

**Appendix 5H**  
**Surge Pressure Analysis**

In 1998, Willbros Engineers Inc. (Willbros) performed a surge pressure analysis on the proposed Longhorn pipeline. Some of the results were invalidated because the maximum allowable operating pressure (MAOP) and the maximum allowable surge pressure (MASP) were calculated from pipe grade and wall thickness data. Another surge pressure analysis was performed using the MASP that was determined from the results of hydrostatic testing. The resulting report was issued on August 4, 1999. As described in Section 5.3.8 of the EA, a total of 61 cases were analyzed, including valve closures (23 cases), pump shutdowns (6), emergency closures (2), and proof cases illustrating mitigation measures (30). An overview of these cases, with the exception of the proof cases, is provided in Table 5H-1.

From left to right, the table lists mileage; location; valve function, description, and identification; the modeled event causing the surge, and the cases modeled for different flow rates. Note that a series of transient cases simulated in August 1998 indicated that the maximum allowable surge pressure (MASP) was not exceeded at 4,800 bpd, so these analyses were not repeated (see rightmost column of Table 5H-1).

At each flow rate considered in the study, the proprietary SPS model was calibrated at steady state using flow data provided by Willbros. Next, the different transient surge simulations were run. The result of the modeled transient surges are summarized on Table 5H-2. Going from left to right again, the unmitigated surge pressures are listed first in the center of the table. They are compared to the MASP and the maximum operating pressure (MOP), and their location relative to sensitive and hypersensitive areas is noted. The bold numbers indicate pressures that exceed the MASP at that particular point of the pipeline. As can be seen from the table, several unmitigated surge pressures exceed the MASP.

On the right side of the table, the impact of various surge pressure mitigation measures are shown. The following mitigation measures are considered:

- Install surge pressure relief systems;
- Interlock the inadvertent closure of a block valve with the shutdown of an upstream pumping station;
- Change the valve motor operators to a two-speed type, whereby the last 10 percent of closure occurs much more slowly than the first 90 percent; and
- Qualify the affected sections of the pipeline for higher MAOP/MASP by hydrostatic testing.

Judicious application of the first three measures lowers most surge pressures to below the MASP, as illustrated by model proof cases (see Table 5H-2, right hand columns); only six exceedances remain.

The report recommends the fourth measure, hydrostatic testing to higher pressures, because the existing MAOPs for the surge pressures calculated are approximately 30 to 160 psig lower than those allowed by ASME B31.4 and DOT Part 195. This measure would increase MAOP and MASPs for these sections to acceptable levels.

An addendum to the August 4, 1999 study was issued on January 13, 2000. It contains the following additional information:

- Greater resolution was achieved by modeling shorter line segments in critical sections of the pipeline;
- In addition to fuel oil, gasoline was also considered as a fluid;
- Two-speed valve actuators were modeled on certain valves; and
- Surge relief bypass valves were also included in the modeling.

Surge pressure violations remained for some of the variations considered. As expected, gasoline showed fewer, and in some cases, no pressure violations. The most successful mitigation measure considered in this addendum were the bypass relief valves, which resulted in only one very small (0.4-1.6 psig) surge pressure violation, using fuel oil as the line fill.

Finally, the impact of installing seven additional check valves was modeled. The Llano River valve SE-16 closure without bypass shows lower surge pressures, but still some MASP exceedances, using fuel oil as the linefill (see Table 5H-3). There are no surge pressure violations if a relief bypass is used, and the pipeline establishes a steady-state flow rate of 2,262 bph (see Table 5H-4).

**Table 5H-1. Summary of Valve Closures and Pump Shutdowns Examined in the Revised Surge Analysis**

Mileage from Galena Park		Location	Valve Function	Valve Description	Valve ID	Surge Initiating Event	Location of Valve Closure/Pump Shutdown from WEI Surge Analysis 8/4/99			Locations in 1998 Surge Analysis not in 1999 Surge Analysis
EA	Surge Analysis						Case 4 3225 bph (77,400 bpd)	Case 1 4850 bph (116,400 bpd)	Case 2 5000 bph (120,000 bpd)	4800 bph (115,200 bpd)
0.00		Galena Park Station	Block	Remote controlled block valve						
5.34		Galena Park Station	Block	Manual block valve						
7.46		Galena Park Station	Block	Manual block valve						
11.99		Mesa Boulevard	Block	Remote controlled block valve						X
21.30		Mesa Boulevard	Block	Manual block valve						
34.09		Satsuma Station	Block	Remote controlled block valve						X
34.14		Satsuma Station	Block	Remote controlled block valve						
63.78	63.80	Brazos River - East	Block	Remote controlled block valve	SE-2	Valve closure		X	X	
64.08		Brazos River - West	Block	Manual block valve						
64.08		Brazos River - West	Check	Check valve						
112.89		Warda Station	Block	Locally motor-operated block valve						X
112.89		Warda Station	Check	Bypass check valve						
112.96		Warda Station	Block	Manual block valve						
133.88	133.90	Colorado River	Block	Remote controlled block valve	SE-6	Valve closure		X	X	
133.88		Colorado River	Check	Check valve						
134.67		Colorado River	Block	Manual block valve						
166.67		Edwards Aquifer - East	Block	Remote controlled block valve						X
175.51	175.50	Edwards Aquifer - West	Block	Remote controlled block valve	SE-9	Valve closure	X	X	X	
181.60		Cedar Valley Station	Block	Remote controlled block valve						X
181.64		Cedar Valley Station	Check	Bypass check valve						
181.67		Cedar Valley Station	Block	Manual block valve						
198.68	198.70	Pedernales River	Block	Remote controlled block valve	SE-11	Valve closure	X	X	X	

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**Table 5H-1. Summary of Valve Closures and Pump Shutdowns Examined in the Revised Surge Analysis (Continued)**

Mileage from Galena Park		Location	Valve Function	Valve Description	Valve ID	Surge Initiating Event	Location of Valve Closure/Pump Shutdown from WEI Surge Analysis 8/4/99			Locations in 1998 Surge Analysis not in 1999 Surge Analysis
EA	Surge Analysis						Case 4 3225 bph (77,400 bpd)	Case 1 4850 bph (116,400 bpd)	Case 2 5000 bph (120,000 bpd)	4800 bph (115,200 bpd)
198.94		Pedernales River	Block	Manual block valve						
211.90		Pedernales River	Block	Manual block valve						
227.90		Eckert Station	Block	Remote controlled block valve	SE-14	Valve closure		X	X	
227.91		Eckert Station	Check	Bypass check valve						
228.02		Eckert Station	Block	Manual block valve						
276.46	276.50	Llano River	Block	Remote controlled block valve	SE-16	Valve closure	X	X	X	
276.64		Llano River	Check	Check valve						
276.64		Llano River	Block	Manual block valve						
288.91			Block	Manual block valve						
295.12		Kimble County Station	Block	Remote controlled block valve	SE-19	Valve closure		X		
295.20		Kimble County Station	Check	Bypass check valve						
295.25		Kimble County Station	Block	Manual block valve						
321.95		Old Fort McKavett Station	Block	Manual block valve						
358.70		Old Fort McKavett Station	Block	Manual block valve						
373.45		Big Lake Station	Block	Remote controlled block valve	SE-23	Valve closure		X		
373.47		Big Lake Station	Block	Manual block valve						
416.63		SE-25	Block	Manual block valve						
457.55		Crane Station	Block	Remote controlled block valve	SE-26	Valve closure		X	X	
457.58		Crane Station	Block	Remote controlled block valve						
492.26			Block	Manual block valve						
523.63			Block	Manual block valve						

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**Table 5H-1. Summary of Valve Closures and Pump Shutdowns Examined in the Revised Surge Analysis (Continued)**

Mileage from Galena Park		Location	Valve Function	Valve Description	Valve ID	Surge Initiating Event	Location of Valve Closure/Pump Shutdown from WEI Surge Analysis 8/4/99			Locations in 1998 Surge Analysis not in 1999 Surge Analysis
EA	Surge Analysis						Case 4 3225 bph (77,400 bpd)	Case 1 4850 bph (116,400 bpd)	Case 2 5000 bph (120,000 bpd)	4800 bph (115,200 bpd)
526.12			Block	Manual block valve						
555.10			Block	Manual block valve						
		Cottonwood Station	Block	Remote controlled block valve	SE-30	Valve closure		X		
576.32		Cottonwood Station	Block	Manual block valve						
576.33		Cottonwood Station	Block	Remote controlled block valve						
607.10			Block	Manual block valve						
638.86			Block	Manual block valve						
668.37			Block	Manual block valve						
694.41	694.40	El Paso Station	Block	Remote controlled block valve	SE-35	Valve closure	X	X		
<b>Station/System Shutdowns</b>										
		Cedar Valley Station				Pump Shutdown	X			
		Eckert Station								X
		Kimble County Station				Pump Shutdown	X	X	X	
		Big Lake Station				Pump Shutdown			X	
		Crane Station				Pump Shutdown		X		
		Entire System				Emergency System Shutdown		X	X	

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**Table 5H-2. Summary of the Results of the Surge Analysis**

Case	ID	Location	MP	Unmitigated Surge Pressure							Mitigated Surge Pressure				
				Event	MP	Max. psig <sup>1</sup>	MASP psig	MOP psig	Sens. Area?	Hyper. Area?	Mitigation	MP	Max psig <sup>1</sup>	MASP psig	
3225 BPH	SE-9	Edwards Aquifer	175.5	Valve closure	64	963	1062	965	X	X					
(GP-Crane: Startup)	SE-11	Pedernales River	198.7	Valve closure	193.3	<b>1117</b>	1062	965	X		Relief at Cedar Valley	34.1	953	1062	
											Interlock SE-11 & CV	64	961	1062	
	SE-16	Llano River	276.5	Valve closure	193.3	<b>1065</b>	1062	965	X	X	Relief at Eckert	193.3	1059	1062	
	SE-26	Crane Terminal	457.6	Valve closure	193.3	1055	1062	965	X	X					
	CVP1	Cedar Valley	182	Pump shutdown	34.1	976	1062	965							
		Kimble County	295	Pump shutdown											
4850 BPH	SE-2	Brazos River	63.8	Valve closure	62.8	<b>1103</b>	1062	965			Relief at Satsuma	62.8	<b>1102</b>	1062	
(GP-EP)											Interlock SE-2 and Sat.	34.1	950	1062	
												576.3	1440	1607	
	SE-6	Colorado River	133.9	Valve closure	113.5	1072	1079	981							
						576.3	1440	1607	1461						
	SE-9	Edwards Aquifer	175.5	Valve closure	64	984	1062	965	X	X					
						576.3	1440	1607	1461						
	SE-11	Pedernales River	198.7	Valve closure	198.7	<b>1141</b>	1062	965	X	X	Relief at Cedar Valley	198.7	<b>1136</b>	1062	
											Interlock SE-11 & CV	64	983	1062	
												576.3	1440	1607	
											SE-11 closure time-10 min	198.7	<b>1173</b>	1062	
	SE-14	Eckert Station	227.9	Valve closure	193.3	<b>1090</b>	1062	965	X	X	Relief at Eckert	193.3	1061	1062	
						198.9	<b>1125</b>	1062	965	X			576.3	1443	1607
	SE-16	Llano River	276.3	Valve closure	193.3	<b>1086</b>	1062	965	X	X	Relief at Eckert	193.3	1061	1062	
						198.9	<b>1112</b>	1062	965	X					
	SE-19	Kimble Station	295.1	Valve closure	193.3	<b>1101</b>	1062	965	X	X	Relief at Eckert	193.3	1057	1062	
						198.9	<b>1124</b>	1062	965	X					
	SE-23	Big Lake Station	373.5	Valve closure	193.3	<b>1100</b>	1062	965	X	X	Relief at Eckert	193.3	1058	1062	
						198.9	<b>1124</b>	1062	965	X					

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**Table 5H-2. Summary of the Results of the Surge Analysis (Continued)**

Case	ID	Location	MP	Unmitigated Surge Pressure							Mitigated Surge Pressure			
				Event	MP	Max. psig <sup>1</sup>	MASP psig	MOP psig	Sens. Area?	Hyper. Area?	Mitigation	MP	Max psig <sup>1</sup>	MASP psig
	SE-26	Crane Station	457.6	Valve closure	193.3	<b>1100</b>	1062	965	X	X	Relief at Eckert & Crane	455.7	1053	1056
					198.9	<b>1121</b>	1062	965	X					
					455.7	<b>1068</b>	1056	960						
	SE-30	Cottonwood Station	576.3	Valve closure	193.3	<b>1100</b>	1062	965	X	X	Relief at Eckert & Crane	455.7	1050	1058
					198.9	<b>1121</b>	1062	965	X			475	1496	1607
					455.7	<b>1068</b>	1056	960						
	SE-35	El Paso Terminal	694.4	Valve closure	193.3	<b>1104</b>	1062	965	X	X	Relief at Eckert & Crane	455.7	1053	1056
					198.9	<b>1134</b>	1062	965	X			614.6	1554	1607
					455.7	<b>1067</b>	1056	960						
	KBP1	Kimble Station	295	Pump shutdown	193.3	1048	1062	965	X	X	Relief at Eckert	193.3	1031	1062
					576.3	1440	1607	1461				576.3	1440	1607
	CRP1	Crane Station	457.6	Pump shutdown	193.3	<b>1101</b>	1062	965	X	X	Relief at Eckert & Crane	193.3	1058	1062
					198.9	<b>1123</b>	1062	965	X			607.1	1440	1607
	Sys	Entire System		Emergency Shutdown	34.1	950	1062	965						
					576.3	1440	1607	1461						
5000 BPH (GP-Crane)	SE-2	Brazos River	63.8	Valve closure	62.8	<b>1106</b>	1062	965			Relief at Satsuma	62.8	<b>1105</b>	1062
											Interlock SE-2 & Satsuma	34.1	951	1062
	SE-6	Colorado River	133.9	Valve closure	133.4	<b>1083</b>	1079	981			Relief at Warda	133.4	<b>1082</b>	1079
											Interlock SE-6 and Warda	64	971	1062
												82	979	1113
	SE-9	Edwards Aquifer	175.5	Valve closure	64	984	1062	965	X	X				
					82	995	1113	1012						
	SE-11	Pedernales River	198.7	Valve closure	198.7	<b>1147</b>	1062	965	X	X	Relief at Cedar Valley	198.7	<b>1144</b>	1062

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**Table 5H-2. Summary of the Results of the Surge Analysis (Continued)**

Case	ID	Location	MP	Unmitigated Surge Pressure							Mitigated Surge Pressure				
				Event	MP	Max. psig <sup>1</sup>	MASP psig	MOP psig	Sens. Area?	Hyper. Area?	Mitigation	MP	Max psig <sup>1</sup>	MASP psig	
											Interlock SE-11 & CV	64	981	1062	
												82	990	1113	
											SE-11 closure time:10 minutes	198.7	1160	1062	
	SE-14	Eckert Station	227.9	Valve closure	193.3	<b>1086</b>	1062	965	X	X	Relief at Eckert	193.3	1061	1062	
					198.9	<b>1115</b>	1062	965	X						
	SE-16	Llano River	276.3	Valve closure	193.3	<b>1090</b>	1062	965	X	X	Relief at Eckert	193.3	1060	1062	
					198.9	<b>1126</b>	1062	965	X						
	SE-23	Big Lake Station	373.5	Valve closure	193.3	<b>1095</b>	1062	965	X	X	Relief at Eckert	193.3	1058	1062	
					198.9	<b>1117</b>	1062	965	X						
	SE-26	Crane Station	457.6	Valve closure	193.3	<b>1095</b>	1062	965	X	X	Relief at Eckert and Crane	183.1	1058	1062	
					198.9	<b>1117</b>	1062	965	X			455.7	1054	1056	
					455.7	<b>1071</b>	1056	960							
	KBP1	Kimble Station	295	Pump shutdown	All pressures < MASP								NA	NA	NA
	BLP!	Big Lake Station	373.5	Pump shutdown	193.3	<b>1099</b>	1062	965	X		Relief at Eckert	193.3	1058	1062	
					198.9	<b>1087</b>	1062	965	X						
	Sys	Entire System		Emergency shutdown	34.1	951	1062	965				NA	NA	NA	

<sup>1</sup> Pressures in bold indicate that surge pressure exceeds the MASP for the selected configuration at that point.

**Table 5H-3a. Longhorn Surge Analysis - Llano River Valve Closure -  
Pressure Comparison with the Addition of Seven New Mainline Check Valves**

	(C)	(D)	(E)	(F)	(G)	Case 1: Llano River Valve Closure (SE-16), Resegmented, New Check Valves, No Bypass Relief		
	Original Operating Pressure	MAOP	Pressure Test Requirements	New Pressure Test Allowable Operating Pressure	Max. Surge Pressure, Bypass Relief Inoperable	MP	MP of Max. Pressure	Max. Pressure (psig)
MP	(psig)	(psig)		(psig)	Max. Pressure (psig)			
0.00	<b>1168</b>	1168	Use original operating pressure	786	486.50	0.00	0.00	485.90
5.30	<b>1168</b>	1168	Use original operating pressure	786	482.00	5.30	6.62	481.80
7.50	<b>1168</b>	1168	Use original operating pressure	786	472.80	7.50	7.50	472.40
9.10	684	786	Tier 2 & 3 90% SMYS test	<b>786</b>	469.20	9.10	9.10	468.70
9.70	660	786	Tier 2 & 3 90% SMYS test	<b>786</b>	477.40	9.70	10.16	476.90
12.00	660	786	Tier 2 & 3 90% SMYS test	<b>786</b>	461.70	12.00	12.00	461.00
21.30	660	786	Tier 2 & 3 90% SMYS test	<b>786</b>	453.60	21.30	21.30	453.30
33.70	<b>851</b>	1168	Use original operating pressure	786	447.80	33.70	34.10	447.30
34.10	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	981.60	34.10	34.10	981.50
34.10	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>		37.00	62.81	980.20
37.00	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	980.20	63.80	63.95	982.80
63.80	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	982.80	64.10	82.02	994.10
64.10	1012	1012	Tier 2 & 3 90% SMYS test to MP 76.22; proof test to MP 87.5	<b>1012</b>	994.30	87.50	91.00	952.50
87.50	<b>965</b>	1012	Proof test at 110% MAOP	965	952.50	113.00	113.48	944.40
113.00	981	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	944.60	125.50	126.50	926.40
113.00	981	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>		128.50	133.41	938.50
125.50	981	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	926.70	133.90	134.30	941.10
128.50	981	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	938.70	134.70	134.70	966.60
133.90	981	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	941.20	141.70	141.70	942.20
134.70	1049	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	969.70	141.80	143.29	944.80
141.70	1049	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	947.00	166.70	166.70	854.50
141.80	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	950.20	171.50	171.50	790.00
166.70	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	854.60	175.50	180.72	732.60
171.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	790.00	181.67	183.08	1013.30

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**Table 5H-3a. Longhorn Surge Analysis - Llano River Valve Closure -  
Pressure Comparison with the Addition of Seven New Mainline Check Valves (Continued)**

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	(C)	(D)	(E)	(F)	(G)	Case 1: Llano River Valve Closure (SE-16), Resegmented, New Check Valves, No Bypass Relief		
	Original Operating Pressure	MAOP	Pressure Test Requirements	New Pressure Test Allowable Operating Pressure	Max. Surge Pressure, Bypass Relief Inoperable	MP	MP of Max. Pressure	Max. Pressure (psig)
MP	(psig)	(psig)		(psig)	Max. Pressure (psig)			
175.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	732.60			
181.67	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1090.10</b>	185.90	190.04	1011.60
181.67	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>		190.50	193.24	1080.10
185.90	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1013.30</b>	193.24	193.32	1093.10
190.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1080.10</b>	193.40	193.40	1080.10
193.24	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1093.10</b>	197.10	198.70	1080.50
193.40	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1080.10</b>	198.70	198.80	1090.40
197.10	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1080.60</b>	198.90	198.90	1071.90
198.70	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1090.50</b>	199.50	199.50	1029.00
198.90	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1126.50</b>	203.50	203.50	1003.80
199.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1076.40</b>	203.62	203.62	1013.40
203.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1046.50</b>	208.10	210.00	996.90
203.62	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1013.40</b>	210.00	210.00	998.90
208.10	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1013.20</b>	211.90	213.30	981.80
210.00	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1013.20</b>	213.30	213.30	1005.50
211.90	959	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	981.80	228.00	264.00	1054.10
213.30	<b>959</b>	1012	Tier 2 & 3 90% SMYS test to MP 215.63; proof test to MP 228	959	1005.50	276.50	276.55	558.50
228.00	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	<b>1054.30</b>	276.60	276.60	556.86
228.00	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>		281.80	281.80	396.86
276.50	965	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	560.20	288.90	288.90	251.61
276.60	<b>973</b>	1012	Proof test at 100% MAOP	973	556.90	295.30	296.25	881.40
281.80	<b>965</b>	1012	Proof test at 100% MAOP	965	396.90	305.80	306.78	733.60
288.90	<b>965</b>	1012	Proof test at 100% MAOP	965	251.61	322.00	322.99	639.00
295.30	<b>965</b>	1012	Proof test at 100% MAOP	965	882.00	358.70	368.07	293.20

**Table 5H-3a. Longhorn Surge Analysis - Llano River Valve Closure -  
Pressure Comparison with the Addition of Seven New Mainline Check Valves (Continued)**

	(C)	(D)	(E)	(F)	(G)	Case 1: Llano River Valve Closure (SE-16), Resegmented, New Check Valves, No Bypass Relief		
	Original Operating Pressure	MAOP	Pressure Test Requirements	New Pressure Test Allowable Operating Pressure	Max. Surge Pressure, Bypass Relief Inoperable	MP	MP of Max. Pressure	Max. Pressure (psig)
MP	(psig)	(psig)		(psig)	Max. Pressure (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)
295.30	<b>965</b>	1012	Proof test at 110% MAOP	966		373.50	373.50	801.97
305.80	952	1012	Tier 2 & 3 90% SMYS test	<b>1012</b>	734.00	404.40	404.40	573.80
322.00	<b>965</b>	1012	Tier 2 & 3 90% SMYS test to MP 346.59, proof test to MP 355.98; Tier 2 & 3 90% SMYS test to MP 358.7	<b>1012</b>	639.20	405.10	405.10	568.73
358.70	<b>964</b>	1012	Tier 2 & 3 90% SMYS test to MP 364.87; proof test to MP 373.5	<b>1012</b>	293.40	416.60	416.60	477.82
373.50	<b>964</b>	1123	Proof test at 110% MAOP	964	802.00	441.90	441.90	226.40
373.50	<b>964</b>	1123	Proof test at 110% MAOP	964		455.70	455.70	223.43
404.40	<b>1020</b>	1461	Proof test at 110% MAOP	1020	573.80	457.60		
405.10	<b>955</b>	1040	Proof test to MP 409.09, Tier 2 & 3 90% SMYS test to MP 416.6	<b>1040</b>	568.73			
416.60	955	1040	Tier 2 & 3 90% SMYS test	<b>1040</b>	477.82			
441.90	960	1040	Tier 2 & 3 90% SMYS test	<b>1040</b>	226.40			
455.70	<b>1461</b>	1461	Tier 2 & 3 90% SMYS test	1040	223.43			
457.60								

Notes:

**XXXX** - indicates MASP exceeded (w/o relief systems).

**Bolded** pressures - indicates operating pressure, final.

Column C is a list of the operating pressures in place when the surge analysis was initiated.

Column D is a list of the maximum design pressures based on 72 percent allowance.

Column E defines the Tier 2 and 3 areas requiring hydrostatic testing at 90 percent of the SMYS and the Tier 1 areas requiring a “proof” test for the segments from Galena Park to Crane.

Column F is a listing of the new operating pressure limits (MAOPs) for the pipeline segments.

The bolded pressures in Columns C and F define the final MAOP levels for each segment (in Tier 1 segments, MASP = 110 percent MAOP).

**Table 5H-3b. Galena Park to Crane at 5000 bph, Fuel Oil Linefill; No Bypass Relief Around River Valves**

MP	(C)	(D)	(F)	(G)	Case 2-6R: Llano River Valve Closure (SE-16) Resegmented			Case 2-6: Llano River Valve Closure (SE-16) Original Analysis		
	Original Operating Pressure (psig)	MAOP (psig)	New Pressure Test Allowable Operating Pressure (psig)	Max. Surge Pressure, Bypass Relief Inoperable (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)
0.00	<b>1168</b>	1168	786	486.50	0.00	0.00	483.10	0.00	0.00	486.50
5.30	<b>1168</b>	1168	786	482.00	5.30	6.62	478.30	5.30	6.62	482.00
7.50	<b>1168</b>	1168	786	472.80	7.50	7.50	468.90	7.50	7.50	472.80
9.10	684	786	<b>786</b>	469.20	9.10	9.10	465.30	9.10	9.10	469.20
9.70	660	786	<b>786</b>	477.40	9.70	10.16	473.40	9.70	10.16	477.40
12.00	660	786	<b>786</b>	461.70	12.00	12.00	457.50	12.00	12.00	461.70
21.30	660	786	<b>786</b>	453.60	21.30	31.22	449.60	21.30	21.30	453.60
33.70	<b>851</b>	1168	786	447.80	33.70	34.10	444.60	33.70	33.70	447.80
34.10	965	1012	<b>1012</b>	981.60	34.10	34.10	981.60	34.10	34.10	981.20
34.10	965	1012	<b>1012</b>							
37.00	965	1012	<b>1012</b>	980.20	37.00	62.81	980.00			
63.80	965	1012	<b>1012</b>	982.80	63.80	63.95	982.60	63.80	63.95	982.70
64.10	1012	1012	<b>1012</b>	994.30	64.10	82.02	993.90	64.10	82.02	994.30
87.50	<b>965</b>	1012	965	952.50	87.50	91.00	952.00	87.50	91.00	952.40
113.00	981	1012	<b>1012</b>	944.60	113.00	113.48	944.40	113.00	113.50	944.60
113.00	981	1012	<b>1012</b>							
125.50	981	1012	<b>1012</b>	926.70	125.50	126.50	926.70			
128.50	981	1012	<b>1012</b>	938.70	128.50	133.41	938.70			
133.90	981	1012	<b>1012</b>	941.20	133.90	134.30	941.10	133.90	134.30	941.20
134.70	1049	1012	<b>1012</b>	969.70	134.70	134.70	969.60	134.70	134.70	969.70
141.70	1049	1012	<b>1012</b>	947.00	141.70	141.70	946.90	141.70	141.70	947.00
141.80	965	1012	<b>1012</b>	950.20	141.80	143.29	950.20	141.80	143.29	950.20
166.70	965	1012	<b>1012</b>	854.60	166.70	166.70	854.60	166.70	166.70	854.60
171.50	965	1012	<b>1012</b>	790.00						
175.50	<b>965</b>	1012	966	732.60	175.50	180.72	732.50	175.50	180.72	732.50

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**Table 5H-3b. Galena Park to Crane at 5000 bph, Fuel Oil Linefill; No Bypass Relief Around River Valves (Continued)**

MP	(C)	(D)	(F)	(G)	Case 2-6R: Llano River Valve Closure (SE-16) Resegmented			Case 2-6: Llano River Valve Closure (SE-16) Original Analysis		
	Original Operating Pressure (psig)	MAOP (psig)	New Pressure Test Allowable Operating Pressure (psig)	Max. Surge Pressure, Bypass Relief Inoperable (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)
181.67	952	1012	<b>1012</b>	1090.10	181.67	183.08	1017.10	181.67	193.35	1090.10
181.67	965	1012	<b>1012</b>							
185.90	965	1012	<b>1012</b>	1013.30	185.90	190.50	1013.30			
190.50	965	1012	<b>1012</b>	1080.10	190.50	193.40	1079.50			
193.24	965	1012	<b>1012</b>	1093.10						
193.40	965	1012	<b>1012</b>	<i>1080.10</i>	193.40	193.40	1079.50			
197.10	965	1012	<b>1012</b>	<b>1080.60</b>	197.10	198.70	1080.60			
198.70	965	1012	<b>1012</b>	<i>1090.50</i>	198.70	198.80	1090.50	198.70	198.80	1090.50
198.90	965	1012	<b>1012</b>	<i>1126.50</i>	198.90	198.90	1126.40	198.90	198.90	1126.50
199.50	965	1012	<b>1012</b>	<i>1076.40</i>	199.50	202.00	1076.40			
203.50	965	1012	<b>1012</b>	<i>1046.50</i>	203.50	203.50	1046.50			
203.62	965	1012	<b>1012</b>	<i>1013.40</i>						
208.10	965	1012	<b>1012</b>	<i>1013.20</i>	208.10	210.00	1013.20			
210.00	965	1012	<b>1012</b>	<i>1013.20</i>	210.00	210.00	1013.20			
211.90	959	1012	<b>1012</b>	<i>981.80</i>	211.90	213.36	980.00	211.90	213.36	980.00
213.30	<b>959</b>	1012	959	<i>1005.50</i>						
228.00	965	1012	<b>1012</b>	<i>1054.30</i>	228.00	264.00	1054.00	228.00	264.00	1054.30
228.00	965	1012	<b>1012</b>							
276.50	965	1012	<b>1012</b>	<i>560.20</i>	276.50	276.55	558.50	276.50	276.55	560.20
276.60	<b>973</b>	1012	973	<i>556.90</i>	276.60	276.60	556.86	276.60	276.60	556.90
281.80	<b>965</b>	1012	965	396.90	281.80	281.80	396.86	281.80	281.80	396.90
288.90	<b>965</b>	1012	965	251.61	288.90	288.90	251.61	288.90	288.90	251.60
295.30	<b>965</b>	1012	965	<i>882.00</i>	295.30	296.25	881.40	295.30	296.25	882.00
295.30	<b>965</b>	1012	966							
305.80	952	1012	<b>1012</b>	734.00	305.80	306.78	733.60	305.80	306.78	734.00

**Table 5H-3b. Galena Park to Crane at 5000 bph, Fuel Oil Linefill; No Bypass Relief Around River Valves (Continued)**

MP	(C)	(D)	(E)	(G)	Case 2-6R: Llano River Valve Closure (SE-16) Resegmented			Case 2-6: Llano River Valve Closure (SE-16) Original Analysis		
	Original Operating Pressure (psig)	MAOP (psig)	New Pressure Test Allowable Operating Pressure (psig)	Max. Surge Pressure, Bypass Relief Inoperable (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)	MP	MP of Max. Pressure	Max. Pressure (psig)
322.00	<b>965</b>	1012	<b>1012</b>	639.20	322.00	322.99	639.00	322.00	322.99	639.20
358.70	<b>964</b>	1012	<b>1012</b>	293.40	358.70	368.07	293.20	358.70	368.07	293.40
373.50	<b>964</b>	1123	964	802.00	373.50	373.50	801.97	373.50	373.50	802.00
373.50	<b>964</b>	1123	964							
404.40	<b>1020</b>	1461	1020	573.80	404.40	404.40	573.80	404.40	404.40	573.80
405.10	<b>955</b>	1040	<b>1040</b>	568.73	405.10	405.10	568.73	405.10	405.10	568.70
416.60	955	1040	<b>1040</b>	477.82	416.60	416.60	477.82	416.60	416.60	477.80
441.90	960	1040	<b>1040</b>	226.40	441.90	441.90	226.40	441.90	441.90	226.40
455.70	<b>1461</b>	1461	1040	223.43	455.70	455.70	223.43	455.70	455.70	223.40
457.60		1012			457.60			457.60		

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**Table 5H-4. Llano River Valve Closure – Pressure Comparison with the Addition of Seven New Mainline Check Valves – Pressure Relief Active<sup>1</sup>**

	(C)	(D)	(F)	(H)	Case 2: Llano River Valve Closure (SE-16)		Case 2-RV50: Llano River Valve Closure (SE-16)		Case 2-RV25: Llano River Valve Closure (SE-16)	
	Original Operating Pressure	MAOP	New Pressure Test Allowable Operating	Max.Steady State Pressure, Bypass Relief Operable, New Steady State Rate, 2262 bph	MP	Pressure (psig)	MP	Pressure (psig)	MP	Pressure (psig)
0.00	<b>1168</b>	1168	786	438.54	0.00	438.54	0.00	438.54	0.00	438.54
5.30	<b>1168</b>	1168	786	424.72	5.30	424.72	5.30	424.72	5.30	424.72
7.50	<b>1168</b>	1168	786	421.58	7.50	421.58	7.50	421.58	7.50	421.58
9.10	684	786	<b>786</b>	417.52	9.10	417.52	9.10	417.52	9.10	417.52
9.70	660	786	<b>786</b>	416.48	9.70	416.48	9.70	416.48	9.70	416.48
12.00	660	786	<b>786</b>	409.42	12.00	409.42	12.00	409.42	12.00	409.42
21.30	660	786	<b>786</b>	388.90	21.30	388.90	21.30	388.90	21.30	388.90
33.70	<b>851</b>	1168	786	357.87	33.70	357.87	33.70	357.87	33.70	357.87
34.10	965	1012	<b>1012</b>	357.00	34.10	357.00	34.10	357.00	34.10	357.00
	965	1012	<b>1012</b>	949.83	34.10	949.83	34.10	949.83	34.10	949.83
37.00	965	1012	<b>1012</b>	936.29	37.00	936.29	37.00	936.29	37.00	936.29
63.80	965	1012	<b>1012</b>	887.45	63.80	887.45	63.80	887.45	63.80	887.45
64.10	1012	1012	<b>1012</b>	886.01	64.10	886.01	64.10	886.01	64.10	886.01
87.50	<b>965</b>	1012	965	756.43	87.50	756.43	87.50	756.43	87.50	756.43
113.00	981	1012	<b>1012</b>	722.05	113.00	722.05	113.00	722.05	113.00	722.05
	981	1012	<b>1012</b>	899.83	113.00	899.83	113.00	899.83	113.00	899.83
125.50	981	1012	<b>1012</b>	839.53	125.50	839.53	125.50	839.53	125.50	839.53
128.50	981	1012	<b>1012</b>	834.44	128.50	834.44	128.50	834.44	128.50	834.44
133.90	981	1012	<b>1012</b>	852.70	133.90	852.70	133.90	852.70	133.90	852.70
134.70	1049	1012	<b>1012</b>	865.33	134.70	865.33	134.70	865.33	134.70	865.33
141.70	1049	1012	<b>1012</b>	830.75	141.70	830.75	141.70	830.75	141.70	830.75
141.80	965	1012	<b>1012</b>	830.55	141.80	830.55	141.80	830.55	141.80	830.55
166.70	965	1012	<b>1012</b>	695.41	166.70	695.41	166.70	695.41	166.70	695.41



**Table 5H-4. Llano River Valve Closure – Pressure Comparison with the Addition of Seven New Mainline Check Valves – Pressure Relief Active<sup>1</sup> (Continued)**

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	(C)	(D)	(F)	(H)	Case 2: Llano River Valve Closure (SE-16)		Case 2-RV50: Llano River Valve Closure (SE-16)		Case 2-RV25: Llano River Valve Closure (SE-16)	
	Original Operating Pressure	MAOP	New Pressure Test Allowable Operating	Max.Steady State Pressure, Bypass Relief Operable, New Steady State Rate, 2262 bph	MP	Pressure (psig)	MP	Pressure (psig)	MP	Pressure (psig)
171.50	965	1012	<b>1012</b>	618.01	171.50	618.01				
175.50	965	1012	<b>1012</b>	542.36	175.50	542.11	175.50	542.36	175.50	542.36
181.67	965	1012	<b>1012</b>	475.01	181.67	474.77	181.67	475.01	181.67	475.01
	965	1012	<b>1012</b>	949.80	181.67	949.80	181.67	949.80	181.67	949.80
185.90	965	1012	<b>1012</b>	936.75	185.90	936.75	185.90	936.75	185.90	936.75
190.50	965	1012	<b>1012</b>	928.26	190.50	928.26	190.50	928.26	190.50	928.26
193.24	965	1012	<b>1012</b>	1009.99	193.24	1009.99				
193.40	965	1012	<b>1012</b>	1005.32	193.40	1005.20	193.40	1005.32	193.40	1005.32
197.10	965	1012	<b>1012</b>	979.01	197.10	978.89	197.10	979.01	197.10	979.01
198.70	965	1012	<b>1012</b>	991.82	198.70	991.69	198.70	991.82	198.70	991.82
198.90	965	1012	<b>1012</b>	982.20	198.90	982.08	198.90	982.20	198.90	982.20
199.50	965	1012	<b>1012</b>	931.98	199.50	931.98	199.50	924.98	199.50	924.98
203.50	965	1012	<b>1012</b>	896.62	203.50	896.38	203.50	896.62	203.50	896.62
203.62	965	1012	<b>1012</b>	893.79	203.62	893.79				
208.10	965	1012	<b>1012</b>	839.45	208.10	839.08	208.10	839.45	208.10	839.45
210.00	965	1012	<b>1012</b>	862.14	210.00	861.65	210.00	862.14	210.00	862.14
211.90	959	1012	<b>1012</b>	813.68	211.90	813.07	211.90	813.68	211.90	813.68
213.30	<b>959</b>	1012	959	831.69	213.30	831.69				
228.00	965	1012	<b>1012</b>	647.29	228.00	646.56	228.00	647.29	228.00	647.29
	965	1012	<b>1012</b>	859.83	228.00	859.83	228.00	859.83	228.00	859.83
276.50	965	1012	<b>1012</b>	786.17	276.50	786.17	276.50	786.17	276.50	786.17
276.60	<b>973</b>	1012	973	793.19	276.60	793.19	276.60	793.19	276.60	793.19

**Table 5H-4. Llano River Valve Closure – Pressure Comparison with the Addition of Seven New Mainline Check Valves – Pressure Relief Active<sup>1</sup> (Continued)**

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	(C)	(D)	(F)	(H)	Case 2: Llano River Valve Closure (SE-16)		Case 2-RV50: Llano River Valve Closure (SE-16)		Case 2-RV25: Llano River Valve Closure (SE-16)	
	Original Operating Pressure	MAOP	New Pressure Test Allowable Operating	Max.Steady State Pressure, Bypass Relief Operable, New Steady State Rate, 2262 bph	MP	Pressure (psig)	MP	Pressure (psig)	MP	Pressure (psig)
281.80	<b>965</b>	1012	965	663.92	281.80	663.92	281.80	663.92	281.80	663.92
288.90	<b>965</b>	1012	965	561.04	288.90	561.04	288.90	561.04	288.90	561.04
295.30	<b>965</b>	1012	965	501.87	295.30	501.70	295.30	501.87	295.30	501.87
	<b>965</b>	1012	966	501.70	295.30	501.70	295.30	501.70	295.30	501.70
305.80	952	1012	<b>1012</b>	421.36	305.80	421.36	305.80	421.36	305.80	421.36
322.00	<b>965</b>	1012	<b>1012</b>	406.54	322.00	406.54	322.00	406.54	322.00	406.54
358.70	<b>964</b>	1012	<b>1012</b>	268.19	358.70	268.19	358.70	268.19	358.70	268.19
373.50	<b>964</b>	1123	964	169.70	373.50	169.50	373.50	169.70	373.50	169.70
	<b>964</b>	1123	964	169.50	373.50	126.86	373.50	169.50	373.50	169.50
404.40	<b>1020</b>	1461	1020	126.86	404.40	125.67	404.40	126.86	404.40	126.86
405.10	<b>955</b>	1040	<b>1040</b>	125.67	405.10	104.16	405.10	125.67	405.10	125.67
416.60	955	1040	<b>1040</b>	104.16	416.60	4.88	416.60	104.16	416.60	104.16
441.90	960	1040	<b>1040</b>	84.81	441.90	84.81	441.90	4.88	441.90	4.88
455.70	<b>1461</b>	1461	1040	84.81	455.70	82.91	455.70	84.81	455.70	84.81
457.60					457.60		457.60	82.91	457.60	82.91

<sup>1</sup> Galena Park Station to Crane Station at 5000 bph, fuel oil linefill; bypass relief around river valves active.

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