# Appendix 9E

# Longhorn Mitigation Plan Mandated Studies Summaries

## 1.0 INTRODUCTION

The Longhorn Mitigation Plan (LMP) in the draft Environmental Assessment (EA) issued October 1999 set forth several studies that Longhorn would undertake – most to be completed prior to project start-up. (See Longhorn Mitigation Commitment [LMC] 19 and LMC 22.) The reasoning for this timing was that the Lead Agencies did not believe that the study results were critical for decision making.

During the public comment period, commentors questioned how a decision could be issued without the results of the studies available to the decision-making process. After reconsidering their position, the Lead Agencies requested that Longhorn complete the studies prior to deciding whether to issue a finding of no significant impact or an Environmental Impact Statement (EIS). The Lead Agencies also requested that the EA Contractor find suitable experts for each study topic to review each study's methodolology and techniques, and also to evaluate study recommendations. This process was completed during spring and summer 2000.

The studies are too large to include in the EA. However, they are available in the public reading room maintained by the Contractor. This appendix summarizes the purposes, approach, results, and recommendations of each study.

Section 2 of this appendix is the first of seven studies. Section 2 summarizes the scour study (also referred to in the LMP as a pipeline stream crossing study), which looks at how flood levels along the various rivers and streams crossed by the pipeline could threaten pipeline integrity. The concern is whether scour induced by floods could expose a sufficient length of pipeline to threaten pipeline integrity.

Section 3 contains the span study summary. The span study looks at whether the engineered spans (not the unintentional pipe exposures) are structurally stable. Spans that are estimated to be potentially inundated during the 100-year flood are also analyzed to estimate whether these spans can withstand the forces induced by the high velocities associated with these flood events; thus, it is linked closely to the scour study.

Section 4 is the root cause analysis summary. This study looks at the root causes of previous failures as a means of identifying both current practices and mitigation measures that are being or will be taken to counteract the cause and eliminate the future occurrence of similar damage. This analysis is based on a recognized methodology in the pipeline industry.

Section 5 summarizes the stress corrosion cracking study to determine whether factors that could contribute to stress corrosion cracking are present on the Longhorn Pipeline System.

Section 6 is a collection of studies called geologic hazards (also part of the "Ground and Water Force Studies" referred to in the LMP.) These studies include earthquake potential, landslide potential, aseismic risks, and soil stress risks.

Section 7 is the valve study summary. The valve study is discussed in LMC 22 of the LMP. This study, which was evaluated and approved by Department of Transportation (DOT), looked at the benefits and risks of adding more valves as a means of reducing the potential spill volume from a pipeline failure at points along the pipeline.

Section 8 is the surge pressure analysis, which was conducted to determine whether the short-term surges of product pressure inside the pipeline could threaten pipeline integrity. Surge analyses will be repeated several times during the life of the Longhorn pipeline based on changes in operation (e.g., increased throughput) or configuration (e.g., additional valves). This surge analysis was conducted based on the addition of seven new check valves recommended by the valve study.

# 2.0 SCOUR STUDIES

## 2.1 PURPOSE AND HISTORY OF THE STUDY

One potential mode of pipeline failure is for the depth of cover to erode during flood flows, exposing the pipeline. If a lateral force was sufficiently large, the pipeline could become overstressed, resulting in a leak. LMC 19 addresses this potential mode of failure by requiring a study to evaluate scour and erosion potential during flooding at stream crossings along the pipeline.

During the scour and erosion study, issues were raised which resulted in a series of individual issue-related studies. These studies and their purpose are listed below:

- Geotechnical Evaluation, Pipeline Waterway Crossings, by Louis J. Capozzoli & Associates. This study is a geomorphic evaluation of 14 selected pipeline waterway crossings (2/10/00). Radian provided oral and informal written comments concerning this study.
- Longhorn Pipeline Stream Crossing Study: A Summary of Stream Scour Potential and Potential for Pipeline Failure (4/7/00). This series of studies includes the original Capozzoli study, supported by a series of additional studies responding to URS Radian comments. The additional studies include stream crossing flood velocity estimates (by IT Corporation), and estimation (by Williams Engineering Services [WES]) of loading on the pipeline by flows of varying velocity around a pipeline. These studies addressed the 14 crossings from the original study only.
- URS Estimates of Peak Flood Velocities at 79 pipeline crossings (5/22/00). These estimates were performed to (1) expand the scope of the scour studies to address pipeline crossings through the entire pipeline and (2) to identify high velocity crossings for selection for historic aerial photograph analysis. These estimates are documented in URS Calculation C-6. Estimation of Velocities at Stream Crossings (8/7/00.
- URS Calculations C-1, Longhorn Pipeline, Fluid Loads on Line (5/9/00), C-2 Resolution of Boundary Loading (6/1/00), C-3 Submerged span lengths in Uniform Flow (6/9/00). These calculations were performed to estimate the length of pipeline that could be exposed to fluid flow of varying velocities without exceeding allowable stresses.

- URS Historic Aerial Photograph Analysis (6/10/00). This study identified crossings that were potentially laterally unstable and selected those crossings for required on-site study.
- Williams Survey of Crossings with Rock Beds (6/26/00). WES field staff visited 9 of the 29 crossings with rock beds which lacked details of original construction. All of the line crossings were found to be within a trench cut in the rock bed. Two of the crossings showed signs of recent work activity to replace cover or showed a need to have cover re-installed. Other rock bed crossings not visited in June 2000 were already scheduled for mitigative work.
- URS Calculations C-4, Longhorn Pipeline, Line Uplift due to Fluid Pressure (7/26/00), and C-5, Uplift Restraint by Concrete Cover (7/26/00. At crossings where the streambed is composed of rock, the pipeline has generally been placed within a trench cut into the rock. During floods at crossings where flow velocities are extremely high, there is the potential for pressure differences across the top of the pipeline to raise an exposed length of pipeline into the flow. These calculations document estimates of lengths of pipeline that could potentially be uplifted from a rock trench into flows of varying velocities.
- Integrity Evaluation, Pipeline Waterway Crossings, by Louis J. Capozzoli & Associates (6/30/00). This study is a revised version of the original study, addressing major crossings, selected urban crossings, and crossings identified by the stream crossing velocity survey and the historic aerial photograph analysis. Evaluation was performed using the HEC20 procedure for stream stability analysis, developed by the DOT.
- Evaluation of the Historic Flood Events Exceeding Recurrence Interval Peak Flows in Selected Basins Along the Pipeline Right-of-Way, by IT Corporation (6/30/00). This study analyzes the flow records from gauges located in the vicinity of seven of the major crossings. The statistical extreme flow rates are derived and compared to the peak floods that have occurred during the lifetime of the pipeline.

## 2.2 SCOPE OF WORK FOR THE STUDY

The potential for scour or erosion-related failure to occur was evaluated as follows:

- The history of scour-related leaks and repairs for the pipeline was reviewed.
- Hydraulic calculations were performed to identify crossings with potentially excessive flood flow velocities.
- Current and historic aerial photographs were procured for each of the crossings of potential concern. These photographs were analyzed to identify crossings that showed evidence of channel instability.
- Site-specific geomorphic studies were performed for fourteen crossings. These studies provide estimated mitigation measures (if any) to address scour.
- Separate studies were performed to address the issue of uplift of the pipeline at high-velocity rock bed crossings.

In general, the study progressed initially as a process of elimination. Crossings, which by their hydrologic or hydraulic characteristics, had minimal potential for excessive scour were eliminated from further study. Crossings where conservative assumptions showed the potential for excessive scour were retained for further, more detailed, study.

## 2.3 ROOT CAUSE STUDY

The Root Cause Study (Longhorn, May 2000) addresses individually the causes of each of the known leaks and repairs for the operational history of the existing pipeline. The report states that "no record or evidence [has been found] that a river or stream crossing failure causing a spill had ever occurred on this pipeline." Three repairs were noted at two crossings. The Brazos River crossing was repaired in 1991 (rip-rap was placed around the pipe) and completely replaced in 1995 (using directional drilling under the streambed). The Colorado River crossing was repaired in 1993. This repair involved covering 80 ft of exposed pipe with sandbags. No scour-related leaks or repairs were noted in the report for any of the other pipeline stream crossings.

The Root Cause Study likely underestimates repairs to replace scoured cover at stream crossings. Later investigation noted past/current/needed repairs at several crossings (Flat Creek, Fitzhugh Creek, Threadgill Creek, Cottonwood Creek) that were related to erosion removal of cover.

The data and methods underlying this study are discussed in more detail in the executive summary of this study, as well as in this appendix.

### 2.3.1 Hydraulic Evaluation of Selected Crossings

The maximum allowable velocity against an exposed pipe span was estimated. The conditions used in the calculations (i.e., pipe dimensions and material type, internal pressure, and material transported) correspond to conservative Longhorn pipeline conditions. The source for choices of maximum allowable stresses is American Society of Mechanical Engineers (ASME) Code for Pressure Piping, B31.4. Details concerning the derivation of these maximum velocities are provided in a documented calculation: URS Dames & Moore, May 9, 2000. The calculations are based upon conservative estimates of pipe materials, material strengths, and end support conditions. Maximum allowable velocities are summarized Table 1 below. The pipe stresses used to define maximum velocity do not correspond to incipient failure of the pipe, and include safety factors presented in the ASME Code. For instance, the allowable sustained load in Table 1 corresponds to 80 percent of the elastic yield stress, which is in itself significantly less than the ultimate stress that potentially results in pipeline failure.

**Table 1. Maximum Pipeline Spans in Flood Flow**

| Flood Flow Velocity at the Pipe (ft/sec) | Maximum Span Allowable (ft)<br>Pipe Perpendicular to Flow*<br>Occasional Load Allowable (0.8 times yield stress) |
|---|---|
| 8 | 140 |
| 9 | 125 |
| 10 | 113 |
| 11 | 103 |
| 12 | 95 |
| 13 | 88 |
| 14 | 81 |
| 15 | 76 |
| 16 | 71 |
| 17 | 67 |
| 18 | 63 |
| 19 | 60 |
| 20 | 57 |

* Per URS calculation C-3, submerged span lengths in uniform flow (6/9/00).

The crossings selected for evaluation include all stream crossings listed in Table 4-17 of the EA, the environmentally sensitive (Tier 2) crossings listed in Table 7-1 of the EA, and the environmentally hypersensitive (Tier 3) crossings listed in Table 7-2 of the EA. This listing includes all the crossings of second stream order and higher and all crossings identified as environmentally sensitive. The 10-year and 100-year flow velocities for each of these crossings were estimated using cross-sections derived from the best available (1:24,000) mapping, flow rates derived from region-specific regression equations, and channel/floodplain roughness values derived from a review of vegetation from project photography. These velocities are presented in Table 2 below. Details concerning the derivation of these velocities are provided in a Summary of Scour-related Study (URS Radian, in draft). Major crossings are not included in Table 2, as these crossings clearly warranted a more detailed site-specific geomorphic study.

## Table 2. Summary of Initial Screening of Scour Risk at Crossings

| Stream Name | Mile-post | Basin Area ($mi^2$) | Rock bed? | Tier 3? | Tier 2? | Further Study Effort: Study Level per DOT HEC20 | Further Study Effort: Aerial Photo Review | Estimated 100-Year Maximum Velocity in Center Channel (fps) | Estimated Velocity vs. Allowable for 100-Year Flow |
|---|---|---|---|---|---|---|---|---|---|
| Cypress Creek | 47.05 | 89.9 | | | | | | 5.3 | Less than allowable |
| Unnamed Trib to Cypress Creek | 48.72 | 3.89 | | | | | | 3.3 | Less than allowable |
| Mound Creek | 50.44 | 43.02 | | | | | | 6.1 | Less than allowable |
| Live Creek | 53.88 | 10.07 | | | | | | 6.4 | Less than allowable |
| Harris Creek Trib | 58.70 | 7.55 | | | | | | 7.7 | Less than allowable |
| Harris Creek Trib | 59.68 | 8.0 | | | | | | 5.3 | Less than allowable |
| Muddy Branch | 69.23 | 9.23 | | | | | | 10.0 | Less than allowable |
| East Fork Mill Creek | 81.20 | 126.0 | | | | | x | 10.3 | Less than allowable |
| Dogwood Creek | 89.23 | 11.13 | | | | | | 9.2 | Less than allowable |
| West Fork Mill Creek | 90.83 | 44.0 | | | | | | 7.8 | Less than allowable |
| Jacks Creek | 98.31 | 11.8 | | | | | | 10.9 | Less than allowable |
| Cummins Creek | 99.23 | 94.32 | | | | | | 9.2 | Less than allowable |
| Rabbs Creek | 112.26 | 81.3 | | | | 1 | | 7.6 | Less than allowable |
| Knobbs Creek | 118.76 | 23.19 | | | | | | 6.3 | Less than allowable |
| Dreissner Branch | 119.86 | 6.78 | | | | | | 8.2 | Less than allowable |
| Pin Oak Creek | 122.55 | 50.11 | | | | | | 10.0 | Less than allowable |
| Gravelly Creek | 122.96 | 18.69 | | | | | | 8.2 | Less than allowable |
| JD Creek | 126.66 | 6.68 | | | | | x | 12.0 | Greater than allowable |
| Alum Creek | 131.47 | 46.06 | | | x | 1 | x | 13.7 | Greater than allowable |
| Little Alum Creek | 132.35 | 4.63 | | | | | x | 11.7 | Greater than allowable |
| Dry Creek | 157.40 | 22.17 | | | | | | 9.4 | Less than allowable |
| Cottonmouth Creek | 162.34 | 2.23 | | | | | | 5.7 | Less than allowable |
| Marble Creek | 163.51 | 3.8 | | x | x | 1 | | 7.5 | Less than allowable |
| Onion Creek | 163.99 | 284.4 | | x | x | 1/2 | x | 15.6 | Greater than allowable |
| Boggy Creek | 168.50 | 1.19 | | x | x | 1 | | 7.8 | Less than allowable |
| Slaughter Creek | 174.66 | 3.03 | | x | x | 1 | | 10.8 | Less than allowable |
| Long Branch | 179.70 | 4.49 | | x | x | 1 | x | 12.8 | Greater than allowable |
| Barton Creek | 180.92 | 40.9 | | x | x | 1/2 | x | 19.0 | Much greater than allowable |
| Fitzhugh Creek | 185.60 | 4.26 | x | x | x | | x | 13.4 | Greater than allowable |
| Unnamed Trib of Ped. | 190.30 | 1.22 | x | x | x | | x | 12.2 | Greater than allowable |
| Flat Creek | 193.21 | 31.04 | x | x | x | | x | 23.0 | Much greater than allowable |
| Unnamed Trib of Ped. (St park) | 196.20 | 0.60 | x | x | x | | | 9.5 | Less than allowable |
| Unnamed Trib of Ped. | 198.20 | 1.88 | x | x | x | | x | 13.8 | Greater than allowable |
| Unnamed Trib of Ped. | 199.40 | 1.58 | x | x | x | | | 10.3 | Less than allowable |
| Unnamed Trib of Ped. | 202.00 | 3.01 | x | x | x | | | 11.3 | Less than allowable |
| Cottonwood Creek | 203.19 | 10.34 | x | x | x | | x | 18.0 | Much greater than allowable |
| Trib of Salter Springs Creek | 205.10 | 0.32 | x | x | x | | | 6.1 | Less than allowable |
| Salter Springs Creek | 206.02 | 1.88 | x | x | x | | | 11.5 | Less than allowable |
| Buffalo Creek | 208.00 | 3.89 | x | x | x | | x | 18.4 | Much greater than allowable |
| Hickory Creek | 209.92 | 12.20 | x | x | x | | x | 14.5 | Greater than allowable |

## Table 2. (Continued)

| Stream Name | Mile-post | Basin Area (mi²) | Rock bed? | Tier 3? | Tier 2? | Further Study Effort: Study Level per DOT HEC20 | Further Study Effort: Aerial Photo Review | Estimated 100-Year Maximum Velocity in Center Channel (fps) | Estimated Velocity vs. Allowable for 100-Year Flow |
|---|---|---|---|---|---|---|---|---|---|
| Spring Creek | 211.52 | 4.68 | x | | x | | x | 13.3 | Greater than allowable |
| White Oak Crerk | 213.26 | 7.52 | x | x | x | | x | 15.5 | Greater than allowable |
| Crabapple Creek | 229.33 | 63.38 | x | x | x | | x | 27.2 | Much greater than allowable |
| Unnamed trib of Crabapple Ck | 230.80 | 0.15 | x | x | x | | | 9.1 | Less than allowable |
| Unnamed trib of Sandy Ck | 233.20 | 0.36 | x | x | x | | | 8.3 | Less than allowable |
| Sandy Creek (1) | 234.85 | 1.45 | x | x | x | | x | 12.1 | Less than allowable |
| Sandy Creek (2) | 236.70 | 2.44 | x | x | x | | x | 13.3 | Marginally less |
| Bemst Creek | 237.81 | 3.75 | x | | | | x | 13.1 | Greater than allowable |
| Blockhouse Creek | 240.30 | 1.59 | x | x | x | | | 11.1 | Less than allowable |
| Cherry Spring Creek | 241.67 | 11.03 | x | | | | | 11.3 | Less than allowable |
| Marschall Creek | 242.67 | 10.92 | x | | | | x | 12.8 | Greater than allowable |
| Cedar Hollow | 248.30 | 1.71 | x | x | x | | | 10.1 | Less than allowable |
| Squaw Creek | 248.49 | 39.63 | x | x | x | | x | 21.0 | Much greater than allowable |
| Threadgill Creek | 249.99 | 117.29 | x | x | x | | x | 23.6 | Much greater than allowable |
| James River | 263.90 | 322.12 | x | x | x | 1/2 | x | 23.4 | Much greater than allowable |
| Mill Creek | 267.87 | 7.33 | x | x | x | | x | 12.4 | Greater than allowable |
| Rocky Creek | 273.69 | 10.49 | x | | | | x | 16.1 | Greater than allowable |
| Terret Draw | 315.94 | 34.6 | | | | | | 8.3 | Less than allowable |
| Middle Valley | 324.21 | 137.21 | | | x | | | 7.6 | Less than allowable |
| Antelope Draw | 334.27 | 61.99 | | | x | | | 7.2 | Less than allowable |
| Big Lake Draw | 402.60 | 46.0 | | | | | | 5.8 | Less than allowable |
| Unnamed | 415.81 | 24.5 | | | | | | 7.1 | Less than allowable |
| China Draw | 433.10 | 17.1 | | | | | | 4.6 | Less than allowable |
| Mayfield Draw (1) | 450.22 | 76.30 | | | | | | 4.0 | Less than allowable |
| Cottonwood Creek | 565.29 | 247.52 | | | | | x | 14.8 | Greater than allowable |
| Cottonwood Creek | 577.29 | 63.4 | | | | | | 8.4 | Less than allowable |
| Frijole Draw | 585.89 | 7.8 | | | | | | 9.0 | Less than allowable |
| Burro Cayon | 597.72 | 8.82 | | | | | | 2.4 | Less than allowable |
| Cox Canyon | 601.13 | 21.2 | | | | | | 5.1 | Less than allowable |
| Unnamed | 625.14 | 16.2 | | | | | x | 13.3 | Greater than allowable |
| Antelope Gulch | 631.0 | 797.8 | | | | | | 11.2 | Less than allowable |
| Antelope Draw | 651.27 | 48.4 | | | | | | 11.2 | Less than allowable |

*All major crossings (Brazos, Colorado, Pedernales, Llano, and Pecos Rivers had Level 1/2 study per HEC20, and aerial photo analysis
**Per URS Calculation C-6, Estimation of Velocities at Stream Crossings

Table 2 presents a comparison of estimated maximum flood flow velocities at each crossing versus maximum allowable flow velocities. It should be noted that this comparison, which is based upon a series of conservative assumptions, is performed for the purpose of identifying crossings needing further study and is not an identification of crossings where failure is likely. The documentation for this comparison is provided in Summary of Scour-related Study (URS Radian, in draft). These results show:

- East of Milepost (MP) 125, each evaluated crossing had flood velocities unlikely to overstress a pipeline, unless a very long length of pipeline was exposed. There is no history of such exposure.
- West of MP 280, only two crossings had potentially unacceptable velocities. The smallest of the two watersheds corresponding to these crossings was 16 square miles. Crossings not evaluated in this reach have watersheds significantly less than 16 square miles.
- Between MP 125 and MP 280, 22 crossings had potentially unacceptable velocities, ranging from "marginally less" to "much greater than" the estimated allowable velocity.

### 2.3.2 Aerial Photograph Analysis

Current and historic aerial photographs were compared for 30 crossings. Twenty-four of the 30 crossings had potentially excessive velocities in the hydraulic study and six were major river crossings (Brazos River, Colorado River, Onion Creek, Pedernales River, Llano River, and Pecos River). Comparisons were made for a distance of one-half mile upstream and one-half mile downstream of each crossing. The purpose of the comparison was to identify any significant changes in stream flow regime or visual evidence of scour which would warrant a site-specific geomorphic study.

No potential significant instabilities in the immediate area of these pipeline crossings were noted. These analyses noted that at three of the crossings there was a potential significant area of instability within one-half mile of each crossing. These crossings were JD Creek, Long Branch, and a Sandy Creek tributary (at MP 236.7). At the Barton Creek crossing, the 1964 photography was exceptionally poor. Given the importance of that crossing, this crossing was also identified for further study.

### 2.3.3 Site-specific Study/Mitigation Design

Fifteen crossings were selected for detailed, site-specific analyses. These include the six major river crossings (Brazos River, Colorado River, Onion Creek, Pedernales River, Llano River, and Pecos River), the four crossings identified in the aerial photograph analysis (JD Creek, Long Branch, Barton Creek, and Sandy Creek at Milepost 236.7), all hypersensitive (Tier 3) crossings with alluvial (as opposed to rock) streambeds (Marble Creek, Boggy Creek, Slaughter Creek), and all sensitive (Tier 2) crossings identified as potentially having excessive flood flow velocities (Alum Creek). The Rabbs Creek and Cedar Creek crossings, which were known by earlier observation to be unstable, were also studied as part of the remedial design process.

These studies were performed in accordance with the procedures for Level 1 study (Geomorphic Analyses) described in “Stream Stability at Highway Structures” (DOT, 1991). These procedures require a site visit by a qualified geomorphologist and site-specific evaluations of lateral, vertical, and overall stream stability. The results from these studies and the recommended mitigations are summarized in Table 3 on the following page.

**Evaluation by Capozolli Associates (6/30/00)**

| Crossing | Mile-post | Stability | | | Risk | Reasoning for Low Risk in Unstable Channel | Recommende |
|---|---|---|---|---|---|---|---|
| | | Overall | Lateral | Vertical | | | |
| Pecos River | 525.5 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Llano River | 276.6 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| James River | 263.9 | Stable | Stable | Stable | low | | |
| Sandy Creek | 236.7 | Stable | Stable | Stable | low | | Replace cover where pipe |
| Pedernales River | 198.7 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Barton Creek | 180.92 | Stable | Marginally unstable | Marginally unstable | low | Small estimated suspended length of pipe in flow | Inspect and reanalyze at le |
| Long Branch Creek | 179.7 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Slaughter Creek Tributary | 174.66 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Boggy Creek | 168.5 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Onion Creek | 164 | Stable | Marginally unstable | Marginally Stable | low | Small estimated suspended length of pipe in flow | Inspect and reanalyze at le |
| Marble Creek | 3.8 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| Cedar Creek tributary | | Marginally unstable | Unstable | Unstable | low | | Replace cover where pipe |
| Colorado River | 134.5 | Stable | Marginally Stable | Marginally unstable | high | | Inspect and reanalyze bian second standard flood |
| Alum Creek | 131.47 | Stable | Stable | Stable | low | | Inspect and reanalyze at le |
| JD Creek | 126.66 | Marginally unstable | Stable | Marginally unstable | high | | Lower crossing to below s |
| Pin Oak Creek | 122.55 | Stable | Marginally unstable | Marginally unstable | low | Small estimated suspended length of pipe in flow | Inspect and reanalyze bian second standard flood |
| Rabbs Creek | 122.96 | Unstable | Unstable | Marginally unstable | high | | Reinstall crossing outside channel limits |
| Cummins Creek | 99.23 | Stable | Marginally unstable | Marginally unstable | low | Small estimated suspended length of pipe in flow | Inspect and reanalyze at le |
| Brazos River | 64 | Stable | Marginally unstable | Marginally unstable | low | Pipeline recently reinstalled by directional drilling | Inspect and reanalyze at le |

For the major river crossings, selected tasks from Level 2 (Basic Engineering Analyses) were also performed. Table 4 below provides a comparison for seven of the major crossings, between floods which have occurred during the life of the pipeline and statistically derived extreme floods. Among these crossings, only the Pedernales River and Pecos River appear to have experienced floods greater than the statistical 50-year flood during the lifetime of the pipeline.

**Table 4. Flood Events Exceeding Recurrence Interval Peak Flows Since Construction of the Pipeline (per IT Corporation, 6/30/00)**

| Stream Name | USGS Station | Period of Record | Flood Events by Recurrence Interval | | | | |
|---|---|---|---|---|---|---|---|
| | | | 10-yr | 25-year | 50-year | 100-year | 200-year |
| Barton Creek at Loop 360 | 8155300 | 1976-1998 | May-81<br>Dec-91 | | | | |
| Brazos River near Hempstead | 8111500 | 1939-1998 | May-65<br>Dec-91<br>Oct-94 | May-57 | | | |
| Colorado River at Bastrop | 8159200 | 1960-1998 | Oct-60<br>Jun-81<br>Dec-91 | | | | |
| Llano River at Junction | 8150000 | 1916-1995 | Sep-80<br>Oct-81<br>Dec-84 | | | | |
| Onion Creek at Hwy 183 | 8159000 | 1976-1998 | | Jun-81<br>Dec-91 | | | |
| Pecos River near Orla | 8412500 | 1938-1998 | Oct-55 | | Sep-78 | | |
| Pedernales River near Johnson City | 8153500 | 1940-1998 | Apr-57<br>Apr-77<br>Aug-78 | Oct-59 | | | Sep-52 |

Four channels noted to be marginally unstable (laterally and/or vertically) were assigned a low risk. The maximum length of suspended pipeline for these four crossings are each estimated within the report to be less than 40 ft. Based upon this small estimated suspended length, the risk for the crossing is stated to be low. These suspended lengths are estimated using rules of thumb derived from the report author's personal experience. This method is not deemed sufficiently conservative for the purposes of this EA. Two of these crossings, Barton Creek and Onion Creek are large crossings with potentially high flood velocities. Cummins Creek and Pin Oak Creeks are relatively large streams with a relatively low estimated maximum velocities. Barton Creek and Onion Creek are also each Tier 3 crossings. Given the above, Barton Creek and Onion Creek should be considered of sufficient width and flow velocity to require some mitigation to constrain the maximum width of pipe suspension during flood flows.

The crossing at Slaughter Creek tributary is noted in the report as an aboveground crossing, but is not included in the listing of intentional spans. The crossing is currently scheduled for burial (conversation with Allan Wolff, WES, 7/3/00).

In addition, the study of the Colorado River crossing notes the crossing as high risk and notes the potential for “detrimental erosion around the rip-rap blanket's edges” during flood events. The report also notes “slump-induced marginal ‘ridges’ on the bank slopes paralleling the channel” and uses this observation as a basis for stating the crossing is marginally stable laterally. Given this, some mitigation should be performed to address this potential erosion and the potential slope instability.

### 2.3.4 Evaluation of Rock Crossings

The estimation of velocities at pipeline crossings showed the potential flood velocities at selected crossings confined within limestone beds and banks to be extremely high, between 18 and 30 feet per second for the 100-year flood. The exposure of more than 40 feet (ft) of suspended pipe to these velocities could potentially lead to excessive pipeline stresses, and, ultimately, leakage.

WES prepared a report addressing the construction of the pipeline crossings within the rock bed region (approximately MP 181 to MP 277). This report included a review of available construction details for crossings within this region and a description of none crossings which were visited in June 2000. In summary the report states:

- Construction specifications exist for selected major river crossings only: the Llano and Pedernales rivers. At these crossings, a trench was to be blasted or cut into the rock bed such that the top of the pipe will be a minimum of 4 inches below the lowest point of the riverbed. The pipe was then backfilled with small rock and earth within 6 inches of the surface of the riverbed and the ditch was then sealed with 6 inches of concrete made smooth and flush with the riverbed.
- The replacement of the James River crossing in May 1998 included the installation of river weights at 50 to 70 ft spacings along the pipeline.
- The nine additional crossings visited in June 2000 included several crossings with extremely high potential flood velocities (Barton Creek, Cottonwood Creek, Crabapple Creek, Buffalo Creek, and Threadgill Creek). These crossings were all found to be placed within a trench in the rock bed such that the pipeline rests below the surface of the streambed. Cover for the pipeline generally consisted of native erodible material. One of the crossings showed signs of recent work to replace cover (Threadgill Creek) and one (Cottonwood Creek) showed a need to have cover re-installed.
- Several of the crossings with rock beds were scheduled previously for mitigation to add/replace cover. These include Flat Creek and Fitzhugh Creek.

Given that the cover for the pipeline within the rock bed crossings has the potential to erode during flood conditions, the pipeline could potentially float up into the flood flow, exposing suspended pipe to flood velocity-induced stresses. A calculation was performed to estimate maximum pipeline lengths exposed for varying flood velocities. This calculation estimated the following:

- The six-inch concrete covering placed over the pipeline for the major river crossings is sufficient to prevent uplift during flooding.

- For 50 ft of exposed trench, there is essentially no risk of the pipeline being uplifted into flow for the range of velocities estimated. For 100 ft of exposed trench, there is essentially no risk of the pipeline being uplifted into flow for velocities under 22 feet per second. For over 150 ft of exposed trench significant lengths of pipeline could be uplifted into flow for velocities over 12 ft per second.

Given the above, five crossings have widths large enough and velocities high enough to warrant prevention of uplift into flood flow. These crossings are Flat Creek, Cottonwood Creek, Crabapple Creek, Squaw Creek, and Threadgill Creek.

## 2.4 STUDY CONCLUSIONS

The basic conclusions to be derived from this study are:

- No leaks have been attributed to failure associated with erosion or scour along the pipeline.
- Minor repairs have been performed to replace eroded cover at a few crossings, and major repairs have been performed at two major river crossings: the Brazos River, and the Colorado River.
- Depth of cover is being enhanced at selected crossings (Fitzhugh Creek, Flat Creek) addressed elsewhere within the LMP.
- The crossings at Rabbs Creek and Cedar Creek tributary are noted as unstable.
- The crossing at Sandy Creek tributary (MP 236.7) was noted to require additional cover.
- The Colorado River crossing is high risk and has the potential for flood-induced erosion at the edges of the rip-rap blanket. Some instability is noted in the bank slopes.
- The crossings at Barton Creek and Onion Creek are marginally unstable (laterally and vertically) and have high potential flood velocities.
- The crossings at Pin Oak Creek and Cummins Creek are marginally unstable (laterally and vertically) and have relatively low potential flood velocities.
- Five crossings have widths large enough and velocities high enough to warrant prevention of uplift into flood flow. These crossings are Flat Creek, Cottonwood Creek, Crabapple Creek, Squaw Creek, and Threadgill Creek.

## 2.5 STUDY RECOMMENDATIONS

Given the study conclusions, the following mitigation measures are recommended:

- The Rabbs Creek crossing should be reinstalled outside of the modern gross channel limits.
- The JD Creek crossing should be lowered to below scour potential.
- Cover should be replaced on exposed pipe at Cedar Creek tributary, Sandy Creek tributary (MP 236.7), Slaughter Creek tributary, and Cottonwood Creek (MP 203.19).
- The Colorado River crossing should be mitigated to prevent erosion of the rip-rap blanket during floods and to prevent further slumping within the bank slopes.

- The pipeline at the Barton Creek crossing should be mitigated to prevent suspension of over 50 ft of pipeline into flow, assuming the entire alluvial low-flow channel bed is eroded below the depth of the current pipeline. The length of 50 ft is derived from the maximum estimated flood flow velocity at the crossing.
- The pipeline at the Onion Creek crossing should be mitigated to prevent suspension of over 70 ft of pipeline into flow, assuming the entire alluvial low flow channel bed is eroded below the depth of the current pipeline. The length of 70 ft is derived from the maximum estimated flood flow velocity at the crossing.
- River weights, or other negative buoyancy measures, should be placed at 50-ft spacing or less within the bank-to-bank span at the crossings of the following creeks to prevent uplift of the pipeline into flood flows: Flat Creek, Cottonwood Creek, Crabapple Creek, Squaw Creek, and Threadgill Creek.

# 3.0 SPAN STUDY

## 3.1 PURPOSE AND HISTORY OF STUDY

The purpose of the subject analysis was to determine the adequacy of the engineered aboveground pipe spans (and their supports) with respect to normal and abnormal external loading. This study was required per LMC 15. The study was performed by WES of Tulsa, Oklahoma and reviewed by URS Radian. An initial draft of the study report was presented in March 2000. Reviewers' comments on the initial draft and on a subsequent draft revision were provided in April 2000 and May 2000, respectively. Comments were incorporated into a final revised report in June 2000. The revised report also contained an addendum containing span calculations with respect to lateral loading in 100-year flood levels, performed by Mustang Engineering of Houston, Texas.

Attachment 9 to this appendix was prepared by Longhorn to clarify the relationship between its depth-of-cover studies and this Span Study.

## 3.2 SCOPE OF WORK

The purpose of the subject report was to verify that all aboveground pipeline spans are adequately supported vertically and restrained laterally from credible loading scenarios, including those due to gravity, internal pressure, and external applied loads (LMC 15a). The study addressed 20 aboveground spans that were identified as aboveground crossings and were to remain as such.

Each aboveground span was visually inspected to verify the existence of an adequate number of pipe supports, such that pipe spans were limited to pre-calculated lengths based on applied dead load (i.e., load due to gravity) and the internal pressure. Pipe coating and pipe supports were also inspected for integrity. Historical floodwater elevations were noted based on field inspections in the main report and against flood plain maps in the addendum. Unusual site-specific conditions were noted and remedial measures were recommended. The field inspections included checklists and site photographs.

The maximum allowable pipe spans were calculated based on ASME B31.4 ("Liquid Transportation Systems for Hydrocarbons, Liquid Petroleum Gas, Anhydrous Ammonia and

Alcohol”) requirements for gravity loads and internal pressure. No corrosion allowance was included as actual measurements from each site were used in the calculations. Allowable span lengths were based on the assumption of a beam fully restrained against rotation at its supports when calculating the applied stresses in the span.

### 3.3 STUDY CONCLUSIONS

The study conclusions indicate that 19 of the aboveground spans are adequate with respect to the length between supports per ASME loading criteria. One span (site 5008) was found to exceed these criteria. However, the existing pipe supports at this location require modification (replacement), and hence, adequate span lengths shall be provided during the design of the new supports. The foundations for the pipe supports at site 5026 were also noted as being in poor condition and will require replacement and/or repair.

Four crossings (sites 7004, 2019, 5025, and 5018) were found to be submerged during normal rainfall, and therefore, will be buried below grade.

The report addendum that addressed pipe spans that could be subjected to lateral loads during flood conditions identified three locations where the pipe spans lay within the 100-year flood plain (sites 5026, 5027, and 5023).

Impact by foreign bodies on the pipeline was addressed qualitatively in the addendum. The effect of impact was not considered to be significant given the margin of safety with respect to ASME design criteria under normal operating loads and given the relatively low velocities typical of the flood conditions of these locations.

### 3.4 STUDY RECOMMENDATIONS

The report recommends:

- Sites 5008 and 5026 require remedial engineering effort to redesign and replace/repair the existing pipe supports. The designs should be consistent with ASME design criteria.
- The four sites where the spans are normally submerged during rainfall (sites 7004, 2019, 5025, and 5018) should be replaced by buried pipe. These sites may require concrete coating to counteract buoyancy.
- All spans will require some coating rework of the exposed pipe, pipe-to-support contact area, and at the pipe-to-ground transition. However, coating rework and pipe support painting can be accomplished as part of normal pipeline maintenance.
- The cradles and pipe guides at sites 5026 and 5027 require reconditioning due to corrosion. They may not be able to resist imparted lateral loads in their current state. Site 5023 should also be reconditioned, as necessary. Structural modifications to the guides at these locations should be considered in conjunction with the repairs in order to increase their load-bearing capacity.
- Exposed spans should be inspected following any incidents of flooding where the pipeline is submerged and any damage/deformation to the pipeline and pipe supports should be noted during inspection, and assessed following inspection, before resuming operations.

# 4.0 ROOT CAUSE STUDY

## 4.1 PURPOSE AND HISTORY

The purpose of the root cause analysis is to evaluate root cause of failures and damage resulting in repairs on the Longhorn Pipeline System. This study was required per LCM 19. The analysis is to identify root causes of previous leaks and damages and to combine these causes with appropriate mitigation to ensure that the damage is not repeated. This removes a 'penalty' in the risk assessment as described in Chapter 6 of the Environmental Assessment (EA).

The history of the development of the analysis is as follows:

- Draft 1. The report "Root Cause Analysis of Accidental Releases on the Former Exxon 18-Inch Kemper to Satsuma Crude Oil Pipeline (LCM 19c, Longhorn Mitigation Plan [LMP])" dated April 4, 2000, addresses 27 incidents that occurred over a 45-year life of the subject pipeline. Kiefner and Associates, Inc. prepared an earlier report on the integrity of this pipeline and prepared this report.
- Draft 2. The report "Root Cause Analysis Report for Failure/Damage Resulting in Repairs from Galena Park to Crane Texas," by Longhorn Partners Pipeline, dated May 2000, expands the work begun in Draft 1 by categorizing and further analyzing the 27 leaks and by including categorization and analysis of repairs.

## 4.2 SCOPE OF WORK

The scope of work of each of the two reports is summarized below.

Draft 1. This study is basically a review of available documentation on previous spills. Twenty-seven spills are tabulated and described in the report. The earliest incident is dated 1970. The descriptions are apparently derived from information provided to Longhorn by Exxon Pipeline Company (EPC). A list of data available for each incident is provided and the type of repair is usually noted. In many cases, incident causes are unknown. Little or no speculation is provided when documentation does not specify causes. No field investigation is noted in the report.

Draft 2. The repair analysis is based on a listing of approximately 195 repairs from EPC and WES records. Approximately 90 repairs were not analyzed since they were classified as system upgrades or non-damage-related adjustments (such as lowering for new roads, etc.). The analysis procedure described in this report is based on a reference book on root cause analysis. All events are classified as "failure" or "repair" and then categorized into one of four "modes": corrosion, incorrect operations, third-party damage, or design deficiency. Probable cause hypotheses were next assigned to each event and verified by detailed review of data surrounding each event. Root cause analyses were then performed using roots of "physical roots," "human root causes" (errors of omission and errors of commission), and "latent root causes." Corrective actions and trends were then identified. Pie charts, bar charts, tree diagrams, and data tables are included.

No field investigation is noted in either draft.

## 4.3 STUDY CONCLUSIONS

Conclusions generally indicate that no unusual or difficult-to-explain failure modes were involved in these incidents. Therefore, the system-wide practices and protocols, including the actions specified in the LMP, should mitigate potential future failures and damages.

## 4.4 STUDY RECOMMENDATIONS

Recommendations are included for each event hypotheses. These refer to LMP-specified or other actions planned or already taken that address the failure or damage initiator, as that initiator is defined in the analysis. No actions beyond those already specified are recommended by the study.

The EA's post-mitigation relative risk assessment reflects this root cause study by removing previously assigned 'penalties' for past failures and repairs. The rationale for the penalties and their removal is described in Chapter 6 of the EA.

# 5.0 CORROSION STUDY

## 5.1 PURPOSE AND HISTORY OF STUDY

The subject study addresses the susceptibility of the Longhorn pipeline to stress corrosion cracking (SCC). This study was required per LMC 19. Kiefner and Associates of Worthington, Ohio performed the study, documenting results with supporting evidence (March 2000 report). URS Radian acted in a review role providing comments on the original study (April 2000). A single revision was made to the report (June 2000), which incorporated the reviewer's comments.

## 5.2 SCOPE OF WORK

The report documenting the susceptibility of SCC is divided into three parts:

- Introduction: An outline of the phenomena of SCC with historical evidence of its effects on pipeline systems.
- Background: A more detailed description of the two SCC mechanisms that potentially could be most relevant to the Longhorn pipeline.
- Conclusion: A judgement as to whether the identified SCC mechanisms could affect the Longhorn pipeline is made, based on supporting qualitative arguments.

The case for SCC not being a significant hazard for the pipeline is presented qualitatively using historical evidence from existing pipelines that are used to transport petroleum products and natural gas, past inspection of the pipeline, and the proposed plans for future inspection of the pipeline during operation. Evidence presented is based on two forms of SCC: high-pH SCC that is more prevalent in gas pipelines and near-neutral pH SCC, which is more dependent on the interaction of the external environment with the pipeline material. The report identifies the conditions for a pipeline that make it susceptible to either type of SCC and the controlling parameters for the SCC mechanism, such as fluctuation in pressure loads (pipeline stress), temperature, and electric potential (corrosion environment). In the general discussion, conditions commonly seen during SCC are identified, such as the presence of disbonded coating, specific terrain conditions, alternating wet and dry conditions, and soils that tend to damage or disbond coatings.

General conclusions are drawn on the susceptibility of the Longhorn pipeline to SCC using the body of evidence in the report as support. Specific conclusions are also made with respect to the Longhorn pipeline based on the pipeline operating conditions and operational experience.

### 5.3 STUDY CONCLUSIONS

The known conditions that are required to develop crack initiation and growth by SCC were compared to those present in the environment local to the Longhorn pipeline. It was concluded that the conditions relating to operating temperature, type of coating, and ground water temperature were not present, and hence, SCC was unlikely to occur.

The theoretical presence of SCC due to an unidentified environmental factor was also discussed by postulation of the presence of a crack that was initiated by SCC. It was noted that the dominant mechanism for crack growth on the pipeline was due to mechanical loading. Consequently, even if the postulated crack was initiated by an SCC mechanism, its effect on the line would be insignificant as crack growth would be due to the mechanical loading rather than a continuous SCC process.

The potential hazard to the Longhorn pipeline from SCC is therefore argued as being small.

### 5.4 STUDY RECOMMENDATIONS

No recommendations for remedial action to modify the existing pipeline are made in the report. The report notes that mechanical fatigue is more of an issue with respect to crack growth and comments that this has already been addressed by a credible operational plan of inspection. This operational plan is also most likely to identify initiation of cracks by both mechanical and SCC effects.

## 6.0 GEOLOGIC HAZARDS

### 6.1 PURPOSE AND HISTORY OF STUDIES

The purpose of the geologic hazards studies was to determine the qualitative and semi-quantitative risk of pipeline failure due to geologic hazards. The studies include geologic hazards such as seismic events (earthquakes), landslides or mass earth movement, subsidence of the ground, and stresses on the pipeline due to soil movement caused by variations in soil moisture.

The studies were conducted by IT Corporation of Houston, Texas between March and June 2000. Fugro-South, Inc. of Houston, Texas conducted a focused sub-study for the subsidence study. The study reports were reviewed by geotechnical engineers and geologists at

URS Radian. Draft reports were submitted to URS Radian who reviewed the reports and provided suggestions for revisions or further studies for the final reports.

## 6.2 EARTHQUAKE HAZARDS

### 6.2.1 Scope of Study

The report titled "Assessment of Earthquake Hazards, Longhorn Pipeline Project" is organized into the following sections:

Section 1 - Introduction
Section 2 - Technical Approach
Section 3 - Regional Patterns of Earthquake Activity
Section 4 - Earthquake Analysis Factors
Section 5 - Analysis of Earthquake-Induced Hazards
Section 6 - Conclusions
References

Section 5 is divided into subsections corresponding to the four seismotectonic provinces in Texas. Each province subsection contains province-specific discussions relating to geologic setting, earthquake history, vibratory ground motion, tectonic faulting, liquefaction and landslides, and aseismic faulting. Aseismic faulting in the Gulf Coastal Plains province is described further in "Study of Aseismic Faults and Regional Subsidence Along Longhorn Partners Pipeline, Harris County, Texas."

The report is based on literature searches and review of earthquake records. No field investigations or site reconnaissance were conducted as part of the study. Data were collected from published and unpublished literature including Georef, Earthquake Engineering Research Institute, Multidisciplinary Center for Earthquake Engineering Research, Bureau of Economic Geology, New Mexico Institute of Mining and Technology, various seismic-related literature from Rice University, licensing documents from the South Texas Nuclear Power Plant and Texas Low Level Radioactive Waste Disposal Authority, United States Geologic Survey (USGS), and "A Compendium of Earthquake Activity in Texas." The report should be consulted for specific references.

Assessment of earthquake-induced hazards along the pipeline was achieved by describing past and potential future seismic and aseismic ground movements in the three seismotectonic provinces through which the pipeline passes. These are the Gulf Coastal Plain, Central Texas, and Rio Grande Graben – West Texas Seismotectonic provinces.

### 6.2.2 Conclusions

The probability of significant earthquakes (and associated ground movements) were classified as "Low" for all four provinces in the state, as was the expected ground acceleration. The expected magnitude of a significant earthquake was listed as less than 5.0 (Richter Scale) for the Central Texas and Gulf Coastal Plain areas and less than 6.0 for the Rio Grande – West Texas area.

### 6.2.3 Recommendations

There were no recommendations for action presented within the earthquake study.

## 6.3 LANDSLIDE/MASS MOVEMENT HAZARDS

### 6.3.1 Scope of Study

The report titled "Evaluation of the Potential for Non-Seismic Induced Slope Failures (Landslides and Debris Flows) Along the Longhorn Pipeline Right-of Way" is organized into the following sections:

Scope of Study
Factors Affecting Soil Stability
Conditions Along the Pipeline Right-of Way
Observations During Site Inspections (Galena Park Terminal to Warda Station)
Observations During the Fly-Over Inspection (Warda Station to El Paso Terminal)
Potential for Slope Failure Along the Longhorn Pipeline

The study was initiated by reviewing the pipeline alignment maps and the associated topography to determine areas with slopes of 20 percent or greater (five horizontal to one vertical). Those areas were then identified and either visited on the ground or viewed from a low-flying, low-speed airplane.

The study also describes the geologic and climatic conditions along the route that could effect the stability of slopes. Geologic conditions were assessed through review of Bureau of Economic Geology maps and literature and climatic conditions were determined from data provided by Texas A&M.

### 6.3.2 Conclusions

Review of geologic and climatic conditions and the site reconnaissance were used to conclude that there is a minimal risk of damage or failure due to landslides or mass earth movements. The only area of potential concern are the rocky regions along the pipeline where pipe is exposed and could be susceptible to damage from rock falls in ravines or below rock bluffs. These area are few and the natural processes that work to produce rock falls work slowly in the semi-arid western reaches of the pipeline, so even this potential risk is considered low.

In order to ascertain the procedures in place to monitor excavation in the vicinity of the pipeline, Allan Wolff of WES was interviewed (7/3/00). The Williams Company, which operates and maintains the Longhorn pipeline has a process management procedure entitled "Project Life Cycle." This procedure states that all capital projects are assigned to an engineer within the Operations and Technical Services Department who technically reviews the project prior to construction. This review would include consideration of slope stability if the project requires excavation on an exposed slope.

Maintenance crews may perform small maintenance projects along the pipeline without engineering input. These projects are less than $5,000 to $10,000 in cost. These projects typically involve repairs of less than 50 ft of pipeline (conversation with Allan Wolff, Williams Pipeline, 7/3/00).

### 63.3. Recommendations

The study recommends covering the pipe where it is exposed in areas susceptible to rock fall damage.

Future unforeseen construction activities near or in the pipeline right-of-way may produce slopes that are not stable and could put the pipeline at risk. These activities include excavation for road or railway cuts, removal of material from the toe of a slope, or adding significant material to the crest of a slope. Given that maintenance activity involving excavation could potentially occur without engineering supervision, it is recommended that safety training of maintenance crews include education on the conditions potentially leading to slope failure. Standard procedures should be written to require notification of an engineer should such conditions be found to exist.

Slope alterations near, but outside the right-of way, by third parties must be monitored and the responsible parties notified and questioned about their project's effect on the pipeline. This recommendation is already addressed by pipeline patrolling measures within the LMP, which includes the task of identifying any construction near the pipeline that could impact the pipeline.

## 6.4 ASEISMIC FAULTING/SUBSIDENCE HAZARDS

### 6.4.1 Scope of Study

This study was undertaken to address potential risk to the pipeline due to well known and documented regional subsidence in the Houston metropolitan area. Significant aseismic activity resulting in ground movement is limited to this reach of the pipeline. The report titled "Study of Aseismic Faults and Regional Subsidence Along Longhorn Partners Pipeline, Harris County, Texas" is organized into the following sections:

- Introduction (Discussion of individual faults that cross the pipeline)
- Possible Fault Crossings
- Effects of Regional Subsidence on the Longhorn Partners Pipeline
- Monitoring Fault Movement
- Design of Bench Marks for Monitoring Fault Movement

The introduction describes the general nature of aseismic faulting in the Houston area, based on IT Corporation's experience and published literature. The faulting is due to consolidation of sediments as a result of groundwater pumping and shallow hydrocarbon production.

The faults that cross, or possibly cross the pipeline were identified using published literature and aerial photographs. This investigation yielded four definite fault crossings and a few other possible crossings. Each of the four confirmed fault crossings were investigated in the field to estimate their rates of movement. Rates on the order of 0.2 inches per year (vertical movement) were estimated from field observations. One of the identified faults, the Breen Fault, was further studied in a focused report by Fugro-South, Inc. Four other possible fault crossings were identified.

The report discusses the history of subsidence in the Houston area, its causes, and its relation to the Longhorn pipeline.

#### 6.4.2 Conclusions

The regional subsidence does not pose a hazard to the pipeline because deformations within the subsidence region are small, gradual, and occur over a distance of some 30 miles or more. Pipelines are tolerable to this kind of movement.

#### 6.4.3 Recommendations

Recommendations for monitoring at the four confirmed fault crossings are consistent with the practice of other pipeline owners/operators in the Houston area. Monitoring will consist of elevation readings on either side of the fault at the pipeline crossing.

### 6.5 SOIL STRESS HAZARDS

#### 6.5.1 Scope of the Study

The purpose of this study was to identify the potential for the shrink or swell behavior of pipeline foundation soils that lead to excessive pipe deflections. The potential for excessive deflections is largely confined to locations where the pipeline connects with a facility (pump station or terminal) on a foundation. In this circumstance, the difference in loading on foundation soils below the pipeline and below the facility could lead to differences in settlement and stresses on connections. The study to address this issue was limited to the preparation of a brief letter report (by WES) describing the engineering controls and construction procedures employed by Longhorn Partners to account for soil shrink/swell behavior at pump stations and terminals.

#### 6.5.2 Conclusions

Longhorn Partners concludes that through the use of engineering controls and certain construction procedures and construction quality assurance that soil shrink/swell behavior will not adversely affect the pipeline. These controls include:

- Adjustable supports for above grade piping,
- Underground pipe supports for below grade piping,
- Pipe straps to limit lateral and vertical pipe movements
- Pipe anchors to limit longitudinal pipe movement, and

- Construction quality control measures designed specifically to minimize soil movements, to include dewatering (if appropriate), and compaction controls.

The report also notes: "Most of the pump station facilities have been constructed for at least a year and no evidence of pipe support settlement or heaving associated with soil shrinkage or swelling has been observed."

#### 6.5.3 Recommendations

There were no mitigation measures recommended.

### 6.6 SUMMARY OF RECOMMENDATIONS

The recommendations presented within each individual study that are not covered by other measures within the LMP are presented again below:

- The landslide/mass movement study identifies portions of the pipeline that lack cover in areas where the pipeline is potentially susceptible to rock fall damage. The pipeline should be covered in these areas.
- Safety training of maintenance crews should include education on conditions which could potentially lead to slope failure. Standard procedures should be written to require notification of an engineer should such conditions exist.
- Monitoring is recommended at the four confirmed aseismic fault crossings. Monitoring will consist of elevation readings on either side of the fault at the pipeline crossing.

## 7.0 SURGE PRESSURE STUDY

### 7.1 PURPOSE AND HISTORY OF THE ANALYSES

Surge pressures are created when a moving fluid, such as liquid product in a pipeline, is suddenly brought to a halt. The kinetic energy is converted to potential energy, resulting in an increase in pressure and the creation of a pressure wave. In a liquid product pipeline, the liquid can be halted suddenly by a valve closure, pump shutdown, or emergency system shutdown. In a fluid-filled pipeline, a positive pressure wave is propagated upstream of the point where the fluid flow is interrupted. A negative pressure wave travels downstream from the point of interruption

Surge pressure analyses of the Longhorn pipeline from Galena Park to El Paso were conducted to determine whether the existing and proposed configuration of the pipeline would pose a safety problem in the event of a sudden interruption in flow. Longhorn made a commitment to keep maximum surge pressures to levels that will not exceed the maximum operating pressure (MOP) in Tier 2 and Tier 3 segments of the pipeline. Several surge pressure studies were performed by Willbros Engineers, Inc. for WES. Reports were issued August 1998 and August 1999.

As a mitigation measure, Longhorn proposed to limit surge pressures in sensitive areas to MOP levels or below. Additional surge analyses were conducted to look more closely at the sensitive areas. As a result, an addendum containing the results of 27 new case studies was issued January 2000. Two additional case studies were performed to determine the effects of adding seven check valves, and the results were added to the addendum in May 2000.

### 7.2 SCOPE OF WORK FOR THE STUDIES

In 1998, Willbros Engineers, Inc. performed a surge pressure analysis of the Longhorn pipeline from Galena Park to El Paso (Willbros, 1998). However, in that analysis, the surge pressures were compared to the maximum allowable surge pressure (MASP) levels that were inconsistent with the MASP levels defined from hydrostatic test results.

Because of these inconsistencies, another surge pressure analysis was conducted by Willbros Engineers, Inc. The report, completed early August 1999 (Willbros, 1999), presents the data used in the surge analysis and a description of the transient analysis program. Four cases were considered in this analysis:

- Galena Park to Crane at a flow rate of 3225 barrels per hour (bph) (Case 4 – startup);
- Galena Park to El Paso at a flow rate of 4850 bph (Case 1);
- Galena Park to Crane at a flow rate of 5000 bph (Case2); and
- Galena Park to El Paso at a flow rate of 8675 bph (Case 3 – ultimate flow rate).

The report presents the results of the surge analysis for each case, including a brief summary of the surge pressures that were calculated as a result of selected valve closures, pump shutdowns, and system shutdowns. Distance plots that include the pipeline profile and the maximum transient pressure heads are presented for each case. Also included are distance plots and results from "proof cases," which are surge analyses that include mitigation measures for any MASP exceedance. In addition, the report provides the results of the computer simulations from Cases 4, 1, and 2, respectively. Finally, the report describes the potential mitigation measures that were considered to ensure that the MASP and MOP values were not exceeded and provides recommendations.

Case 3 represents the hypothetical maximum flow rate at which the pipeline could operate. However, neither the location of the additional pump stations needed to achieve the maximum flow nor the pump performances at the projected stations are accurately known. Because of the level of uncertainty associated with Case 3, a surge analysis at the proposed maximum rate was not performed.

Sixty-one cases were examined in the 1999 analysis. Most involved valve closures, with valve closure times ranging from 1.5 to 3.2 minutes. Several pump shutdown and emergency system shutdown cases were also examined. For the purposes of this study, the transported product was assumed to be No. 2 fuel oil, which has the highest specific gravity of any of the liquids proposed for transportation in the pipeline. The fuel oil provided the most severe transient conditions in the analysis.

Several additional cases were examined in later studies and are included in an addendum. In two of these cases, the impact on the surge pressure of adding seven new proposed check valves was evaluated.

The SPS program Version 2.0, developed by Stoner Associates, Inc., was used for the most recent surge analysis. For Cases 1, 2, and 4, the effects of transient valve closures and pump shutdowns were determined for most of the remote control valves and pump stations along the pipeline. At some locations, the 1998 surge analysis indicated that calculated surge pressures were significantly below the MASPs, and these cases were not repeated in the 1999 study.

In the 1999 study, the unmitigated surge pressures were initially determined and compared to the MOPs and MASPs along the pipeline. The MOPs and MASPs were determined from Longhorn hydrostatic test data. The surge pressures found in the analyses exceeded the MOP and MASP limits for many of the modeled valve closures and pump shutdowns in the cases under consideration. The MOP and MASP exceedances primarily occurred in four areas; near the Brazos River, near the Colorado River, near the Pedernales River, and upstream of Crane Station.

In the areas where the MASP levels were exceeded, several hardware-based measures were considered for reducing the surge pressure below the respective MASP limits. These methods are listed below:

- Install surge pressure relief systems at Satsuma, Warda, Cedar Valley, and Eckert stations;
- Interlock the inadvertent closure of a block valve with the shutdown of an upstream pump station; and
- Change to slower valve closure times.

The surge analysis was repeated with one or more of the above mitigation measures being assumed for those events that had produced surge pressures above MASP levels. Certain line segments were shortened in the hydraulic model to determine surge pressures within sensitive and hypersensitive areas. Additional surge analyses were performed to determine the maximum surge pressures in these sensitive areas.

### 7.3 CONCLUSIONS

Surge pressures exceeded MASP and MOP levels at some locations along the pipeline for several of the cases investigated. Several mitigation measures were proposed as possible solutions. One or more of the proposed mitigation measures produced surge pressures that were below the MASP for all the events and locations included in the analysis. However, in some Tier 2 and Tier 3 locations, the MOPs were still exceeded. Mitigation measures to limit surge pressures in sensitive areas to MOP levels or below were identified and recommended.

### 7.4 RECOMMENDATIONS

At the conclusion of the surge analysis, a solution to eliminate the overpressure conditions was recommended. After considering the potential mitigation measures, the recommended solution was to hydrostatically test the affected segments of the pipeline to a higher pressure. According to the surge analysis report, the existing MOP levels for the current system are approximately 30 to 160 pounds per square inch gauge (psig) lower than those allowed by ASME B31.4 and 49 CFR 195. By successfully hydrostatically testing approximately 85 miles of pipeline to higher pressures, the MOP and MASP levels can be raised to or above the surge pressure in the segments of concern. This alternative can minimize the need for surge pressure relief systems and valve interlock systems and can eliminate the operational risks associated with these systems. The hydrostatic testing is currently being conducted.

In the case in which the effects of seven additional check valves on the surge pressure were analyzed, however, bypass relief systems were needed around some valves to reduce maximum surge pressures to levels below the MOP and/or MASP levels.

### 7.5 REFERENCES

Willbros, 1998: Willbros Engineers, Inc, "Surge Pressure Analysis of the Longhorn 18-Inch and 20-Inch Pipelines from Galena Park to El Paso," Tulsa, OK, August 1998.

Longhorn, 1999a: Longhorn Partners Pipeline, Longhorn Pipeline Project Description, March 1, 1999.

Willbros, 1999: Willbros Engineers, Inc, "Surge Pressure Analysis of the Longhorn 18-Inch and 20-Inch Pipelines from Galena Park to Dl Paso," Project No. 50335-700, Document No. 001, Tulsa, OK, August 4, 1999.

## 8.0 VALVE STUDY

### 8.1 PURPOSE AND HISTORY OF THE STUDY

Longhorn contracted with APR Companies to perform a water crossing valve study as prescribed in Longhorn Mitigation Commitment (LMC) 22 of the Longhorn Mitigation Plan. In the LMC, Longhorn commits to perform a study that quantifies the costs and benefits of additional valves at 13 selected river and stream crossings. The study was to follow a methodology similar to that shown in the California State Fire Marshal Hazardous Liquid Pipeline Risk Assessment (March 1993).

Based on the results of the study, Longhorn was to determine whether additional valves would be beneficial in reducing impacts on the selected crossings. If additional valves were determined to be beneficial, Longhorn would install the valves within six months of notice of concurrence from the DOT.

At the request of Longhorn, the scope of the valve study was expanded into a second phase to evaluate potential release volume mitigation in areas of dense population (Houston and Austin), areas of sensitive water resources, and areas of threatened or endangered species habitat. APR issued a report on the expanded study May 22, 2000.

### 8.2 SCOPE OF WORK FOR THE STUDY

The report is organized in 11 sections; the last four (Sections VIII through XI) contain reference material. Section I, which is the Introduction, contains background material on the purpose of the study and brief summaries of the study methodology and conclusions. The study methodology is described more fully in Section II. Section III includes a description of the California State Fire Marshal Hazardous Liquid Pipeline Risk Assessment ("Risk Assessment"), which includes the data and conclusions used to evaluate the need and effectiveness of additional valves.

Section IV lists of the regulatory valve requirements fulfilled on the Longhorn pipeline. The analysis of the valve needs at the selected water crossings (Phase I of the analysis) is discussed in Section V, and the evaluation of additional check valves to reduce line draindown is summarized in Section VI. The conclusions of both the Phase I and II efforts are summarized in Section VII.

Valves were initially located on the Longhorn pipeline at points determined by regulation 49 CFR §195.260. There are no regulatory guidelines regarding valve placement based upon potential spill volumes or valve spacing. The risk assessment used statistical analyses of spill data and historic costs to determine the costs and benefits of block valves for reducing spill volumes. The risk assessment concludes that block valves are not necessarily effective in reducing the draindown release volumes.

The conclusions of the risk assessment are used to guide this current valve study. A team of pipeline engineers, a hydrologist, and a biologist reviewed all data, pipeline profiles, topographical maps, and flow contour maps to determine whether additional valves would provide effective spill mitigation at the listed crossings.

This study also evaluates pipeline profiles and pipeline fill volumes to estimate whether the addition of a valve at specific locations would reduce the total volume released in the event of a spill. The addition of block valves to long segments of the pipeline is also evaluated as a means of reducing drain volumes. This is done by estimating the maximum volume that could be released and comparing this volume to the volume that could be expected from the conclusions of the risk assessment. This study evaluates potential release volumes at areas where a release could impact densely populated areas (Houston and Austin), sensitive water resources, and threatened and endangered species.

The two components of a release are (1) the continued pumping that occurs before the line can be shut down and (2) the liquid that drains from the pipe after the line has been shut down. No volumetric criteria for evaluating a release were provided in the risk assessment. A volume equivalent to the continued pumping release (assumed to be 5 minutes of pumping) was assumed as a starting mitigation benchmark. A number of other assumptions were made, which are listed in the APR report.

In evaluating the potential of additional valves in reducing draindown volumes, the potential draindown volumes were calculated as the product of number of miles of 18-inch pipe and 1570.8 barrels per mile. These volumes represent line fill and overstate the actual draindown volumes. Since a pipeline is a closed system, hydraulic head and/or a displacement gas is needed to affect line drainage. Hilly terrain can create natural check valves that limit hydraulic head and gas displacement of pipeline liquids.

The Phase II study does consider the placement of check valves as alternatives to block valves. Check valves add smaller incremental risk to a pipeline system compared to block valves. The higher incremental risk of block valves was considered a cost with potentially high consequences. A formal cost/benefit analysis was not conducted because Longhorn elected not to use cost/benefit analysis to exclude values that had environmental and safety benefits. Check valves respond almost immediately to reverse flow and are not subject to most of the incremental risks associated with block valves. In the Longhorn pipeline, check valves offer significantly greater potential mitigation of the reverse flow draindown.

Pipeline segments identified as candidates for spill reduction were prioritized for evaluation in order of the following criteria: (1) to protect human health and safety, (2) to protect drinking water supplies, (3) to protect the environment and endangered species, and (4) to reduce draindown volumes where practical. Human health/safety and drinking water protection received greater emphasis so that valve placement was evaluated and considered, even when the line fill and draindown volumes did not necessarily indicate the need for such placement.

### 8.3 STUDY CONCLUSIONS

The study concluded that additional valves at most of the selected crossings would add little or no effective spill mitigation. It also concluded that, on the basis of the incremental risk imposed by block valves, coupled with the minimal benefits identified in the Risk Assessment, block valves should not be added to the Longhorn pipeline. Check valves provide effective draindown control at less risk than other types of block valves.

Another conclusion from the study was that additional block or check valves to limit the draindown in the event of spills do not, in general, provide effective mitigation in most of the sensitive areas considered in the study. However, the study found that the addition of check valves at seven locations would provide incremental protection to the populated areas of Austin, to the water resources west of Austin, and to threatened or endangered species habitat.

### 8.4 RECOMMENDATIONS

As a result of this study, the installation of check valves downstream of Flat Creek (MP 193.21), Hickory Creek (MP 209.9), and White Oak Creek (MP 213.23) crossings were recommended. Additional check valves were recommended at four other sensitive locations between MP 193 and 214. In total, seven new check valves should be added to the Longhorn pipeline. The final locations of the seven check valves recommended by the study are:

| Milepost | Location | Milepost | Location |
|---|---|---|---|
| 171.5 | In Austin over Edwards Aquifer Contributing Zone | 203.5 | Protection of Cottonwood Creek in the Pedernales River watershed |
| 175.5 | In Austin over west end of Edwards Aquifer Recharge Zone | 209.9 | Protection of Hickory Creek/Pedernales watershed |
| 193.2 | West side of Flat Creek | 213.3 | White Oak Creek/Pedernales watershed |
| 199.4 | West of Pedernales River to be redundant to existing check valve on the west side of the river | | |

# Attachment A to Appendix 9E

# Evaluation of Longhorn Pipeline Spans

## Purpose

The purpose of Longhorn Mitigation Item 15 is to verify that all pipeline spans are adequately supported and protected from external loading.

## Analysis of Spans

### Depth-of-Covered Analysis

In 1998 and 1999, Longhorn performed a depth-of-cover survey which identified areas of shallow or exposed pipe; pipeline spans constitute a subset of exposed pipe. Analysis of the depth of cover survey data includes several analytical steps, including whether or not a length of unsupported pipe (whether with supports between such length or without engineered support mechanisms) exceeded a calculated maximum span length to the extent that additional support or other mitigation was required. See report entitled Depth of Cover Study of the Longhorn Partners Pipeline, dated April 22, 1999 (document identification number RAD293233 RAD29368). The Depth of Cover Study identified three sites (4006, 6001, and 5027) that exceed the depth of cover study maximum allowable unsupportable span length of 60 feet. Site Number 5027 became the object of the formal Span Study, as described below; site numbers 4006 and 6001 were excluded from analysis, as described in the section titled Spans Excluded From Analysis.

### Span Study—Engineered Spans

As a result of the Longhorn commitment to verify that all pipeline spans are adequately supported and protected from external loading, the engineered pipeline spans were identified for analysis in the Span Study based upon the existence of characteristics that might result in an external force being applied to the pipeline. Those characteristics included rivers, streams, creeks, and draws, as well as the potential that a span was within the reach of a 100-year flood. The Span Study also analyzed spans that are supported by external, man-made structures such as pipe supports or stanchions. The Span Study evaluated the spans for coating integrity, pipe support integrity, maximum allowable span length, and potential lateral loading. The Span Study describes the details of the evaluation and identifies recommended remediation measures.

### Spans Excluded from Analysis

Two pipeline spans were not included in the Span Study because they are addressed by other commitments of the Longhorn Mitigation Plan (i.e., will be lowered and/or replaced). These spans will receive an engineering analysis as part of the mitigation project planning. These two spans are at the crossings of Marble Creek in Travis County and Rabbs Creek in Fayette County.

Longhorn Mitigation Commitment Items 5 and 18 identify areas of exposed pipe that will be lowered and/or replaced prior to system startup.  As a result, each of those sections was eliminated from potential consideration for analysis by the Span Study.  In addition, Longhorn Mitigation Commitment Items 19 and 34 remove four locations from potential consideration by the Span Study.

**Conclusion**

The Longhorn Depth-Cover-Analysis analyzed all pipeline spans to determine whether or not they exceeded a maximum unsupported span length.  Subsequent to that analysis, a subset of spans was identified on the basis of factors that could lead to external loading or because man-made supports were employed.  Sites analyzed by the Span Study did not include those locations as to which Longhorn had previously committed to lower and/or replace the pipeline; rather, those locations will be analyzed in the context of project engineering planning, depending upon the mitigation commitment (e.g., a span that is to be lowered will not be designed as a span, but will be designed to avoid potential scour effects).

Table 1 set forth below identifies the population of pipeline spans and the mechanism by which those spans were analyzed.

## Table 1

| ID | Milepost | Span Study | Mitigation Plan | Depth of Cover |
|---|---|---|---|---|
| Span 7005 | 13.41 | X | | |
| Span 7004 | 14.17 | X | | |
| Span 5027 | 15.74 | X | | |
| Span 5026 | 17.19 | X | | |
| Site 7002 | 19.25 | | | X |
| Span 3005 | 22.52 | X | | |
| Span 5025 | 29.04 | X | | |
| Site 2020 | 47.04 | | | X |
| Span 2019 | 48.72 | X | | |
| Site 4015 | 77.25 | | 18 | |
| Site 2013 | 105.64 | | 18 | |
| Span 2010 | 111.27 | X | | |
| Rabbs Creek | 112.26 | | 8 | |
| Site 6001 | 113.60 | | 5 | |
| Span 5018 | 118.55 | X | | |
| Exposure | 127.87 | | 34 (Buescher) | |
| Cedar Creek | 143.94 | | 19 | |
| Site 4006 | 144.10 | | 5 | |
| Span 5011 | 149.40 | X | | |
| Span 5009 | 149.54 | X | | |
| Span 5008 | 149.55 | X | | |
| Span 5007 | 149.57 | X | | |
| Marble Creek | 163.50 | | 5 | |
| LPP-2467 | 174.16 | | 5 | |
| LPP-2546 | 179.61 | | 5 | |
| EACZ Repl. | 184.95 | | 3 | |
| LPP-2627 | 185.74 | | 5 | |
| LPP-2713 | 193.19 | | 5 | |
| Flat Creek | 193.31 | | 19 | |
| LPP-2751 | 196.39 | | 5 | |
| LPP-2753 | 196.60 | | 5 | |
| Site 2016 | 222.07 | | 18 | |
| Span 4017 | 230.84 | X | | |
| Span 5023 | 234.90 | X | | |
| Span 5022 | 236.23 | X | | |
| Sandy Creek | 236.40 | | 19 | |
| LPP-3386 (Site 5019) | 236.71 | | 5 | X |
| 7006,7007 | 257.35 | | 18 | X |
| Span 7500 | 276.14 | X | | |
| Span 8001 | 287.68 | X | | |