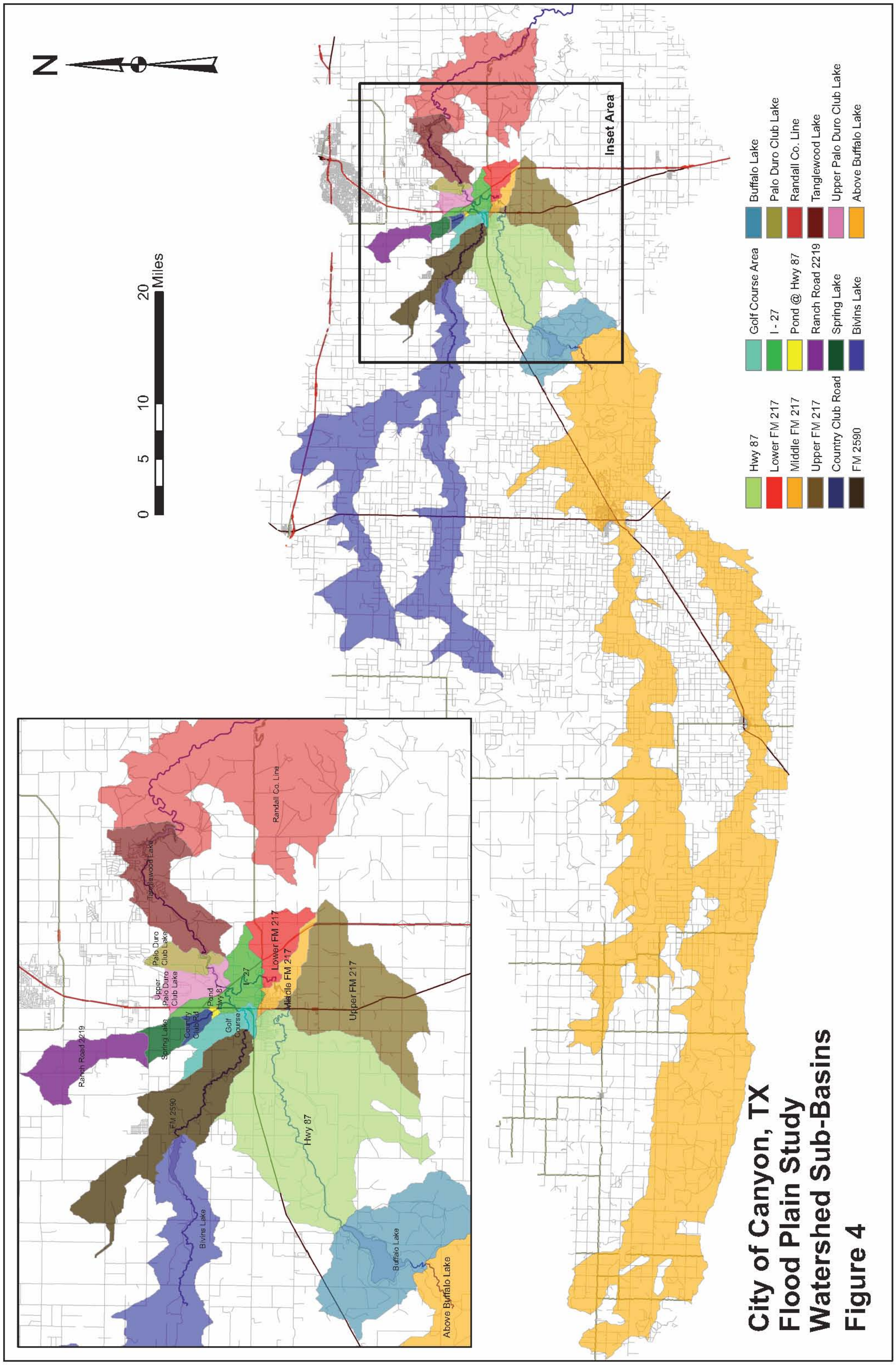

City of Canyon, TX
Flood Plain Study
Watershed Sub-Basins
Figure 4
N
0
5
10
20
Miles
Inset Area
Hwy 87
Lower FM 217
Middle FM 217
Upper FM 217
Country Club Road
FM 2590
Golf Course Area
I - 27
Pond @ Hwy 87
Ranch Road 2219
Spring Lake
Bivins Lake
Buffalo Lake
Palo Duro Club Lake
Randall Co. Line
Tanglewood Lake
Upper Palo Duro Club Lake
Above Buffalo Lake

Table 1 Basin Parameters

| Subbasin | Lag Time hr. | Peaking Coefficient | Initial Loss | Constant Loss | Impervious Area, % |
|---|---|---|---|---|---|
| Above Buffalo Lake | 35.62 | 0.75 | 0.08 | 0.10 | 0.0 |
| Buffalo Lake | 3.07 | 0.65 | 0.08 | 0.10 | 0.0 |
| Hwy 87 | 4.72 | 0.67 | 0.08 | 0.10 | 1 |
| Upper FM 217 | 3.05 | 0.65 | 0.08 | 0.10 | 1 |
| Middle FM 217 | 1.49 | 0.61 | 0.08 | 0.10 | 1 |
| Lower FM 217 | 2.25 | 0.63 | 0.08 | 0.10 | 1 |
| Bivins Lake | 15.09 | 0.74 | 0.08 | 0.10 | 0.0 |
| FM 2590 | 5.15 | 0.69 | 0.08 | 0.10 | 1 |
| Golf Course Area | 1.86 | 0.62 | 0.08 | 0.10 | 2 |
| Ranch Road 2219 | 3.10 | 0.65 | 0.08 | 0.10 | 1 |
| Spring Lake | 1.18 | 0.60 | 0.08 | 0.10 | 0.0 |
| Country Club Rd | 0.92 | 0.59 | 0.08 | 0.10 | 0.0 |
| Pond @ Hwy 87 | 0.29 | 0.54 | 0.08 | 0.10 | 0.0 |
| I-27 | 0.82 | 0.58 | 0.08 | 0.10 | 3 |
| Upper Palo Duro Club Lake | 2.10 | 0.63 | 0.08 | 0.10 | 1 |
| Palo Duro Club Lake | 1.10 | 0.6 | 0.08 | 0.10 | 2 |
| Tanglewood Lake | 3.51 | 0.66 | 0.08 | 0.10 | 1 |
| Randall Co. Line | 4.93 | 0.68 | 0.08 | 0.10 | 1 |
| Palo Duro Canyon | 8.30 | 0.7 | 0.08 | 0.10 | 0.0 |

All reaches in the models use the Muskingum Routing method.  The travel time through the reaches was estimated based on the slope of the channel.  Initially the travel times for the models were based on a range of 3.0 to 1.0 feet per second (fps) depending on the steepness of the channel. The Muskingum Routing parameters are shown in Table 2.

Table 2 Muskingum Routing Parameters

| Reach | Muskingum K | Muskingum X |
|---|---|---|
| **Palo Duro Creek** | | |
| Bivins Lake to FM 2590 | 4.59 | 0.2 |
| FM 2590 to Hwy 87& 60 | 1.2 | 0.1 |
| Hwy 87&60 to I-27 | 1.11 | 0.1 |
| **Tierra Blanca Creek** | | |
| Upper Buffalo Lake Reach | 3.69 | 0.2 |
| Buffalo Lake to Hwy 87 Basin | 12.99 | 0.2 |
| Hwy 87 to McSpadden | 1.13 | 0.1 |
| Lower FM 217 Reach | 2.00 | 0.05 |
| FM 217 to I-27 | 7.34 | 0.05 |
| **Spring Draw** | | |
| RR2219 to Hwy 87&60 | 0.97 | 0.1 |
| Spring Lake to Country Club Rd | 1.10 | 0.20 |
| Country Club Rd to Pond at Hwy 87 | 0.28 | 0.2 |
| Hwy 87 & 60 Northernmost I-27 (Pond @ Hwy 87 to I-27) | 1.15 | 0.2 |
| **Prairie Dog Town Fork Red River** | | |
| I-27 to Palo Duro Club Lake | 1.24 | 0.2 |
| Palo Duro Lake – Tanglewood | 6.67 | 0.2 |
| Tanglewood-Randall Co. Line | 13.20 | 0.2 |
| County Line to Palo Duro Canyon (below County Line) | 14.83 | 0.2 |

There are a total of eight reservoirs incorporated into the model including Buffalo Lake, Bivins Lake, McSpadden Lake, Palo Duro Club Lake and Tanglewood Lake. There are three small reservoirs in the model on Spring Draw identified as Spring Lake, the Reservoir at Country Club Road and the Pond at Highway 87.

Buffalo Lake also called Umbarger Dam is located on Tierra Blanca Creek and is represented in the model as a reservoir. The lake constructed in 1938–39, is owned and operated by the U.S. Fish and Wildlife Service (USFWS). The lake is currently operated as a dry lake after being modified in 1990 due to dam safety issues (reference 12&13). The top of the dam was lowered and faced with roller compacted concrete so that the entire embankment is used as a weir for large storms. The elevation-storage data was provided by the USFW Service. The discharge data was calculated for flow over the top of the embankment using the weir equation, Q = CLH^3/2. The coefficient was assumed to equal 3.0. The top of the embankment is 947 feet long with an elevation of 3654.3 feet

National Geodetic Vertical Datum (NGVD). Table 3 includes the summary of the elevation-storage-discharge information. The beginning elevations for the record floods in 1941and 1978 calibration models were 3633.2 feet NGVD and 3620.0 feet NGVD respectively. This information was gathered from reports which outlined historical flood data. The beginning elevation for the current study is 3614.5 feet NGVD, 0.5 feet above the lowest point in the natural streambed. Table 3 shows Elevation Storage Discharge relationships for Buffalo Lake.

Table 3 Buffalo Lake: Elevation-Storage-Discharge

| Elevation | Storage, ac-ft | Discharge, cfs |
|---|---|---|
| 3610.0 | 0 | 0 |
| 3625.0 | 2660 | 0 |
| 3635.0 | 13581 | 0 |
| 3643.0 | 30909 | 0 |
| 3650.0 | 56561 | 0 |
| 3654.0 | 74489 | 0 |
| 3654.3 | 75720 | 0 |
| 3656.0 | 82693 | 6297 |
| 3657.0 | 87429 | 12604 |
| 3658.0 | 95068 | 20220 |
| 3660.0 | 107681. | 38662 |
| 3662.0 | 121554 | 60703 |
| 3664.0 | 128824 | 85828 |
| 3665.0 | 139050 | 99437 |
| 3666.0 | 147671 | 113697 |
| 3669.0 | 165389 | 160121 |
| 3670.0 | 177248 | 176734 |
| 3671.0 | 186391 | 193886 |

Bivins Lake owned by the City of Amarillo is located 5 1/2 miles upstream from the City of Canyon on Palo Duro Creek. This dam built in 1926 was designed and constructed as a water supply reservoir for Amarillo. The lake currently remains empty. The dam is about 44 feet high and discharges through an uncontrolled earthen spillway. There is a 24 inch diameter underflow pipe. The uncontrolled spillway was adequate for water supply but inadequate to meet state dam safety requirements. The elevation-storage-discharge data shown in Table 4 was taken from a report written by Freese and Nichols dated August 2007 (reference 14). That report evaluated the dam with respect to current dam safety regulations. The beginning water elevation for all models was considered to be the lowest point in the original streambed. Because the lake is dry, water infiltrates into the underlying aquifer rather rapidly. One potential flood risk reduction alternative is to convert this unused water supply reservoir into a large regional detention facility.

Table 4 Bivins Lake: Elevation-Storage-Discharge

| Elevation | Storage, sc-ft. | Discharge, cfs |
|---|---|---|
| 3599.0 | 0 | 0 |
| 3600.0 | 0 | 0 |
| 3605.0 | 35 | 0 |
| 3610.0 | 190 | 0 |
| 3615.0 | 560 | 0 |
| 3620.0 | 1190 | 0 |
| 3625.0 | 2190 | 0 |
| 3630.0 | 3520 | 0 |
| 3634.7 | 5131 | 0 |
| 3635.0 | 5260 | 569 |
| 3636.4 | 5848 | 3224 |
| 3639.3 | 7066 | 15276 |
| 3640.0 | 7360 | 19433 |
| 3642.4 | 8488 | 33684 |
| 3644.0 | 92400 | 45421 |

McSpadden Lake, southeast of the City of Canyon, consists of an embankment approximately eight feet high. The elevation-storage-discharge data was developed using the USGS topographic survey. The discharge data was calculated assuming flow over the top of the embankment using the weir equation with C Coefficient = 3.0 and the length of dam equal to 300 feet. Table 5 has the summary of the elevation-storage-discharge data.

Table 5 McSpadden Lake: Elevation-Storage-Discharge

| Elevation | Storage, ac-ft. | Discharge, cfs |
|---|---|---|
| 3480.0 | 0 | 0 |
| 3486.0 | 77 | 0 |
| 3488.0 | 120 | 849 |
| 3490.0 | 213 | 10037 |
| 3495.0 | 473 | 58105 |
| 3500.0 | 2388 | 127952 |

Palo Duro Club Lake is downstream from the City of Canyon and is located on the Prairie Dog Town Fork of the Red River. Elevation-Storage-Discharge information was taken from the Phase I Inspection Report prepared by the Texas Water Development Board (TWDB) for the U.S. Army Corps of Engineers (USACE) dated August 1979 (reference 15). The beginning water elevation was the normal pool elevation 3455.0 feet NGVD.

Tanglewood Lake is the furthest downstream lake on the Prairie Dog Town Fork Red River. The elevation-storage-discharge information was taken from the Phase I Inspection Report prepared by the TWDB for the USACE dated August 1979 (reference 16). The beginning water elevation for all the models is the elevation of the normal pool 3373.0 feet NGVD.

The height of the dam for Spring Lake was estimated in the field using a clinometer. The USGS topographic map was used for determining the elevation of the top of dam and spillway. The storage for the lake was measured using the USGS DEM data and the discharge was calculated using the field measurements of the spillway and the weir formula with a coefficient of 3.0 and the length of the weir equal to 86 feet.

The storage data for the Spring Draw Reservoir at Country Club Road was developed using the USGS DEM data. The elevation of the dam was estimated using data gathered in the field and the city's topographic information. The discharge was calculated using the elevation and size of the culverts. The discharge over the embankment (roadway) was calculated using the weir equation with a coefficient of C = 3.0.

The storage data for the Pond at Highway 87 was calculated from the city's topographic map while the elevations of the top of the dam and the spillway were estimated from field data. The discharge was calculated using the elevation and size of the culverts. The discharges over the spillways (roadway) were calculated using the weir equation with a coefficient of 3.0.

Three separate hydrologic models were developed for each stream in this study. Two of the models were for calibration purposes and the third was for the frequency storm analysis.

The model was calibrated to two historic storms, June 5, 1941 and May 26, 1978. The rainfall recorded at existing gages during each storm was used to develop isohyetal lines for each storm. The gages used for the 1941 storm were Adrian, Bushland, Claude, Endee, Forrest, Friona, Hereford, Umbarger and Vega. The gages used in the 1978 storm were Canyon, Claude, Dimmit 2N, Dimmit 6E, Friona, Hereford, Umbarger and Vega. The area between each set of isohyetal lines within each sub-basin was measured and a weighted rainfall for the sub-basin calculated to provide for a mean-areal distribution of the measured rainfall. The only time series data for both storms was at the Amarillo gage and this data was used to provide the temporal distribution in the model. In the previous study the 100 year storm rainfall was reduced by 84.4% to produce flows of the adopted frequency curve. That reduction was also taken for the 1941 storm. The reduction was not taken for the 1978 storm due to the much larger amount of rainfall that fell much closer to the City of Canyon and less in the outlying sub-basins. The loss rates were estimated based on soils and frequent rainfall recorded in the area in the previous months. The loss rates were 0.08 inches initial and 0.10 inches constant for both storms.

The Muskingum routing parameters were adjusted during the calibration process and two lag times were inserted on Tierra Blanca Creek between Highway 87 and McSpadden Lake an area that is very wide, flat and marshy. The peak flows that the model was calibrated to were found in the reports on the lakes outlining historic storms including beginning lake elevations, water depths and estimated peak flows through the lakes. Table 6 has the summary of the historical data, the calculated model peak discharges and data from the previous FEMA Flood Insurance Studies.

The data for the 24 hour duration frequency storms came from National Weather Service Hydrology Technical Paper 35 (reference 17) and Technical Paper 40 (reference 18). The intensity position for the distribution of the rainfall is at 50 percent. Using the calibrated models, the peak discharges for all the sub-basins were calculated and entered into the hydraulic model.

All Hydrologic and Hydraulic models used are products of the USACE Hydrologic Engineering Center. Those models are standards of the Corps of Engineers as well as for most Architectural Engineering firms who work in water resources. No other models were considered for this study.

Table 6 Historic, FIS, and Study Model Hydrologic Data

| Year | Buffalo Lake | | | Palo Duro Club Lake | | Tanglewood Lake | Golf Course | Hwy 87 | Spring Draw | Upper FM217 |
|---|---|---|---|---|---|---|---|---|---|---|
| | Inflow | Q | Elevation | Above | Below | | | | | |
| X Sec. | 2999+72 | | | 1585+67 | | 1077+79 | 90+92 | 2124+71 | 50+08 | 2078+33 |
| **1978** | | | | | | | | | | |
| Historic | | | 3639.3 | 34000* | | 28300 | | | | |
| Model | 4662 | 0 | 3640 | 32553 | 32026 | 31426 | 6531 | 26407 | 4223 | 32370 |
| | | | | | | | | | | |
| **1941** | | | | | | | | | | |
| Historic | 11300* | 3583 | 3647.7 | 3890 | | | | | | |
| Model | 10582 | 3404 | 3648 | 3994 | 3959 | 3466 | 1210 | 3401 | 1119 | 3942 |
| | | | | | | | | | | |
| **500 Yr.** | | | | | | | | | | |
| Current FIS | | | | 58200 | 57250 | | 31000 | 38500 | 9950 | 38500 |
| Model | 53551 | 39411 | 3660 | 55869 | 54061 | 53499 | 28443 | 39291 | 2850 | 39284 |
| | | | | | | | | | | |
| **100 Yr.** | | | | | | | | | | |
| Current FIS | | | | 30200 | 29200 | | 17100 | 17150 | 6000 | 21700 |
| Model | 31570 | 13953 | 3657.2 | 30494 | 30135 | 29525 | 16946 | 16799 | 691 | 20873 |
| | | | | | | | | | | |
| **50Yr.** | | | | | | | | | | |
| Current FIS | | | | 22350 | 21700 | | 13350 | 11750 | 4700 | 17000 |
| Model | 24149 | 5369 | 3655.7 | 21091 | 20896 | 20560 | 12883 | 13606 | 660 | 16698 |
| | | | | | | | | | | |
| **10 Yr.** | | | | | | | | | | |
| Current FIS | | | | 9400 | 9100 | | 5900 | 5600 | 2400 | 8250 |
| Model | 15241 | 0 | 3651.0 | 11638 | 11431 | 11265 | 7570 | 8953 | 602 | 10916 |
| | | | | | | | | | | |

* Old USGS Stream Gage Site - Estimated Flow

## C. Hydraulic Analysis

The hydraulic model was developed using the Hydrologic Engineering Center Geographic River Analysis System (HEC GEO RAS) (reference 19) to define the channel alignment, elevations, banks and flow paths. HEC-RAS version 4.0 (reference 20) was used for the hydraulic analysis. Available topographic maps and subsidized field surveys were used to define the channel alignment, elevations, banks and flow paths. The bottom elevation of the channels was modified based on the USGS contours. The bridge and culvert data was gathered by field surveying the height, width and length on site. The lakes are represented with an inline structure in the HEC-RAS model. The embankment elevations and spillway configurations are as stated in the engineering reports for each structure. Channel roughness factors (Manning's "n" values) were chosen using engineering judgment based on field observations. Table 7 summarizes the Manning's 'n' values used in the hydraulic model. The watershed is in an arid region, thus most of the vegetation is located within the channel where the water is most prevalent. The vegetation in the overbank areas tended to be shorter and thinner.

The beginning water surface elevations are set at the normal pool for each structure.

Table 7 Manning's "n" Values

| Reach | Channel | Overbank |
|---|---|---|
| Tierra Blanca | 0.045 - 0.075 | 0.043 – 0.065 |
| Prairie Dog Town | 0.045 – 0.10 | 0.045 – 0.065 |
| Palo Duro – US & DS | 0.043 – 0.07 | 0.041 – 0.065 |
| Spring Draw | 0.045 – 0.10 | 0.043 – 0.07 |

Plates 1- 22 shows the water surface profiles for the existing conditions based on the 8 various frequency floods as noted. A number of different models were developed for various alternatives to determine flood elevation reduction for different frequency floods. For future evaluations, any other potential alternative can be evaluated by modifying the base hydraulic models from this report to determine extent of flood elevation reduction. Plates 23 – 56 show the water surface elevation profiles based on different flood risk reduction alternatives.

## D. Floodplain Mapping

Using the flood elevation profiles from the hydraulic analysis floodplain boundaries were drawn on the best available topographic maps. The floodplain boundary maps are included as Map Panels 1 – 11 that show existing conditions for Canyon and Randall County. Map Panel 12 shows flood plain areas with flood risk reduction alternatives for modification of Bivins Lake with channelization and upstream detention with channelization.

Hydrologic and Hydraulic Summary data such as electronic HEC- RAS models, Digital Mapping, etc are included as an exhibit to this report.

# VII. ALTERNATIVE MITIGATION MEASURES

Several flood risk reduction measures were analyzed to determine alternative solutions for Canyon, Randall County and surrounding areas. The following sections identify the alternatives in more detail. Some of these solutions would be potential USACE Section 205 Flood Risk Reduction options. Some other alternatives presented are measures that would best be completed by the City of Canyon or other local officials. These local drainage measures can be accomplished slowly over time as funds become available. Alternative measures include those summarized below:

- Modify Golf Course Pond Dam, Spillway and Channel
- Diversion Channel through the Golf Course
- Upstream Detention Ponds
- Bivins Lake Modification for Flood Control
- Upstream Detention Plus Diversion Channel
- Bivins Dam Rehabilitation with Diversion Channel
- Elevate Structures
- Acquire (Buy out/ Relocate) Structures in Floodplain
- Flood Walls Through the Golf Course Area for Isolated Groups of Structures
- Flood Warning

- Stream and Culvert Maintenance  Plus New Culverts or bridges
- Dry Floodproofing
- Wet Floodproofing
- Floodplain Regulation and Higher Standards
- Combination of Alternatives

## VIII. MODIFY GOLF COURSE POND  & SPILLWAY

Improving the hydraulic capacity of the existing channel through the Canyon City Golf Course can be done by removing the obstruction in the channel that is used for golf cart access on the eastern edge of the golf course and constructing a concrete spillway in the pond dam on the northeast corner of the golf course.  The golf cart access should be replaced with a bridge.  The concrete pond spillway was modeled as being 105 feet long and 10 feet wide at elevation 3490.0 feet NGVD.  These modifications will decrease the flooding from the small frequency storms.  The water surface elevation is lowered for the two year storm between Jynteewood and the pond by as much as 1.2 feet in some areas. The flood water surface elevation reduction varies through the study reach.  During the five year frequency storm the flood water surface elevation is reduced by as much 0.5 feet.  When approaching the 10 year storm this modification of the creek does not create a significant reduction in water surface elevations.  Removing the abandoned street upstream near Jynteewood and replacing the culverts and low water crossings in the upstream reach of the Canyon City Golf Course area do not significantly reduce flood elevations. Flood elevation profiles for this alternative are shown on Plate 23-24.

# IX. DIVERSION CHANNEL

This option provides for a vegetated diversion channel to be constructed in the area of the existing smaller diversion channel. This channel is 75 feet wide and begins upstream at station 15453, the approximate location where the existing diversion channel begins. The channel continues and intersects Palo Duro Creek immediately west of the pond in the northeast corner of the Canyon City Golf Course. Although the channel is modeled as a flat bottomed trapezoidal channel, it can be improved aesthetically by constructing a narrow meandering pilot channel in the bottom. A 75 foot wide diversion channel through Canyon City Golf Course would be most beneficial for the smaller frequency floods. This option would reduce the two to five year floods up to two feet. The 500-year flood would be lowered by 0.5 feet. This option is possibly more appealable for a local or FEMA mitigation plan. After further studies this may also be a potential plan for a U.S. Army Corps of Engineers local flood mitigation economic plan. The cost for this 75 foot wide 5-year channel is about 3 to 5 million dollars. A more detailed analysis of costs and benefits is recommended. Flood elevation profiles for this alternative are shown on Plates 25-31.

# X. UPSTREAM DETENTION PONDS

For this alternative two detention facilities were located on Palo Duro Creek upstream of the Canyon Golf Course. The proposed design was for off line detention that would capture high flows to reduce the peak flow through the developed area. A small permanent pool or “flow through” style detention structure may be appropriate for certain situations. Two areas for proposed offline detention structures have been identified upstream of the Canyon City Golf Course. Figure 5 shows locations for potential upstream detention structures. These detention ponds were modeled as dry structures and can be used for recreation areas such as soccer fields or parks during times of dry weather. One structure has an estimated surface area of 130 acres and the other 112 acres.

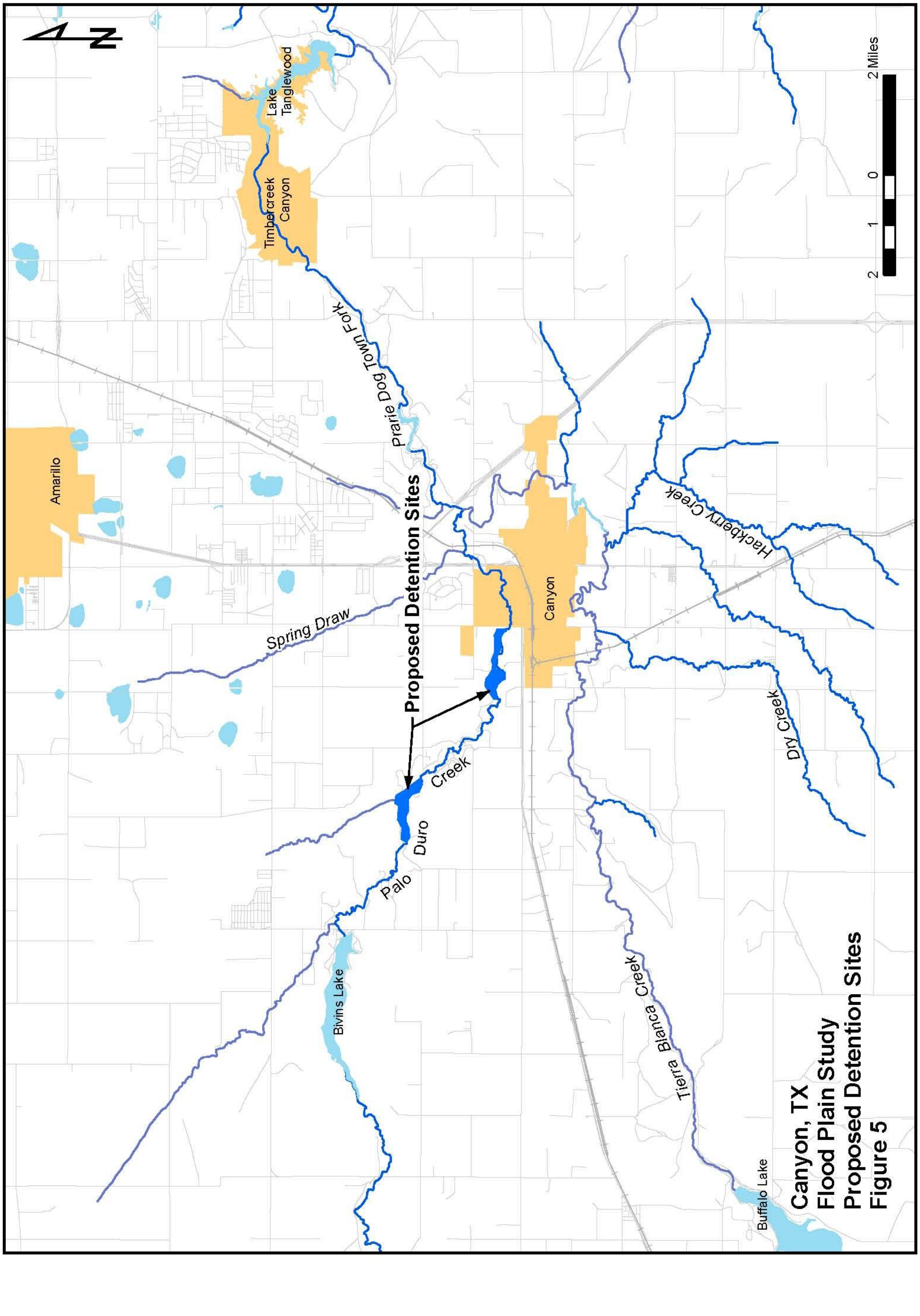
Proposed Detention Structure #1 is located between cross sections 30653 and 18098, immediately upstream from FM 2590. This structure has an estimated surface area of 130 acres. The creek is re-routed along the southern edge of the lower watershed bottom. It has two reinforced concrete culverts that outlet at station 18098, both two feet in diameter with an inlet elevation of 3496.2 feet NGVD and an outlet elevation of 3496.0 feet NGVD. The estimated storage volume of the structure is 3978 acre-feet. The floodwater is designed to flow into the structure when the water reaches elevation 3527 feet NGVD. The inflow weir is 350 feet long. The top of the embankment is 3530.5 feet NGVD.

Proposed Detention Structure #2 is located between cross sections 57579 and 48528. This area is upstream of the Canyon City Country Club where a tributary to Palo Duro Creek comes in from the north. Palo Duro Creek will have to be re-located along the southern edge of the canyon bottom and the tributary to the east edge. This structure has an estimated surface area of 112 acres and an estimated storage volume of 2744 acre-feet. This structure also has 2 reinforced concrete culverts for outlets, located at cross section 48528. The inlet elevation of the culverts is 3554.7 feet NGVD and the outlet is at 3554.4 feet NGVD. The inlet weir is at elevation 3575.5 feet NGVD and is 100 feet long. The top of the embankment is elevation 3579.0 feet NGVD. Constructing both of these structures would decrease the peak discharge during various frequency storms. Table 8 shows the percentage reduction in the peak flows for each frequency storm. Plates 32 – 36 show flood profiles with the detention alternative.

Through time as funds become available, additional detention facilities could be built. The cost to purchase land for detention sites may be costly initially, however the land could be donated or leased and the facilities would still be usable for multiple purposes. The construction of detention facilities would be highly recommended option to reduce the flood flows. The detention ponds could be used alone as well as combined with other methods to allow other mitigation measures to be more effective.

Table 8 Reduction in Peak Flows with Upstream Detention

| Storm Frequency | Percent Reduction in Peak Flows |
|---|---|
| 2 year | 0 % |
| 5 year | 2.5 % |
| 10 year | 15 % |
| 25 year | 20 % |
| 50 year | 23 % |
| 100 year | 27 % |
| 500 year | 4 % |




Canyon, TX
Flood Plain Study
Proposed Detention Sites
Figure 5

# XI. BIVINS LAKE MODIFICATION

This alternative is to modify Bivins Lake to provide flood storage above the City of Canyon and to operate essentially as a dry structure. Rehabilitation of Bivins Lake for flood storage would reduce the 100-year flood profile as much as two feet through the Canyon City Golf Course area. The plan would lower the 25-year flood elevation about one foot. Modification to Biven Dam is estimated to cost about 8 to 15 million dollars. This alternative would require significant coordinating with the City of Amarillo as lake owners and State of Texas regarding dam safety and water rights permitting. The costs could be significantly higher which may not support flood damage benefits. However, this option is viable for future evaluation with other benefits such as recreation or water supply. Additional studies are recommended with one alternative of leaving the dam and essentially a near empty pool to serve as upstream detention and ecosystem restoration.

This alternative requires raising the dam to at least elevation 3659 feet NGVD plus freeboard, installing two – 4 feet x 8 feet box culverts at the bottom of the channel and providing two spillways; one for the various frequency storms and one to pass the Probable Maximum Flood (PMF). This storm is required to meet dam safety regulations. The lower spillway would be at elevation 3631.0 feet NGVD and 45 feet wide. To pass the PMF it may be necessary to place roller compacted concrete on the embankment and use it as the spillway for the PMF. This alternative reduces the peak discharges for most storms. The water surface elevations decrease by more than one foot in some areas through the golf course. Table 9 shows the percent reduction in the peak flows by storm frequency. Plates 37 - 42 show water surface flood profiles with modification of Bivins Lake.

Table 9– Reduction in Peak Flows for Bivins Lake Improvements

| Storm Frequency | Percent Reduction in Peak Flows |
|---|---|
| 2 year | 0 % |
| 5 year | 37 % |
| 10 year | 39 % |
| 25 year | 36 % |
| 50 year | 33 % |
| 100 year | 29 % |
| 500 year | 21 % |

## XII. DETENTION PONDS PLUS DIVERSION CHANNEL

Another promising alternative is a combination of upstream detention along with an enlarged diversion channel through the Canyon City Golf Course area. The upstream detention ponds combined with a 75 foot wide diversion channel will provide a greater reduction in flood elevations. This alternative would reduce flood elevations for all storms and for the 100-year flood by about 1.5 feet. A more refined analysis is recommended and for smaller frequency floods this may prove to be economically justified under federal authorities. Plates 43 – 49 show the flood elevation profiles for Detention plus Channel Diversion.

## XIII. BIVINS LAKE MODIFICATION PLUS CHANNEL

This proposed flood risk reduction alternative would combine modifying Bivins Lake and also constructing a 75 feet wide diversion channel through the Canyon City Golf Course. This alternative would lower the water surface flood profiles through the golf course as much as two feet for the two year storm and would lower the 500 year frequency flood profile by more than one foot. This alternative decreases the peak discharges the same as for the improvements to Bivins Lake as shown in Table 9. Modification of Bivins Lake combined with a diversion channel provides a significant reduction of the 100-year flood. This option should be evaluated for future consideration and may also be a potential Federal project. Plates 50 -56 show flood elevation profiles for the Modification of Bivins Lake plus Diversion channel.

## XIV. ELEVATE STRUCTURES

Elevating individual structures would reduce the flood risk for individual sites. This "flood proofing" option raises the first floor of a structure to above flood level. Although this would keep water out of the living area, it would not eliminate the need for flood insurance. However it could reduce flood insurance rates. The cost to elevate a home would range from about $30,000 to $75,000. These costs can vary quite a bit based on type of structure, height, locality and available contractors.

The floodplain outlines developed during the study identifies estimated flood areas based on best available topography. Elevations from the flood water surface profiles would more accurately identify flood elevations to reference structure elevations. If the ground floor elevation of the structure is below the flood elevation, the structure could be raised in place to elevations above the 100-year flood elevation or higher. This option is especially viable for new construction because most of the basins are still undeveloped.

## XV. ACQUIRE (BUYOUT) STRUCTURES

The purchase of flood-prone structures is an option often considered under FEMA flood mitigation measures for repetitive flood loss structures. The number of structures within the floodplain can be identified from the mapping produced in the study, but the surveyed elevations of the individual structures are not provided in this report. Acquisition is usually a volunteer program with costs based on pre-flood values.

This method could provide more individualized flood risk reduction. It can be done by the community, with FEMA Hazard Mitigation Grants or by individuals. If there are repetitive loss structures in a group this option should be identified in the local Hazard Mitigation Plan for future FEMA funding.

When flood prone structures are acquired they can be destroyed or moved (relocated) to areas outside the floodplain. Vacant land remaining from acquisition must remain open space. That land can be used for parks, detention and other recreational open space.

When flood prone lands are acquired for recreation there could be a maintenance cost for recreation sites or clean up resulting from flooding. There may also be a short term loss of use of the facilities following a flood. However this clean up is better than having structures flooded and lives in danger.

Acquisition could also provide opportunities for ecosystem restoration measures greenbelts, etc. Riparian corridors and wetlands provide numerous environmental benefits such as flood control, wildlife habitat, groundwater recharge, sediment and nutrient control, and non-point source pollution control.

# XVI. FLOOD WALLS BERMS OR LEVEES

Flood walls, Berms or small ring levees can be built to protect individual structures or small clusters of structures. Flood walls were evaluated near the golf course and were determined to be one of the more viable flood risk reduction measures for houses there. These walls could vary in protection provided. A 100-year flood wall would range from two to six feet with freeboard. Although flood risk reduction would be provided flood insurance may still be needed in certain cases. A flood wall compared to a berm would require less space however would cost more. These methods could be used in developed or in rural areas where there is more space. This option provides for the construction of a flood wall through the Canyon City Golf Course area on both the north and south sides of the golf course. Two hydraulic models were run, one each for the 100-year and 500-year storms. The floodwall on the north side of the golf course begins at stream station 17897 and continues to station 17083. It then begins again at station 15295 and continues to station 14122. The height of these flood walls vary from 1 foot to 5 feet in this area. The floodwall on the south side of the golf course begins at station 17083 and continues to station 8360, next to the highway on the east side of the golf course. This flood wall varies in height from 3 feet to 10.5 feet with a typical height of 5.5 feet for the 500-year storm.  The highest portion of the wall is located immediately upstream from Hunsely Hills Boulevard and is only for a short distance. The 100-year storm level is approximately two feet lower than the 500 year storm throughout the length of the golf course, except near Hunsley Hills Boulevard.  In that area the 100-year storm is about 2.5 to 3 feet lower than the 500-year flood profile.    Flood walls would cost about $150.00 to $200.00 per linear feet depending on height. Figure 6 shows the potential location for building a flood wall.


City of Canyon, TX
Flood Plain Study
Proposed Floodwalls
Figure 6

## XVII. FLOOD WARNING

Flood warning is always recommended whether it be a comprehensive alert system, reverse 911 or local law enforcement notification. In most Randall County areas adequate warning time is likely. However, for small watersheds and road crossings flood warning would be more appropriate to save lives and property. For water crossings signage and education about driving through floodwater is a must.

## XVIII. MAINTENANCE & CULVERT REPLACEMENT

Bridges and culverts, along with their roadway embankments, can create significant upstream backwater flooding. For future bridge and culvert work, it is recommended that the sizing be reviewed and constructed to minimize any increases. Maintenance of existing bridges is critical to maintain flow capacity. Replacing Existing structures is harder to accomplish due to funding limitations and coordination with highway project construction efforts. This methodology is most likely to occur where communities have limited budgets and can complete smaller projects as funding becomes available.

## XIX. DRY FLOODPROOFING

Dry Floodproofing measures can be used to prevent flood waters from entering a structure. This method may be appropriate for commercial structures where flood depths are three feet or less. This method would add a water tight barrier to the exterior of a structure. It can be used for houses, however flood insurance would still be required if the lowest adjacent grade is below the base flood elevation. Closures would need to be added for doors. Some applications in this area could be to provide water barriers to structures next to the creek channel.

## XX. WET FLOODPROOFING

Wet Floodproofing measures can be used to minimize flood damage. This can be as simple as using water resistant materials or elevating utilities above flood level. This may be an only option where other measures are not practical or too costly. This method would allow an area to flood but apply measures to reduce damages. An appropriate wet flood proofing measure in this area would be to elevate water heaters, air conditioning and heating units. When repairing after a flood event the use of water resistant materials such as wall board, insulation and floors would minimize future damage. Also wiring and outlets can be raised up above flood level.

## XXI. FLOODPLAIN REGULATION

The best available option for preventing future flood damages is floodplain development regulation. Randall County, Canyon and other Communities participate in the Federal Emergency Management Agency's (FEMA) National Flood Insurance Program (NFIP). It is recommended that the communities investigate joining the FEMA Community Rating System (CRS) that provides a reduction in insurance premium as a reward for more stringent floodplain regulations and other tasks accomplished to reduce flood loss. One regulation that successfully prevents flood damages is the requirement for compensatory flood storage for any future development. For single structures where compensatory flood storage is not practical, the community could consider a fee in lieu of storage. That fee could be used for constructing or maintaining regional detention sites. Due to the amount of new development occurring in the county, both the City of Canyon and Randall County should consider these new ordinances.

## XXII. FUTURE DEVELOPMENT CONDITIONS

It is recommended here that the communities continue to regulate future land development to assure that all new construction is built to ultimate development runoff standards so future increased flooding does not significantly increase risk. It is recommended to continue in the NFIP but also to adopt more stringent flood development guidelines. This concept will pay off by reducing future flood loss to the community, individuals and public entities. It would save in future costs for infrastructure repair and cleanup as well as search and rescue costs.

Peak discharges for Spring Draw were developed to reflect changes caused from future development in the Spring Draw basin. The percent impervious area in the basin was changed to 20% to reflect development based on a 1.0 acre lot size. The water surface profiles differed from existing conditions only upstream from Country Club Road. All other locations in the basin were essentially unchanged. The depth of water upstream of Country Club Road increased 0.9 feet for the 500 year storm. The other changes in the water surface profiles were a maximum of 0.8 feet in the same location.

## XXIII. ESTIMATED COSTS

For planning purposes these rough cost estimates were determined. Prior to construction or more detailed feasibility studies a more detailed cost estimate should be made.

| | |
|---|---|
| Upstream Detention | $500,000 - $2 Million |
| Channel 75 feet wide | $2 - $5 Million |
| Rehabilitation of Bivins Lake | $8 - $15 Million |
| Elevating Structures | $30,000 - $75,000 each |
| Multi-purpose Reservoirs | $50 - $100+ Million each |
| Flood Wall | $150 - $200 per foot |
| Regulation or Zoning | Fees and Review Labor |

## XXIV. ECONOMIC ANALYSIS

The economic approach for this watershed study is to provide the flood damages prevented to compare with a wide range of flood mitigation alternatives. This gives the community information to plan for future projects either with local, State or FEMA funding. Further U.S. Army Corps of Engineers studies would determine the National Economic Development (NED) plan that provides the most benefits and U.S. Army Corps of Engineers capabilities.

# XXV. ENVIRONMENTAL EVALUATION

If a federal project is initiated an Environmental Impact Statement would be required. For this drainage study existing environmental conditions were identified and a field inspection was done to evaluate future potential Ecosystem Restoration opportunities. This limited environmental review was done to determine future potential issues when implementing flood risk reduction measures. Ecosystem restoration has become a greater interest for Corps of Engineers as well as local communities and citizens.

## A. EXISTING ENVIRONMENTAL CONDITIONS

**Location Evaluated**

Palo Duro Creek is located in Canyon, Randall County, Texas. The proposed project area encompasses approximately 2917 meters (9,570 feet) of man creek channel and 880 meters (2887 feet) of tributary creek channel and immediately adjacent stream bank beginning at U.S. Highway 60 upstream to FM 2590. The Palo Duro Creek watershed is heavily urbanized within the project area and is primarily comprised of residential and commercial development. Upstream of FM 2590, the watershed is beginning to experience minor development; however the floodplain is mostly intact with minor residential development. The watershed drains approximately 499 square kilometers (193 square miles).

**Natural Resources**

**Terrestrial**

The project area lies within the High Plains Level III ecoregion and within the Llano Esticado and Caprock Canyons, Badlands, and Breaks Level IV ecoregions (Omernik 1987 (reference 23) and Griffith *et al.* 2007 (reference 24)). Elevations of the Llano Esticado range from 756 – 1341 meters (2480 – 4400 feet) comprised primarily of level, elevated plains decreasing in elevation from west to east transitioning into the Caprock Canyons. The Caprock Canyons, Badlands, and Breaks range in elevation from 381 –

1066 meters (1250 – 3500 feet) and are comprised of steep canyons, escarpments, rounded bandlands, and dissected river breaks.

**Wetlands and Water Quality**

No water quality data, with regard to wetlands or ponds, is currently available. Wetland areas are numerous throughout the project are due to the construction storm water detention facilities along U.S. Highway 60 and the numerous backwater areas within the Palo Duro Creek channel at low water crossings located throughout the Palo Duro Creek Golf Course. While the golf course is now owned and operated by the City of Canyon, Palo Duro Creek has been encroached upon by private homes, highway improvements, and ongoing development and construction in areas adjacent to the creek and golf course (Figure 7). The study area is bounded by U.S. Highway 87 at the downstream point and Farm to Market Road (FM) 2590 at the upstream point. No significant tributaries were noted during the site visit within the study reach. The study area has experienced major flooding events in 1951 and 1978 with minor events resulting in street flooding/local flooding between 2000 and 2010.

Some ecological degradation of the stream bank is present within the project area caused by the impact of increased impervious surfaces on the volume of runoff resulting in surface erosion and undermining of the stream banks during high flow events (Figure 8 and Figure 9).

Figure 7.  Private home construction in areas adjacent to the project area.

Figure 8.  Bank failure due to undercutting and overland erosion.

Figure 9. Bank collapse due to overland erosion and bank undercutting.

Other areas within the project area provide valuable wetland habitat in an area with limited surface water resources. These areas are utilized by wildlife and include pooled water above low water crossings (Figure 10 and Figure 11) and a large storm water detention facility adjacent to U.S. Highway 60 (Figure 12).

Figure 10. Pooled water above a low water crossing on Country Club Drive.

Figure 11. Mallards utilizing aquatic habitat created by the pools formed above a low water crossing on Country Club Drive.

Figure 12.  Storm water detention facility and wetland complex adjacent to U.S. Highway 60.

**Fish and Wildlife**

**Fish**

Fish species present in the project area are likely typical of the species assemblage present in upper North Canadian River and upper Red River basins of Texas and Oklahoma.  Common species would likely be comprised by those reported to be widely distributed by Pigg, Coleman, and Duncan (1992) (reference 25) and include:  common carp, gizzard shad, golden shiner, bullhead minnow, fathead minnow, emerald shiner, mosquito fish, plains killifish, green sunfish, longear sunfish, largemouth bass, and white crappie.

**Amphibians and Reptiles**

Amphibian and reptile species present in the project are typical of urbanized areas of the Texas High Plains in Randal County.  Common species include:  frog, salamander, toad, copperhead, snapping turtle, eastern painted turtle, spotted whiptail, six-lined racerunner, western diamond-backed rattlesnake, pygmy rattlesnake, ribbon snake, kingsnake, and Texas horned lizard. A complete species account for the High Plains Ecoregion, including Randall County, is presented by Holt (1999) (reference 26).

**Birds**

Bird species present in the project area are typical of urbanized areas of the Texas High Plains in Randall County. Common species includes geese, ducks, coots, sandhill crane, mourning dove, American crow, horned lark, swallows, robins, starling, sparrows, longspur, blackbirds, and cowbirds. The Texas Parks and Wildlife Department has compiled a complete species account for the High Plains Ecoregion, including Randall County (Seyffert 2002) (reference 27). This species account is accessible at: http://www.tpwd.state.tx.us/publications/pwdpubs/media/pwd_bk_w7000_0760.pdf. According to information collected by the U.S. Fish and Wildlife Service, birds of conservation concern within the High Plans and Caprock Canyon ecoregions (Level IV) include: lesser prairie-chicken, bald eagle, golden eagle, prairie falcon, snowy plover, mountain plover, upland sandpiper, long-billed curlew, burrowing owl, Lewis's woodpecker, willow flycatcher, Bell's vireo Sprague's pipit, lark bunting, McCown's longspur, chestnut-collared longspur, horned grebe, American bittern, ferruginous hawk, peregrine falcon, yellow rail, marbled godwit, black-billed cuckoo, short-eared owl, red-headed woodpecker, loggerhead shrike, Pinyon jay, sage thrasher, Brewer's sparrow, sage sparrow, grasshopper, sparrow, Baird's sparrow, and dickcissel (US Fish and Wildlife Service 2008) (reference 28).

**Mammals**

Species of mammal present in the project area are typical of urbanized areas of the Texas High Plains in Randall County. Common species includes opossum, several species of bat, armadillo, desert cottontail, eastern cottontail, black-tailed jackrabbit, ground squirrel, and gopher, several species of mice and rat, coyote, swift fox, grey fox, raccoon, American badger. A complete species account of the mammals of Texas can be found in Davis and Schmidly (1994) (reference 29).

## Threatened and Endangered Species

Federally listed threatened and endangered species in Randall County, Texas the bald eagle (delisted but still monitored), interior least tern (endangered), lesser prairie-chicken (candidate species), mountain plover (threatened), and whooping crane (endangered).

## Air Quality

A non-attainment area is an area which does not meet one or more of the National Ambient Air quality Standards (NAAQS). The EPA Office of Air Quality Planning and Standards has set NAAQS for the six criteria pollutants listed in Table 10. Information reported in 40 CRF Part 81 (2009) by the Texas Commission on Environmental Quality (TCEQ) and the Oklahoma Department of Environmental Quality indicates that the project is not located in a non-attainment area.

Table10. National Ambient Air Quality Standards for criteria pollutants (carbon monoxide (CO), nitrogen dioxide ($NO_2$), ozone ($O_3$), lead (Pb), particulate matter less than 2.5 micrometers ($PM_{2.5}$), particulate matter less than 10 micrometers ($PM_{10}$), and sulfur dioxide ($SO_2$)) and attainment status of Air Quality Control Regions (AQCR) 188, 189, 210, and 211.

| Pollutant | Type of Average | Primary Standard | Secondary Standard | Designation (2010) | |
|---|---|---|---|---|---|
| | | | | OK[1] | TX[2] |
| CO | 8-hour | 9 ppm | None | Unclassifiable/Attainment | Unclassifiable/Attainment |
| | 1-hour | 35 ppm | | | |
| $NO_2$ | Annual Arithmetic Average | 53 ppb | Same as Primary | Cannot be classified or better than national standards | Cannot be classified or better than national standards |
| | 1-hour | 100 ppb | None | | |
| $O_3$ | 8-hour | 0.075 ppm | Same as Primary | Unclassifiable/Attainment | Unclassifiable/Attainment |
| | 1-hour | 0.12 ppm | Same as Primary | Unclassifiable/Attainment | Unclassifiable/Attainment |
| Pb | Rolling 3-Month Average | 0.15 $ug/m^3$ | Same as Primary | Not reported | Not designated |
| $PM_{2.5}$ | Annual Arithmetic Average | 15.0 $ug/m^3$ | Same as Primary | Unclassifiable/Attainment | Unclassifiable/Attainment |
| $PM_{10}$ | 24-hour | 150 $ug/m_3$ | Same as Primary | Not reported | Unclassifiable |
| $SO_2$ | Annual Arithmetic Average | 0.03 ppm | 0.5 ppm/3-hour | Better than national standards | Better than national standards |
| | 24-hour | 0.14 ppm | | | |
| | 1-hour | 75 ppb | None | | |

1. AQCR 188 and 189 (40 CFR § 81.337)
2. AQCR 210 and 211 (40 CRF § 81.344)

## B. AQUATIC ECOSYSTEM RESTORATION

To evaluate Aquatic Ecosystem Restoration opportunities a field visit was made of the Palo Duro Creek Golf Course, a municipal golf course owned and operated by the City of Canyon, Texas, on 9 and 10 January 2011.

The Palo Duro Creek Golf Course is located along Palo Duro Creek. The golf course is located in an urbanized area of Canyon, Texas. Its drainage area is approximately 193 square miles upstream of US Highway 60. Development of the golf course was completed in two separate phases between 1959 and 1965. While the golf course is owned and operated by the City of Canyon, Palo Duro Creek has been encroached upon by private homes and highway improvements constructed adjacent to the creek and golf course. The study area is bounded by U.S. Highway 87 at the downstream point and Farm to Market Road (FM) 2590 at the upstream point. No significant tributaries were noted during the site visit within the study reach. The study area has experienced major flooding events in 1951 and 1978 with minor events resulting in street flooding/local flooding between 2000 and 2010.

During the site visit it was noted there is a potential for several different stakeholder groups to have diverse goals for the Palo Duro Creek stream and riparian corridor within the study area. Goals are likely to include flood damage reduction, bank stabilization, aesthetics, and ecosystem restoration. The following ideas were developed during the site visit and are based on a minimum of information, additional investigation and coordination will be necessary to determine whether they are feasible from an engineering, ecological, economic, and political perspectives.

Stormwater management. Much of the ecological degradation of urban streams is caused by the impact of increased impervious surfaces on the volume of runoff. Stormwater management measures can have the following benefits:

1. Reduction of peak flows downstream (reduces erosion, flood damages, and improves the ecological function of the channel downstream).

2. Improved water quality (potential to assist in meeting NPDES permit requirements).

3. Creation of habitat at site.

4. Improved aesthetics at site.

The Palo Duro Golf Course has the potential for improved stormwater management and aquatic ecosystem restoration. The land is currently publicly owned. There appears to be sufficient area to allow for stakeholders to formulate and assess multiple scenarios of addressing stormwater management and aquatic ecosystem restoration. Additionally, areas upstream of the project area, while currently privately owned, are largely undeveloped and would allow ample area for the development of upstream stormwater detention facilities that could be designed to enhance both stormwater management and aquatic and riparian habitat.

Flooding considerations. It is unlikely that stakeholders would support measures that would increase the likelihood of a 1% probability flooding event (100-year flood). However many of the features that would be included in ecosystem restoration / habitat improvement measures could increase roughness of the creek and reduce conveyance, resulting in increased flood stages. The following methods would be useful to assess stormwater management and habitat restoration measures:

1. Ensure hydraulic and hydrologic analyses fully capture the current conditions.
2. Incorporate the most recent and accurate channel surveys into any study efforts.
3. Increase storm water conveyance by enlarging the channel cross section where applicable/desirable.
4. Increase storm water conveyance through upgrading/replacement of low-water crossings within the study area.
5. Lower flood stages through stormwater management practices.
6. Implement in-stream and riparian habitat measures that have significant benefits at low and normal flows, and insignificant impacts at flood stages (especially the 1% probability flood).

Use of stone toe protection for bank stabilization. This bank stabilization technique is applied at the toe of the bank slope without grading the bank. The upper portion of the bank will normally re-vegetate on its own. Since this method doesn't require the bank to be graded to a stable slope, construction impacts (soil compression, loss of vegetation) and construction costs can be minimized. The use of stone toe protection methods allow existing riparian trees to remain in place during construction. This technique is best applied to bank slopes that have not been heavily degraded.

Use of grade control structures. This technique is applied to streams with excessive scour and channel incision. The application of combined grade control structures and road crossings would allow the preservation of existing "wetted" pools throughout the study area and allow increased stormwater conveyance over the existing low water road crossings. One limiting factor in the use of grade control structures is the final siting within the stream. The reach upstream of a grade control structure should be stable and provide a straight approach. If the bank of the upstream reach is not stable, scour and flanking of the structure could occur. Therefore if pairing grade control structures and road crossings, upstream realignment and stabilization may be necessary.

Vegetation. There is very little vegetation in the creek channel and vegetation along the banks is heavily fragmented. The ecological benefits of a continuous belt of riparian vegetation are numerous and include the following:

1. Provide shading of aquatic habitat resulting in less thermal stress on aquatic organisms.
2. Provide food and shelter to resident and migratory fauna.
3. Provide a corridor for wildlife movement.
4. Increase bank stability/decrease erosion and soil loss.

The incorporation of vegetation into a flood control channel will take close coordination between the hydraulic engineer, the ecologist, and the stakeholders. A bank stabilization technique, such as stone toe protection, will allow vegetation to grow on the stabilized bank. As time passes, the composition and size of the vegetation will change, along with its impact on conveyance. Therefore, it may be necessary to manage the vegetation (by tree removal, for example) to meet both ecologic and hydraulic goals.

Potential for trails within the study area. Improved riparian habitat throughout the golf course would allow for extending the birding trail located along Palo Duro Creek west of FM 2950 to the wetland complex at U.S. Highway 87/60. The trail could be used for multiple purposes including watchable wildlife, recreation, hiking, biking and jogging.

Geomorphic assessment. During any feasibility study, a geomorphic assessment should be performed to determine the dominant processes occurring in the stream channel, as well as the stability of various reaches.

Future condition of watershed. The hydrology for future conditions should be computed and used as input to the design.

## XXVI. RECOMMENDATIONS

This watershed drainage study provides extensive information on the existing floodplain as well as some hydraulic models of alternatives for flood hazard mitigation. There are some less costly measures that are recommended for the city to consider on their own as maintenance or less costly measures with city funds. Additional measures could be requested through the FEMA pre-disaster or post disaster Hazard Mitigation funding grants. We also recommend that the City of Canyon and Randall County continue to pursue a U.S. Army Corps of Engineers Section 205 study option.

We recommend that the local flood plain regulations be modified to regulate higher than the FEMA minimum. We suggest building the first floor of new structures to at least two feet above the base flood elevation and adjacent ground elevation at or above one foot. We recommend that flood warning be implemented in the more developed areas. The local Community should consider acquiring some worst flooded homes and possibly consider elevation of structures. Non-structural alternatives include flood warning, as well as adopting more stringent flood development ordinances to require on site flood retention for all new developments to mitigate an increase in the flood and elevation two feet above base flood elevation.

The recommended structural plan is to construct an earthen channel diversion through the golf course area and construct two detention facilities in the upper watershed. Additional detention ponds would be recommended possibly near the west end of the golf course area and upstream. This alternative and others would need more extensive benefit to cost analysis if a Section 205 Flood Risk reduction Study is implemented. It also is recommended to build flood walls in various locations to protect structures still at risk.

Some of the proposed flood risk reduction projects could be implemented by the USACE, FEMA, TWDB, or the Community subject to available funding. Some more localized measures can be accomplished slowly over time by the local community as maintenance or storm water management as funding becomes available.

# XXVII. EXECUTIVE SUMMARY

This Master Drainage Study was prepared for the City of Canyon and Randall County, Texas under the Corps of Engineers Floodplain Management Services Program Authorized by Section 206 of the 1960 Flood Control Act as amended. Funding was provided by the City, County and Texas Water Development Board. About 10 % of the study came from the Floodplain Management Services Program Funding. Detailed Hydrology and Hydraulic data was developed for the study. Many scenarios were evaluated to determine various flood risk reduction alternatives for the most developed portion of the watershed which was at the Canyon Golf Course area. This master drainage plan would provide significant data for a Corps of Engineers Section 205 Flood Risk reduction project. Although direct credit for this study cannot be applied as a local share for a 205 study the overall cost of a reconnaissance study would be reduced by the cost of this master plan. The flood Risk reduction approach was to evaluate smaller frequency floods as well as large flood events. Smaller events or local drainage issues can be addressed more easily by the City of Canyon and other local entities as watershed maintenance funds become available.

Data from this study will be useful in any future U.S. Army Corps of Engineers feasibility studies. This could be a Section 205 project or authorized basin study. The hydrologic and hydraulic data developed for this study can be evaluated for potential revisions to the FEMA Flood Insurance rate Maps and implementation of FEMA Risk Map initiatives for Canyon and Randall County, Texas. Any data developed for this study could provide a basis for revisions to the FEMA Flood Insurance Rate Map. Map revisions would be required if flood risk reduction measures are implemented that would alter the FEMA base flood.

Flood mitigation alternatives identified by this study may also be eligible for funding under the TWDB financial assistance programs. Application requirements and eligibility criteria are identified under the TWDB rules specified in Chapter 363 of the Texas Administrative Code. This report would be appropriate for use in support of an application to the TWDB for financing the proposed improvements.

For a larger scale potential federal authorized project we recommend an evaluation for the rehabilitation of Bivins Dam. This option may produce multiple benefits such as flood reduction, water supply and recreation as well as some possible ecosystem restoration. This alternative potentially could produce the most flood reduction however at a very high cost. This plan would be more than the Section 205 dollar amount therefore would need to be Specifically Authorized by Congress.

The most aggressive flood risk reduction plan would be to rehabilitate the Bivins Dam to provide flood reduction, and possible water supply and recreation; however critical dam safety issues must be addressed.

The recommended and likely most cost effective flood risk reduction measure is upstream detention on Palo Duro Creek combined with channelization through the golf course development area. This method would provide the most impact for the dollars spent. Channel improvements in this diversion area could be done in stages by local crews to reduce costs and provide significant flood reduction for small flood events as well as the 100 year flood. Another high impact method potentially by local funding would be to modify the golf course pond dam and spillway, and remove the golf cart path crossing obstruction.

Some intermediate initiatives that would be very effective are stream maintenance and cleaning and possible replacement of bridges and culverts. This methodology would be more effective in reducing street and localized flooding from smaller frequency flood events. The local communities should remain as participants in the national Flood Insurance Program (NFIP). They should consider adopting more stringent floodplain regulations and joining the Community Rating System (CRS). The CRS program through the NFIP would provide reduced flood insurance premiums for the community.

A list of comments from the TWDB and City of Canyon are provided followed by a list of responses.

**ATTACHMENT I**
**Review of Draft Report of Contract No. 1004831053**
**City of Canyon, Randall County, Flood Mitigation Study**

1. Please provide an Executive Summary.

2. The Grant Application and Contract Scope of Work contain an Environmental Inventory task. The draft report does not describe the results of performing this task in order to identify potential environmental impacts. Please provide this discussion in the final report.

3. There are several prior studies mentioned in the report but are not properly cited. Several examples are: page 5, 2nd paragraph discusses a "study of the City of Canyon done in 1991" from which the FEMA Flood Insurance Rate Maps are based; the 1982 FEMA Flood Insurance Study for Randall County; studies for the Village of Lake Tanglewood and Timbercreek Canyon; and numerous other studies which are referenced throughout the report. Please provide proper citations for all studies referenced in the report, as per report preparation guidelines, and please include a List of References in the final report.

4. Page 4, 2nd paragraph of the Section entitled "AUTHORITY", states that TWDB provided 50 percent of the funding through "a flood hazard mitigation grant". Please amend to read "a flood protection planning grant available through the TWDB's Research and Planning Fund".

5. Please perform a final edit for typos, grammar, inconsistent usage of acronyms and abbreviations, and so on. Example, page 4 last line should say "severe" water quality problem, not "sever".

6. The draft report provides a very cursory description of the hydrologic and hydraulic methods utilized in the analysis. Please consider providing a more thorough description of the methodologies for the final report, as well as statements addressing why one method of analysis was used over another possible method.

7. As part of the contract requirements, public meetings were held but there is no discussion of the public meetings in the draft report. Please provide in the final report.

8. Sections and subsections are not numbered. Please consider adopting a section numbering format which will aid the general organization of the report.

9. The draft report has two major sections, one starting on page 16, "Summary of Flood Risk Reduction", with subsections describing structural projects which were analyzed by the study. And the other section starting on page 21 entitled "Alternative Flood Mitigation Measures – Planning Summary", which has several subsections also of structural projects (a few of which were also included in the previous section) but also several subsections of non-structural mitigation alternatives. Please provide additional explanation within these two sections with respect to what is trying to be presented within one section as apposed to the other section, or consider combining into a single alternatives analysis section.

10. Page 26 has two major sections, "Floodplain Regulation" and "Future Development Conditions". These two seem to be additional non-structural alternatives which were reviewed by the study. Please consider reorganizing the report to include these with the review of the other non-structural alternatives in the previous section.

11. Modification of Bivins Lake is one of the structural projects included in the study analysis. Please consider including the acre-ft of additional storage that will result in the described modification to the lake. In addition, it is noted on page 21 that this modification to the dam will require coordination with the TCEQ Dam Safety Program. Please consider also including a discussion of the probable Water Rights permitting amendments, also through TCEQ, which will need to be addressed.

12. The study follows standard methodologies and practices utilizing acceptable HEC modeling in the engineering aspects of hydrologic and hydraulic techniques. The hydrologic modeling parameters were determined based on the calculation and engineering judgments for the existing and ultimate conditions. Mitigation alternatives identified by the study are eligible for funding under the Board's financial assistance programs. Application requirements and eligibility criteria are identified by Board rules specified in Chapter 363 of the Texas Administrative Code. The report would be appropriate for use in support of an application to the Board for financing the proposed improvements. All additional information required by Board rules, 31 TAC 363.401-404, as well as necessary information to make legal findings as required by Texas Water Code Chapter 17.771-776, would be required at the time of loan application.

# Memorandum

**To:** Randy Criswell, City Manager

**From:** Danny Cornelius, Director of Code Enforcement

**Date:** May 3, 2010

**Re:** Comments on the Army Corps of Engineers Draft Report, Flood Mitigation Study for Canyon and Randall County.

---

I reviewed the draft report and have the following observations. I would like to visit with Joe and get some input on items 1- 3.

1. The study concludes that replacing the culverts in the upstream reach of the Canyon City Golf Course area would not significantly reduce flood elevations. The culvert at the Country Club crossing restricts stream flow during heavy rains, causing street flooding on Country Club Dr. Traffic on Country Club Dr. creates wave action and threatens the homes in the area. Since the low elevation of the street crossing acts as a spillway or low water crossing, I agree that BFE's in the area would probably not be significantly affected by culvert improvements. However, I believe that street flooding could be prevented during less significant storm events.

2. There is some discrepancy between the current FEMA Flood Insurance Study and Plate 17 of the Corps of Engineers Study. Beginning at the confluence with the Tierra Blanca Creek to about 12000 feet above the confluence, the Palo Duro Creek water surface profile for a 100 year flood in the Corps of Engineers study is 1.5 feet to 2 feet higher than the 100 year flood in the current Flood Insurance Study.

3. The current Flood Insurance Rate Map places the properties on Mulligan Circle and the west part of Cottonwood Lane outside the SFHA. Map Panel No. 8 of the Corps of Engineers study places these properties within the SFHA.

4. Channel improvements in the diversion area of the golf course looks like an interesting option. We could look at doing it in stages, with city crews, to keep costs down.

Responses to the Canyon, Texas, Flood Mitigation Draft Report are shown below:

RESPONSES TO COMMENTS FROM TEXAS WATER DEVELOPMENT BOARD

1. An Executive Summary was prepared and added to the report.
2. An Environmental Report was prepared and included in the report.
3. References were noted and listed in the back of the report.
4. Description of funding and authorities was revised.
5. An edit for grammar etc. was done for the final report.
6. A more detailed description of the hydrologic and hydraulic methodologies was provided.
7. A coordination section was included to discuss public meetings and other coordination activities.
8. Sections were numbered and an index with numbers was added to the report.
9. A re write of the report was done to eliminate duplication and have one section focus on mitigation measures rather than duplicate in technical write up.
10. Report was clarified to describe structural and non-structural mitigation alternatives.
11. Additional information was provided for Bivins Lake.
12. Better descriptions and references to modeling techniques were added. More information on Texas State funding authorities was included in the Report.

RESPONSES TO COMMENTS FROM CITY OF CANYON

1. As stated some of the culvert obstructions and fill affect local drainage more than the larger frequency floods. This description was clarified since it was misleading in the draft report.
2. The hydraulic modeling was revised due to a discrepancy in input data. The revised water surface profile now more closely matches the FEMA flood profile.
3. The revised flood map took these properties out of the flood area.
4. The channel diversion would provide the most flood reduction for the cost. It also is something the City could implement in stages and be done as funds become available.

## XXVIII. TECHNICAL SUPPORT DATA

This report provides electronic files of all backup data including Geographical Information System Project. Backup data in electronic form and some paper copies is furnished for the hydrologic and hydraulic computations. Data will be available at the Tulsa District Corps of Engineers for at least five years.

# XXIX. REFERENCES


1. Federal Emergency Management Agency, Flood Insurance Study, Randall County, Texas and Incorporated Areas
2. FEMA Flood insurance Study, City of Canyon, Randall County, Texas, May 15, 1991 revised from March 30, 1982.
3. FEMA Flood Insurance Study Randall County Texas Unincorporated areas, March 30, 1982.
4. FEMA FIS Village of Lake Tanglewood, Randall County, Texas, March 1982
5. FEMA FIS Village of Timbercreek Canyon, Randall County, Texas, January 18, 1985
6. Topographic mapping developed by Williams Stackhouse in 1998 for Canyon. T
7. Topographic mapping done in 2003 by Dunway for Walmart development.
8. US Army Corps of Engineers, Hydrologic Engineering Center (HEC) Davis California, Hydrologic Management System (HMS) program version 3.1.1
9. Hydrologic Engineering Center hydrology computer program HEC 1.
10. HEC Water Management System WMS version 8.0, program, July 2008.
11. Tulsa District USACE Regional Rural Basin Parameters
12. Examination of Buffalo Lake Dam and Appurtenant Facilities Designed and Constructed by the Soil Conservation service and Operated by the Bureau of Sport Fisheries and Wildlife. Buffalo Lake National Wildlife Refuge, Umbarger, Texas. July 6, 1967.
13. Red River Basin Umbarger Dam (Buffalo Lake), Randall County, Texas, Inventory Number TX00026. Phase 1 Inspection Report National Dam Safety Program. US Army Engineer District, Fort Worth, prepared by the Texas Department of Water Resources, August 1979.
14. Bivins Lake Dam TX 03584, Breach Analysis, August 2007 prepared for City of Amarillo by Freese and Nichols, Inc.
15. Red River Basin Palo Duro Club Dam, Randall County, Texas, Inventory Number TX03588. Phase 1 Inspection Report National Dam Safety Program. US Army Engineer District, Fort Worth, prepared by the Texas Department of Water Resources, August 1979.
16. Red River Basin Lake Tanglewood Dam, Randall County, Texas, Inventory Number TX03587. Phase 1 Inspection Report National Dam Safety Program. US Army Engineer District, Fort Worth, prepared by the Texas Department of Water Resources, August 1979.
17. NOAA Technical Memorandum NWS HYDRO-35, June 1977.
18. National Weather Service Technical Paper #40 (TP40), May 1961.
19. Hydrologic Engineering Center, Geographic River Analysis System (GEORAS). Version 4.2.92 BETA July 2008.
20. Hydrologic Engineering Center, River Analysis System (HEC-RAS) version 4.0.
21. Flood Plain Information Report, Palo Duro Creek, Tierra Blanca Creek, Canyon Texas. Prepared by the Tulsa District US Army Corps of Engineers February 1971 for the City of Canyon, Texas.
22. Flood Hazard Evaluation for Buffalo Lake, Umbarger, Texas. Prepared by the Tulsa District USACE June 1981

23. Omernik, James M. 1987. Ecoregions of the Conterminous United States. Annals of the Association of American Geographers, 77(1):118-125.
24. Griffith, G., S. Bryce, J. Omernick, and A. Rodgers. 2007. Ecoregions of Texas. Texas Commission on Environmental Quality.
25. Pigg, J., M.S. Coleman, and J. Duncan. 1992. An Ecological Investigation of the Ichthyofauna of the North Canadian River in Oklahoma: 1976 – 1989. Proceedings of the Oklahoma Academy of Science. 72:21-32(1992).
26. Holt, E.A. 1999. The Distribution and Diversity of Texas Vertebrates: An Ecoregion Perspective. Master's Thesis. Texas Tech University, Department of Wildlife Sciences, Lubbock, Texas. 117pp
27. Seyffert, K.D. 2002. Birds of the High Plains and Rolling Plains of Texas. Texas Parks and Wildlife Department. PWD BBK W7000-760 (3/02), Austin, Texas.
28. United States Fish and Wildlife Service (USFWS). 2008. Birds of Conservation Concern, 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia. 85pp.
29. Davis, W.B. and D.J. Schmidly. 1994. The Mammals of Texas. Texas Parks and Wildlife Department, Austin, Texas. 338pp.

## XXX. EXHIBITS:

**A. PHOTOGRAPHS OF FLOOD MITIGATION MEASURES**

**B. FLOOD ELEVATION PROFILES PLATE 1-56**

**C. FLOODPLAIN BOUNDARY MAPS PANEL 1-12**

# EXHIBIT A

# PHOTOGRAPHS OF FLOOD MITIGATION MEASURES

Flood risk reduction alternatives implemented in other parts of the Country are shown in the following photographs. These pictures may be useful for local officials to decide on an alternative measure. Visualization of a detention pond or elevated structure provides examples of what certain flood risk reduction alternatives look like where done in other communities.

**OFF LINE DETENTION**

**These "Off Line" examples of Detention are from the Mingo Creek Project in Tulsa, Oklahoma. These are excellent examples of how detention can work and provide recreation in the form of sports fields, water enhanced parks and green open space or wetlands.**

**OFF LINE DETENTION**

**MULTI PURPOSE DETENTION**


**CHANNEL IMPROVEMENTS RESTORE NATURAL BENEFICIAL USES**


**ACQUISITION OF FLOOD LOSS STRUCTURES**


**RELOCATION OF STRUCTURE**


Detention site with recreational benefits

**ELEVATED HOUSE EXTENDED FOUNDATION**

**ELEVATED STRUCTURE ON FILL**

**ELEVATED HOUSE CRAWL SPACE**


**COMMERCIAL FLOOD WALL**


**RESIDENTIAL FLOOD WALL**


**LEVEES OR BERMS**


**DRY FLOOD PROOFING COMMERCIAL**

**WET FLOOD PROOFING**