CITY WIDE DRAINAGE STUDY

M. A. COLLINS
39270

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CITY OF LA PORTE

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klotz associates

KLOTZ ASSOCIATES, INC.
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EXECUTIVE SUMMARY

A City Wide Drainage Study (CWDS) for the City of La Porte (City) was undertaken to identify, develop and recommend drainage improvements to address drainage problems and lessen flooding and its impacts across the City. Reasons for existing drainage and flooding problems include 1) insufficient flow capacity in ditches and channels, 2) ponding of waters in streets and adjacent properties, 3) undersized storm sewers, 4) temporary blockage of storm water inlets by debris, 5) backup of storm waters in sewers, and 6) lack of overland or sheet flow paths. Also contributing to the drainage problems are natural effects common to coastal areas: Relatively small ground slopes making it difficult to rapidly drain away runoff waters; tides and storm surges causing rising water levels which impede drainage; and frequent but severe storm events with large amounts of rain falling in short periods of time. Future drainage problems can, on the other hand, result if the runoff from future land development is not controlled. Flooding is a fact of life in coastal areas and control of flooding in coastal areas presents significant challenges.

The strategy used to address drainage and flooding issues had two components: 1) remedy of current drainage and flooding problems, and 2) mitigation of future drainage problems. The bases of our recommendations are summarized in the Engineering Summary following this Executive Summary. Details of the engineering analyses leading to the recommendations are provided in the main body of this report.

Current Flooding and Drainage Problems

To address the current drainage and flooding problems, 1) channel improvements, 2) detention ponds for flood flow diversion, 3) storm sewer upgrades, and 4) development of relief swales (i.e., directed sheet flow pathways) options are evaluated. Improvements proposed in prior studies by others were incorporated into the proposed solutions of this study when appropriate.

Relief swales are a very cost effective (i.e., low cost/benefit ratio) drainage improvement. Relief swales reduce or limit ponding of runoff waters in streets and low lying areas for small to moderately large storm events which exceed the City's standard design frequency for storm sewers. Swales, in effect, enhance local drainage system capabilities. Relief swale projects will require only limited coordination with the Harris County Flood Control District for implementation. Twelve relief swales, sometimes constructed in conjunction with sewer system outfall improvements, are recommended, as follows:

Recommended Relief Swale Projects

Project ID	Subdivision/ Area Benefiting	Type of Improvement	Project Construction Cost	COST/BENEFIT: Construction Cost Per Loss Removed[1]
1	Pinegrove Valley	Relief Swale	$6,000	$140
2	Brookglen	Relief Swales & Outfall Pipe Upgrade	$95,000	$350
3	Fairmont Park West	Relief Swales & Outfall Pipe Upgrade	$57,000	$370
4	Glen Meadow	Relief Swales & Outfall Pipe Upgrade	$30,000	$540
5	Meadow Park	Relief Swales & Outfall Pipe Upgrade	$13,000	$540
6	Fairmont Park	Relief Swales & Outfall Pipe Upgrade	$19,000	$560
7	Creekmont Section 1	Relief Swale & Outfall Pipe Upgrade	$34,000	$610
8	Fairmont Park East	Relief Swales & Outfall Pipe Upgrade	$65,000	$860
9	Spencer Highway	Relief Swale	$30,000	$1,360
10	Villa Del Rancho	Relief Swale	$24,000	$2,670
11	Battleground Estates	Relief Swale	$35,000	$17,500
12	Old La Porte	Relief Swale & Outfall Pipe Upgrade	$336,000	$21,000
		Total 12 Projects	**$744,000**	

[1] Total construction cost divided by the number of structures that have been reported in the past to have flooded and for which the recommended project will alleviate flooding in the future.

Construction costs for the above recommended relief swales projects include right-of-way costs assuming right-of-way can be placed on existing open land or the property line between adjacent residential lots. These projects should be given high priority for construction.

Additional details about these projects are given in Table ES-1, while the project locations are shown in Figures ES-1 to ES-6 (these table and figures as provided at the end of this summary).

Flood control projects are intended to provide a high level of flood protection, with their design based upon an extreme flood event as defined by a 100-year rainstorm event (i.e., only a 1 in 100 chance of occurring in any one year).

All flood control projects are either 1) channel widening; 2) channel lining with concrete when right-of way is insufficient for widening; 3) diversion of flood waters to a detention pond (referred to simply as a "diversion pond"); or some combination of these three. All channel widening or lining projects also include, as part of the project, a detention pond to mitigate (hence the name "mitigation pond") the adverse downstream impacts arising from the enhanced discharge capabilities of the improved channel. Project costs include land acquisition costs.

Because of the high level of protection they provide, channel improvement and detention pond projects are more expensive than relief swale projects. Based upon their relatively low cost/benefit values, eight channel improvement and diversion pond projects are recommended to address eight areas of significant flooding problems; these projects are listed on the following page. The recommended improvement and pond projects are separate projects and can be individually constructed as funds become available. The various cost/benefit ratios, all of which are $87,500 or less, can be used to help define priorities for construction.

Projects with higher cost/benefit ratios could be selected to address other flooding problem areas; these less economically efficient projects are given in Table ES-1 (the Engineering Summary following this Executive Summary discusses these other projects in more detail). One of these projects, for example, is a linear detention pond previously proposed by others along channel F216-00-00 (Project 46 in Table ES-1 and Figure ES-4 at the end of this summary). The approximate location of all evaluated projects is shown in Figures ES-1 to ES-6. Pond location, size and configuration are all approximate.

Total expenditures for projects will depend upon the projects selected for construction. Total cost and cost-benefit as well as availability of construction funding and the opportunities for construction phasing will have to be considered in project selection. The cost-benefit ratio of recommended relief swales is low ($21,000 or less), but channel improvements and diversion ponds, while having a higher cost-benefit ratio, provide greater protection against larger floods. Some of the construction cost impacts on the City can be reduced by using alternative, less traditional funding sources such as state or federal loans or grants, joint funding of projects in cooperation with other governmental entities, or establishing a storm water utility as an independent revenue source.

Recommended Channel Improvement and Detention Pond Projects to Address Flooding Problems

Project ID	Subdivision/ Area Benefiting	Type of Improvement	Project Construction Cost	Construction Cost Per Loss Removed[1]
13	Fairmont Park, Fairmont Park East	Channel Widening	$781,000	$23,000
14	Brookglen	Channel Lining	$5,494,000	$29,400
15	Meadow Park, Villa Del Rancho	Channel Widening	$1,701,000	$47,000
16	Lennox Gardens, L Street	Pond for Diversion	$1,092,000	$50,000
18	Battleground Estates, Pinegrove Valley, P Street	Channel Lining	$1,032,000	$54,000
19	Shady River	Channel Widening	$361,000	$60,200
21	Woods on the Bay, Pine Bluff, Shady River	Channel Widening	$600,000	$75,000
23	Meadow Crest, Creekmont, Glen Meadows, Fairmont Park, Fairmont Park West	Pond for Diversion	$8,314,000	$87,500
		Total 8 Projects	**$19,375,000**	

[1] Total Construction cost divided by the number of structures that have been reported in the past to have flooded and for which recommended projects will alleviate flooding in the future.

As the cost/benefit ratio rises, projects become less economically efficient. At some point, the cost/benefit ratio becomes so high as to render a project unreasonably expensive. An evaluation of the cost/benefit ratio (discussed at greater length in the Engineering Summary) for various potential projects indicates that projects with cost/benefits ratios of $87,500 or less should be considered for construction while those greater than this amount warrant considerable justification. All recommended projects meet this criterion.

When project costs are judged to be too high for the benefits obtained, options to consider include 1) no action; 2) citizen evacuation when severe flooding is anticipated, 3) extensive flood proofing of individual buildings; 4) property buy-out and/or building relocation; and 5) reliance upon insurance or emergency relief funds for cost recovery after damage is incurred.

Subdivisions where storm sewer system improvements are needed and/or more detailed investigation is needed to determine the extent of needed sewer improvements have been identified and are listed in Table ES-2 in order of estimated drainage problem severity. Of these subdivisions, Brookglen, Creekmont Section 1, Glen Meadows, Fairmont Park East, Pinegrove Valley, and Spencer Highway Estates have high drainage problem severities; and thus should be given high priority for problem solution. The Creekmont Section 2 Project is already nearing construction. Initially proposed improvements have been already identified for Brookglen, Creekmont Section 1, Glen Meadows, Fairmont Park East; these improvements include relief swales as part of the project but will require further engineering investigation for defining full project details.

Future Drainage Issues

Future drainage problems may arise from land development for residential or commercial structures which would, without mitigation, result in increased rates of runoff and possibly overtax drainage facilities. Developers are usually required by the City to provide mitigation of runoff increases. Two approaches are commonly used to provide necessary mitigation: on-site detention or regional detention. The choice between the two is typically dictated by economics.

When regional detention is used, dual use of the detention facilities can also be considered. Not only can a detention pond mitigate excess runoff from land development, but it can also provide detention for flood water diversion and mitigation of channel capacity improvements, as well as habitat improvement, a community amenity, or, during dry periods, recreational opportunities. Detention ponds can be constructed in phases, with early phases being used to provide detention for diversion or mitigation and later phases being used to provide detention of increased runoff from land development.

Table ES-3 lists potential regional detention ponds which could be used to mitigate future land development impacts or, in some cases, also be used for diversion or channel improvement mitigation. Approximate locations of the various detention facilities are shown in Figures ES-1 through ES-6.

On-site detention costs are borne by a developer, while regional detention, which combines the necessary detention mitigation for several different development sites into one "regional" detention facility, may be constructed using a variety of funding mechanisms. Costs, all or in part, for regional detention could be borne by developers; the City; by governmental entities partnering with the City; or some combination of these. Estimated costs for construction of the various potential detention facilities, when fully developed, range from $613,000 to $26,752,000.

As an aid to assessing these costs, a cost per acre of estimated area available for development upstream of the detention pond is also listed. Cost per acre of developable land ranges from a low of $5,800 to a high of $64,000. Ponds at the higher levels of cost are unlikely to be economically viable; but even for those ponds which are economically viable, the particular ponds which should or will be built will depend to a considerable extent upon how city development patterns evolve over time and the urgency for use of a regional pond.

Concluding Remarks

This CWDS recommends a variety of drainage improvement and flood control projects, including those that can be relatively easily implemented in the short term, those which are more complex and expensive but which provide a high level of flood protection, and those which can be used to address impacts of future development in the City.

Projects can be implemented individually and are not contingent upon each other; sequencing of projects can be used to implement a series of projects over time. While guidance has been provided to assist in deciding which projects should receive priority for implementation, the decisions as to the priorities for construction of improvement projects is, in the final analysis, the responsibility of City leaders.

TABLE ES-1
LIST OF PROPOSED IMPROVEMENTS FOR EXISTING CONDITIONS

ID	Channel	Location Benefiting	Modification Type	Description[10,11] (See Table 4-1 & 4-2 for Additional Details)	Total Construction Costs[15] ($)	Total Losses Removed (#)	Construction Cost Per Loss Removed ($)	Estimated Land Acquisition Area (acres)	Recommended For Rapid Implementation	Comments
Relief Swales[12,13]										
1	F101-30-00 F101-03-00	Pinegrove Valley	• 1 Relief Swale	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	$6,000	42	$140	0.03	Yes	No outfall improvement proposed
2	B112-00-00, B112-02-00	Brookglen	• 7 Relief Swales • 9 Outfall Pipes	• Trapezoidal (Concrete) Channel with Bottom Width 1 ft & Typical Depth: 3 ft, • Increase Outfall Pipe Sizes	$95,000	270	$350	0.4	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
3	B116-00-00	Fairmont Park West	• 5 Relief Swales • 5 Outfall Pipes	• Trapezoidal (Concrete) Channel with Bottom Width 1 ft & Typical Depth: 3 ft, • Increase Outfall Pipe Sizes	$57,000	154	$370	0.24	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
4	B106-00-00	Glen Meadow	• 2 Relief Swales • 2 Outfall Pipes	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft Increase Outfall Pipe Sizes	$30,000	56	$540	0.12	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
5	B106-05-00	Meadow Park	• 1 Relief Swale • 1 Outfall Pipe	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; • Increase Outfall Pipe Size	$13,000	24	$540	0.058	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes.
6	B106-00-00	Fairmont Park	• 2 Relief Swales • 2 Outfall Pipes	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; • Increase Outfall Pipe Sizes	$19,000	34	$560	0.081	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
7	B106-09-00	Creekmont Section 1	• 1 Relief Swale • 1 Outfall Pipe	• 1 Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft, • Increase Outfall Pipe Size	$34,000	56	$610	0.15	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes.
8	B106-30-00, B106-32-00	Fairmont Park East	• 4 Relief Swales • 5 Outfall Pipes	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft, • Increase Outfall Pipe Sizes	$65,000	76	$860	0.28	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
9	B109-30-00	Spencer Highway	• 1 Relief Swale	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft;	$30,000	22	$1,360	0.13	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes.
10	B106-05-00	Villa Del Rancho	• 1 Relief Swale	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft.	$24,000	9	$2,670	0.1	Yes	Proposed Relief Swale and Outfall Pipe can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes.
11	F101-00-00	Battleground Estate	• 1 Relief Swale	• Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	$35,000	2	$17,500	0.15	Yes	No outfall improvement proposed
12	F216-00-00	Old La Porte	• 1 Relief Swale • 1 Outfall Pipe	• Trapezoidal (Concrete) Channel with Bottom Width 1 ft & Typical Depth 3 ft • Increase Outfall Pipe Size	$336,000	16	$21,000	1.44	Yes	Proposed Relief Swale and Outfall Pipe are in different locations. They can be constructed individually. The cost associated with this recommendation accounts for all the relief swales and outfall pipes
Channel Improvements and Diversion Ponds[14]										
13 (27)[1]	B106-02-00	Fairmont Park, Fairmont Park East	• Channel Improvement • Mitigation Pond	• Trapezoidal, earthen channel (Grass); Length: 2350 ft; Excavation Volume: 3.2 ac-ft; Maximum Top Width: 41 ft; Typical SS: 1:2.1 • Mitigation Pond (240' x 240') (including 30' berm); Excavation Volume: 4.0 ac-ft	$781,000	34	$23,000	2.5	-	Channel Improvement and Mitigation Pond should be constructed simultaneously, Pond can be constructed to serve multiple detention purposes

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ID	Channel	Location Benefiting	Modification Type	Description[10,11] (See Table 4-1 & 4-2 for Additional Details)	Total Construction Costs[15] ($)	Total Losses Removed (#)	Construction Cost Per Loss Removed ($)	Estimated Land Acquisition Area (acres)	Recommended For Rapid Implementation	Comments
Channel Improvements and Diversion Ponds[14]										
14 (20)[2]	B112-00-00	Brookglen	• Channel Improvement • Mitigation Pond	• Trapezoidal, (Concrete) Channel, Length: 5459 ft, Excavation Volume: 58.3 ac-ft; Maximum Top Width: 114 ft, Typical SS: 1:1 • Mitigation Pond (575' x 575') (including 30' berm); Excavation Volume: 65 ac-ft	$5,494,000	187	$29,400	12.6	-	Channel Improvement and Mitigation Pond should be constructed simultaneously. Pond can be constructed to serve multiple detention purposes.
18 (27)[3,4,6]	F131-00-00	Battleground Estates, Pinegrove, Residents along P St.	• Channel Improvement • Mitigation Pond	• Trapezoidal (Grass) Channel, Length: 40000 ft; Excavation Volume: 5.3 ac-ft, Maximum Top Width: 77 ft; Typical SS: 3:1 • Mitigation Pond (250' x 250') (including 30' berm); Excavation Volume: 7 ac-ft	$849,000	19	$45,000	1.4	-	Channel Improvement and Mitigation Pond should be constructed simultaneously. Construction cost considers the recently acquired right-of-way for channel improvements. Land acquisition is still required for the mitigation detention pond
15 (17)[3]	B106-05-00	Meadow Park, Villa Del Rancho	• Channel Improvement • Mitigation Pond	• Trapezoidal, Earthen Channel (Grass); Length: 4608 ft, Excavation Volume: 8.0 ac-ft; Maximum Top Width: 41 ft; Typical SS: 2.4:1 • Mitigation Pond (300' x 300') (including 30' berm); Excavation Volume: 10.0 ac-ft	$1,701,000	36	$47,000	6.1	-	Channel Improvement and Mitigation Pond should be constructed simultaneously
16 (24, 30)[4]	F101-03-00, F101-05-00	Lomax Garden, Residents along L St.	• 2 Diversion Pond	• Dimensions 410' x 410' (including 30' berm); Excavation Volume: 23.0 ac-ft • Dimensions: 450' x 450' (including 30' berm); Excavation Volume: 29.0 ac-ft	$1,092,000	22	$50,000	8.5	-	Pond can be constructed to serve multiple detention purposes. Recognize that system is interconnected with F101-06-00 and should be analyzed as a system in further detail.
17 (35)[3]	B106-05-00	Meadow Park, Villa Del Rancho	• 1 Diversion Pond	• Dimensions: 590' x 590' (including 30' berm); Excavation Volume: 32 ac-ft	$1,945,000	36	$54,000	8.0	-	-
19	A104-00-00	Shady River	• Channel Improvement • Mitigation Pond	• Trapezoidal, earthen Channel (Grass), Length: 1608 ft; Excavation Volume: 4.2 ac-ft; Maximum Top Width: 78 ft, Typical SS: 3:3, • Mitigation Pond (255' x 255') (including 30' berm); Excavation Volume: 6.0 ac-ft	$361,000	6	$60,200	3	-	Channel Improvement and Mitigation Pond should be constructed simultaneously
20 (14)[2]	B112-00-00	Brookglen	• 1 Diversion Pond	• Dimensions: (1290' x 1290') (including 30' berm); Excavation Volume: 313.5 ac-ft	$11,324,000	187	$60,600	38.2	-	-
21 (29)[6]	A104-12-01	Woods On The Bay, Pine Bluff, Shady River	• Channel Improvement • Mitigation Pond	• Trapezoidal, earthen channel (Grass), Length: 6000 ft; Excavation Volume: 4.7 ac-ft, Maximum Top Width: 26 ft, Typical SS: 1.2:1 • Mitigation Pond (255' x 255') (including 30' berm); Excavation Volume: 6.0 ac-ft	$600,000	8	$75,000	7.3	-	Channel Improvement and Mitigation Pond should be constructed simultaneously; Pond can be constructed to serve multiple detention purposes.
22 (13)	B106-02-00	Fairmont Park, Fairmont Park East	• 1 Diversion Pond	• Dimensions: (700' x 700') (including 30' berm); Excavation Volume: 75.0 ac-ft	$2,794,000	34	$82,000	31.2	-	Pond can be constructed to serve multiple detention purposes
23 (25)[7]	B106-00-00	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	• 1 Diversion Pond	• Dimensions: (700' x 700') (including 30' berm); Excavation Volume: 228.5 ac-ft	$8,314,000	95	$87,500	29.3	-	Pond Site is the same location as Pond Site of option 25.
24 (16, 30)[4]	F101-03-00	Lomax Garden, Residents along L St.	• Channel Improvement • Mitigation Pond	• Trapezoidal (Concrete) Channel; Length: 9225 ft, Excavation Volume: 7.9 ac-ft, Maximum Top Width 13 ft; Typical SS: 1:1 • Mitigation Pond (340' x 340') (including 30' berm); Excavation Volume: 10.0 ac-ft	$2,378,000	22	$108,000	8.9	-	Channel Improvement and Mitigation Pond should be constructed simultaneously; Pond can be constructed to serve multiple detention purposes.
25 (23)[7]	B106-00-00	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	• Channel Improvement • Mitigation Pond • Diversion Pond	• Trapezoidal (Concrete) Channel, Length: 4320 ft, Excavation Volume: 40.4 ac-ft, Maximum Top Width: 110 ft; Typical SS: 1:1 • Mitigation Pond (540' x 540') (including 30' berm); Excavation Volume: 48.0 ac-ft • Diversion Pond (1060' x 1060') (including 30' berm); Excavation Volume: 207.0 ac-ft	$11,752,000	95	$123,700	36.4	-	Channel Improvement, Mitigation Pond and Diversion Pond should be constructed simultaneously. Ponds can be constructed to serve multiple detention purposes. Pond Site is the same location as Pond Site for option 23

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Channel Improvements and Diversion Ponds[14]										
26 (28, 30)[8]	F216-01-00	Beach Park, La Porte High School	• Channel Improvement • Mitigation Pond	• Trapezoidal Concrete Channel, Length: 2500 ft; Excavation Volume: 7.3 ac-ft; Maximum Top Width: 14 ft; Typical SS: 1:1 • Trapezoidal, earthen Channel (Grass), Length: 3500 ft; Excavation Volume: 2.3 ac-ft; Maximum Top Width: 55 ft, Typical SS: 3:1 • Mitigation Pond (270' x 270') (including 30' berm), Excavation Volume: 11.1 ac-ft	$1,454,000	9	$161,555	7	-	Channel Improvement and Mitigation Pond should be constructed simultaneously. Pond can be constructed to serve multiple detention purposes.
27 (18)[5]	F101-00-00	Battleground Estates, Pinegrove, Residents along P St	• 1 Diversion Pond	• Dimensions: (1010' x 1010') (including 30' berm), Excavation Volume: 167.0 ac-ft	$6,155,000	19	$324,000	23.4	-	-
28 (26, 30)[8]	F216-01-00	Beach Park, La Porte High School	• Channel Improvement • Mitigation Pond	• Trapezoidal concrete Channel, Length: 2500 ft, Excavation Volume: 7.3 ac-ft, Maximum Top Width: 14 ft, Typical SS: 1:1 • Drainage Pipe Replacement, Length: 3500 ft • Mitigation Pond (270' x 270') (including 30' berm), Excavation Volume: 11.1 ac-ft	$3,970,000	9	$441,111	2.2	-	Channel Improvement and Mitigation Pond should be constructed simultaneously. Pond can be constructed to serve multiple detention purposes.
29 (21)[6]	A104-12-01	Woods On The Bay, Pine Bluff, Shady River	• 1 Diversion Pond	• Dimensions: (790' x 790') (including 30' berm), Excavation Volume: 98.0 ac-ft	$2,794,000	8	$578,000	14.3	-	Pond can be constructed to serve multiple detention purposes.
31 (32)[9]	F212-00-00	Bay Front to La Porte, San Jacinto Homes	• Channel Improvement • Mitigation Pond	• Trapezoidal, earthen channel (Grass); Length: 5275 ft; Excavation Volume: 17.0 ac-ft, Maximum Top Width: 66 ft, Typical SS: 3:1 • Mitigation Pond (340' x 340') (including 30' berm); Excavation Volume: 19.1 ac-ft	$1,687,000	2	$844,000	7.1	-	Channel Improvement and Mitigation Pond should be constructed simultaneously
30 (26, 28)[8]	F216-01-00	Beach Park, La Porte High School	• 1 Diversion Pond	• Dimensions: (1170' x 1170') (including 30' berm) Excavation Volume: 229.0 ac-ft	$8,413,000	9	$935,000	31.4	-	-
32 (31)[9]	F212-00-00	Bay Front to La Porte, San Jacinto Homes	• 1 Diversion Pond	• Dimensions: (1010' x 1010') (including 30' berm), Excavation Volume: 167.0 ac-ft	$6,156,000	2	$3,078,000	23.4	-	-
Projects Previously Prepared by Others Recommended for Implementation										
46	F216-00-00	La Porte	• Channel Improvement • Inline Detention Pond	• Length: 10,562 ft, Lower flowline from SH 146 to Sens Rd, SS: 3:1 • Inline Detention, Length: 2,720 ft, Excavation Volume: 131 ac-ft	$3,200,000	15	$213,000	12.4	-	Channel Improvement and Mitigation Pond should be constructed simultaneously. Pond can be constructed to serve multiple detention purposes.

Note 1. The City is given the option of selecting any of the noted improvements for B106-02-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 2. The City is given the option of selecting any of the noted improvements for D112-00-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 3. The City is given the option of selecting any of the noted improvements for B106-05-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 4. The City is given the option of selecting any of the noted improvements for F101-07-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 5. The City is given the option of selecting any of the noted improvements for F101-00-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 6. The City is given the option of selecting any of the noted improvements for A104-12-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 7. The City is given the option of selecting any of the noted improvements for B106-00-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 8. The City is given the option of selecting any of the noted improvements for F216-01-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 9. The City is given the option of selecting any of the noted improvements for F212-00-00 for the same benefits. Values in parenthesis is an alternate project for the channel.
Note 10. Please note that though various detention ponds are labeled as mitigation, diversion, or regional detention, they are essentially the same type of structure. The different labels are merely used to convey the purpose of the detention structure. The purpose of a mitigation detention pond is to mitigate the adverse impacts of a channel improvement, a diversion detention pond serves to handle the flows diverted from the channel in question. The purpose of a regional detention pond is to serve the additional run-off from future development.
Note 11. Maximum Top Width for Channels does not include maintenance berm.
Note 12. Relief swales are short-term projects that can be rapidly implemented by the City but might require limited coordination with HCFCD.
Note 13. For further details on the relief storm sewer (a specialized relief structure), please see Project ID 45 in Table ES-2. Figures XXX shows the location of this drainage improvement.
Note 14. Channel improvements and diversion ponds are longer-term projects that will require significant coordination with HCFCD and other entities for their implementation.
Note 15. Construction costs include estimated land acquisition costs.
Note 16. Due to recent land acquisition by the City, the construction cost for the F101-00-00 improvement assumes a grass trapezoidal channel instead of the concrete-lined trapezoidal channel proposed in the main text of this report.

TABLE ES-2
DRAINAGE AND STORM SEWER IMPROVEMENTS PROJECTS REQUIRING FURTHER ANALYSIS

Name of Flood-Affected Area (See Exhibit 7, 8, & 9 for location)	Relative Importance on Scale of 1 to 10 (10 being the Highest)	Number of Residents Likely to Directly Benefit from Drainage Improvement	Likely Significant Source/Cause of Flooding	Drainage Improvements[1]
Creekmont Section 2 (Project ID 45)	6	30	Insufficient Storm Sewer Capacity	•Project ID 45 (See Figure ES-3) •Detailed Engineering Analysis Performed •Project Approved by HCFCD •Currently in Construction Negotiations
Brookglen	10	600	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (B112-00-00)	•Upgrade Storm Sewer to 48" @ Gladwyne and Bandridge; Length: 1,000 ft •Concrete Relief Swale (flume) •2 Property Buy Outs
Creekmont Section 1	10	110	Insufficient Storm Sewer Capacity	•Upgrade Storm Sewer to 48", Length: 250 ft •Concrete Relief Swale (flume) •2 Property Buy Outs
La Porte	9	375	Insufficient Channel Capacity (F216-00-00)	Detailed Engineering Analysis Required
Glen Meadows	9	160	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (B106-00-00)	•Upgrade Storm Sewer to 48", Length: 180 ft •Concrete Relief Swale (flume) •Construct New 48" Storm Sewer Pipe •2 Property Buy Outs •Concrete Relief Swale (flume)
Fairmont Park East	8	500	Insufficient Storm Sewer Capacity	•Upgrade Storm Sewer to 72", Length: 5,400 ft •Upgrade Storm Sewer on Side Streets to 48": Length 13,890 ft •Replace 70 Inlets •1 Property Buy Outs •Detention Pond Excavation
Pinegrove Valley	8	220	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (F101-00-00)	Detailed Engineering Analysis Required
Spencer Highway Estates	8	100	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Fairmont Park West	7	390	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Shady River	7	154	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (A104-12-00)	Detailed Engineering Analysis Required
Bay Colony	7	128	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Fairmont Park	6	330	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Bayside Terrace	5	252	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Lomax Garden	5	160	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (F101-03-00)	Detailed Engineering Analysis Required
Meadow Park	5	91	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (B106-05-00)	Detailed Engineering Analysis Required
Old La Porte	4	150	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (F216-00-00)	Detailed Engineering Analysis Required
Battle Grounds Vista	4	10	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Pine Bluff	3	180	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (A104-12-00)	Detailed Engineering Analysis Required
Bay Shore Park	3	50	Requires Detailed Analysis	Detailed Engineering Analysis Required
Beach Park	3	50	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Woods On The Bay	2	76	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (A104-12-00)	Detailed Engineering Analysis Required
Villa Del Rancho	2	21	Mixture of Insufficient Storm Sewer Capacity and Insufficient Channel Capacity (B106-05-00)	Detailed Engineering Analysis Required
Spencer Landing	2	10	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Meadowcrest	1	50	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Battleground Estate	1	20	Insufficient Storm Sewer Capacity	Detailed Engineering Analysis Required
Bay Front To La Porte	0	40	Requires Detailed Analysis	Detailed Engineering Analysis Required
San Jacinto Homes	0	40	Requires Detailed Analysis	Detailed Engineering Analysis Required

Note 1: See Appendix D of report for construction costs associated with select projects.

TABLE ES-3
LIST OF PROPOSED IMPROVEMENTS FOR FUTURE CONDITIONS

ID	Channel	Location Benefiting	Modification Type	Description	Total Construction Costs[1] ($)	Future Developable Land (acres)	Estimated Land Acquisition Area (acres)	Construction Cost Per Acre of Development ($)
33	B106-02-00	Fairmont Park, Fairmont Park East	• 1 Regional Detention Pond	• Dimensions: 310' x 310' (including 30' berm), Excavation Volume: 16.8 ac-ft	$613,000	13	2.2	$48,000
34	F101-03-00	Lomax Garden, Residents along L St.	• 1 Regional Detention Pond	• Dimensions: 440' x 440' (including 30' berm); Excavation Volume: 21.3 ac-ft	$844,000	13	4.4	$64,000
35	F216-01-00	Beach Park, La Porte High School	• 1 Regional Detention Pond	• Dimensions: 330' x 330' (including 30' berm); Excavation Volume: 24.6 ac-ft	$939,000	18	2.5	$52,000
36	F101-06-00	Pinegrove Valley, Residents along L St and P St	• 1 Regional Detention Pond	• Dimensions: 500' x 500' (including 30' berm); Excavation Volume: 28.3 ac-ft	$1,114,000	18	5.7	$63,000
37	F212-00-00	Bay Front to La Porte, San Jacinto Homes	• 1 Regional Detention Pond	• Dimensions: 650' x 650' (including 30' berm); Excavation Volume: 83.3 ac-ft	$2,991,000	65	9.7	$46,000
38	B112-00-00	Brookglen, Spencer Highway Estates	• 3 Regional Detention Ponds	• Dimensions: 470' x 470' (including 30' berm); Excavation Volume: 41.0 ac-ft • Dimensions: 390' x 390' (including 30' berm); Excavation Volume: 16.0 ac-ft • Dimensions: 580' x 580' (including 30' berm); Excavation Volume: 39.0 ac-ft	$3,652,000	148	16.3	$24,700
39	F101-00-00	Battleground Estates, Pinegrove, Residents along P St.	• 1 Regional Detention Pond	• Dimensions 930' x 930' (including 30' berm); Excavation Volume: 107.5 ac-ft	$4,153,000	80	39.7	$52,000
40	F216-00-00	Old La Porte, La Porte	• 3 Regional Detention Ponds	• Dimensions 680' x 680' (including 30' berm); Excavation Volume: 52.0 ac-ft • Dimensions: 770' x 770' (including 30' berm); Excavation Volume: 72.0 ac-ft • Dimensions: 300' x 300' (including 30' berm); Excavation Volume: 9.0 ac-ft	$5,184,000	576	26.3	$9,000
41	A104-12-00	Woods On The Bay, Pine Bluff, Shady River	• 1 Regional Detention Pond	• Dimensions: 1040' x 1040' (including 30' berm); Excavation Volume: 136.0 ac-ft	$5,243,000	100	24.8	$52,000
42	B106-05-00	Meadow Park, Villa Del Rancho	• 1 Regional Detention Pond	• Dimensions: 1050' x 1050' (including 30' berm); Excavation Volume: 160.6 ac-ft	$6,031,000	119	25.3	$51,000
43	B106-00-00	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	• 1 Regional Detention Pond	• Dimensions: 1050' x 1050' (including 30' berm); Excavation Volume: 203.0 ac-ft	$7,356,000	1260	25.3	$5,800
44	A104-00-00	La Porte, Shady River	• 3 Regional Detention Ponds	• Dimensions 1200' x 1200' (including 30' berm); Excavation Volume: 183.0 ac-ft • Dimensions: 540' x 540' (including 30' berm); Excavation Volume: 34.0 ac-ft • Dimensions: 1630' x 1630' (including 30' berm); Excavation Volume: 510.0 ac-ft	$26,752,000	890	101	$30,058

Note 1: Construction costs include estimated land acquistion costs.

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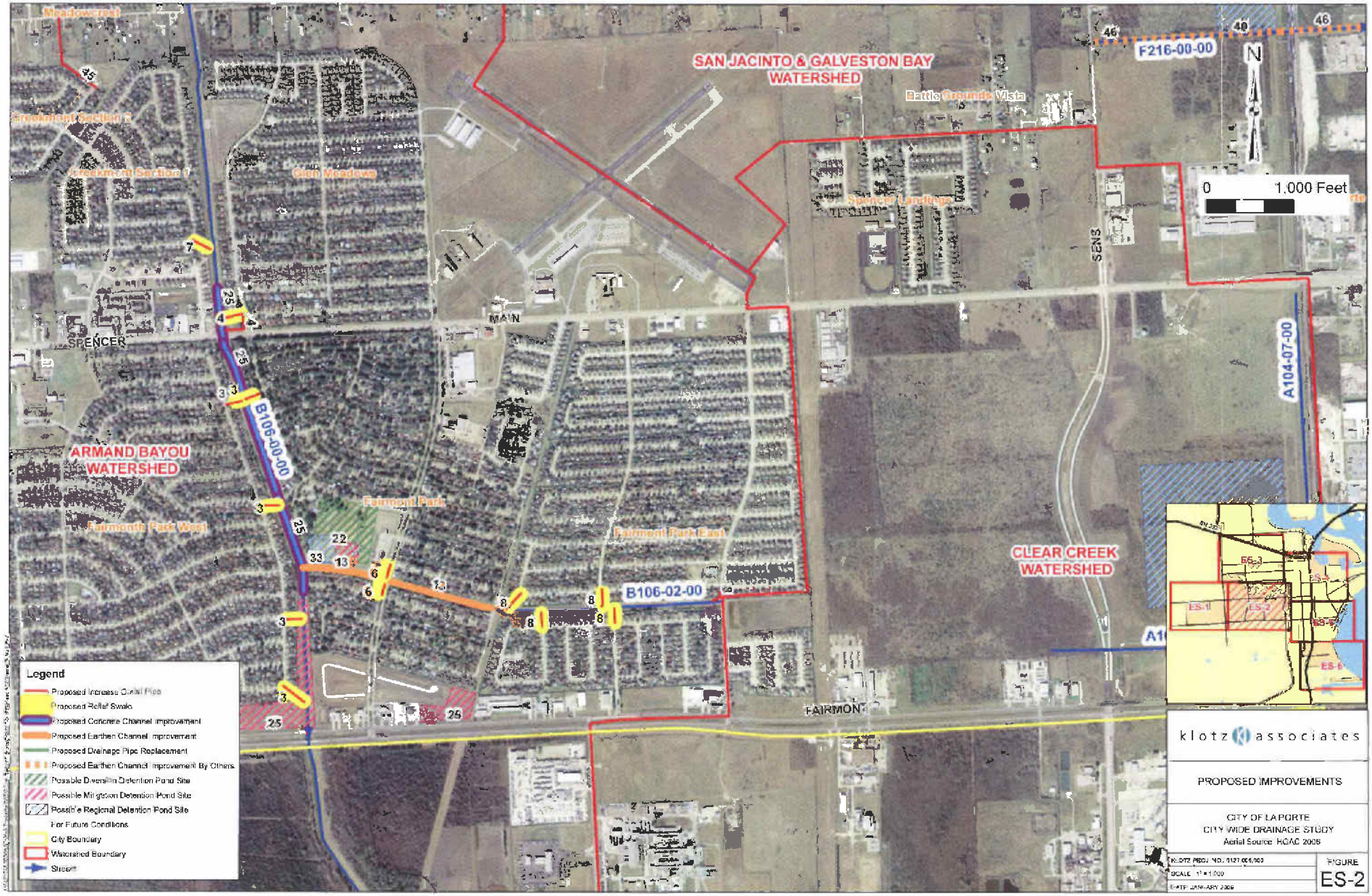
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO.: 0127 008 000
SCALE: 1" = 1,000'
DATE: JANUARY 2008

FIGURE
ES-1



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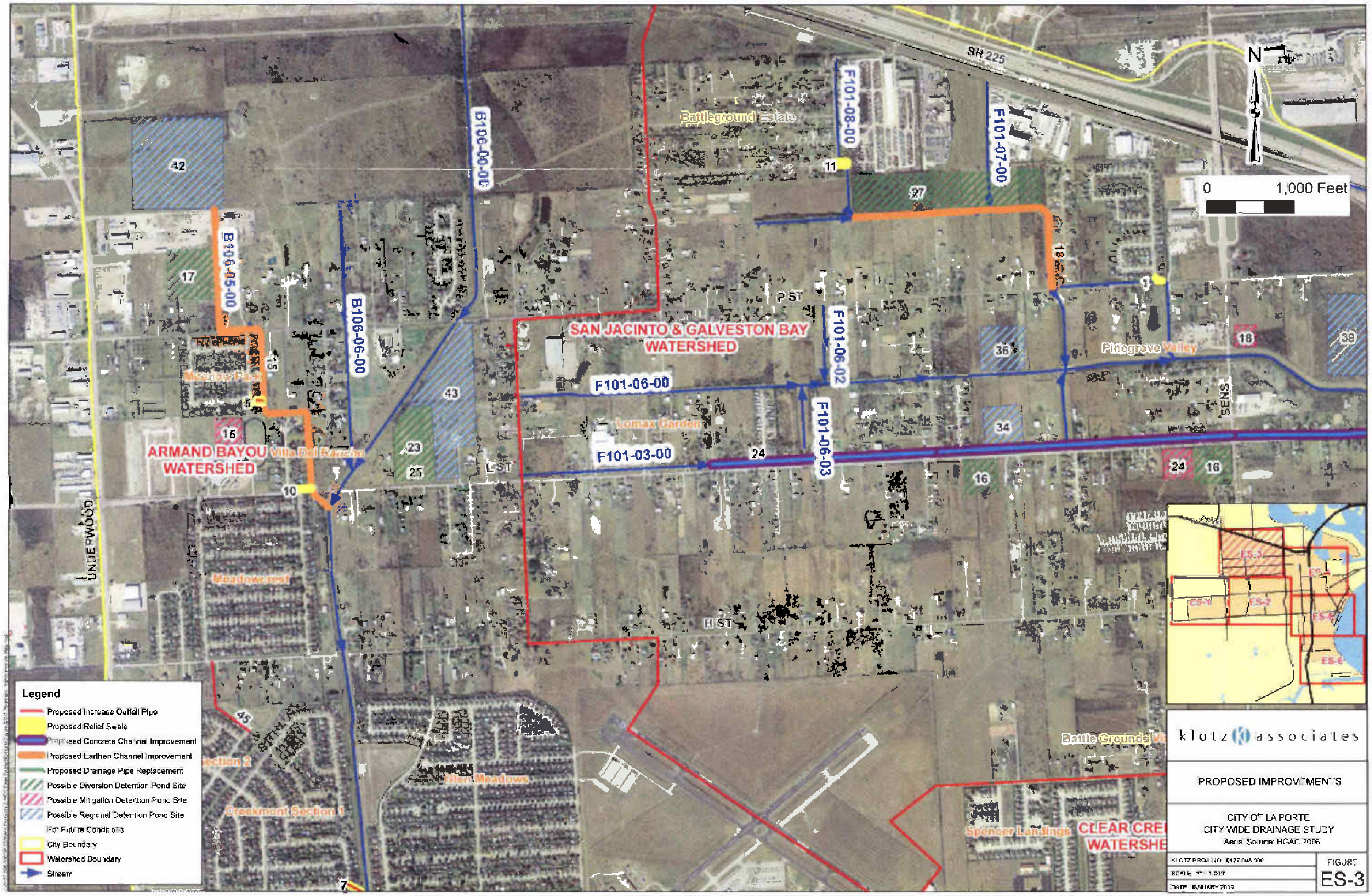
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source HGAC 2006

KLOTZ PROJ. NO. 0127.006.000	FIGURE ES-2
SCALE 1" = 1,000	
DATE JANUARY 2006	



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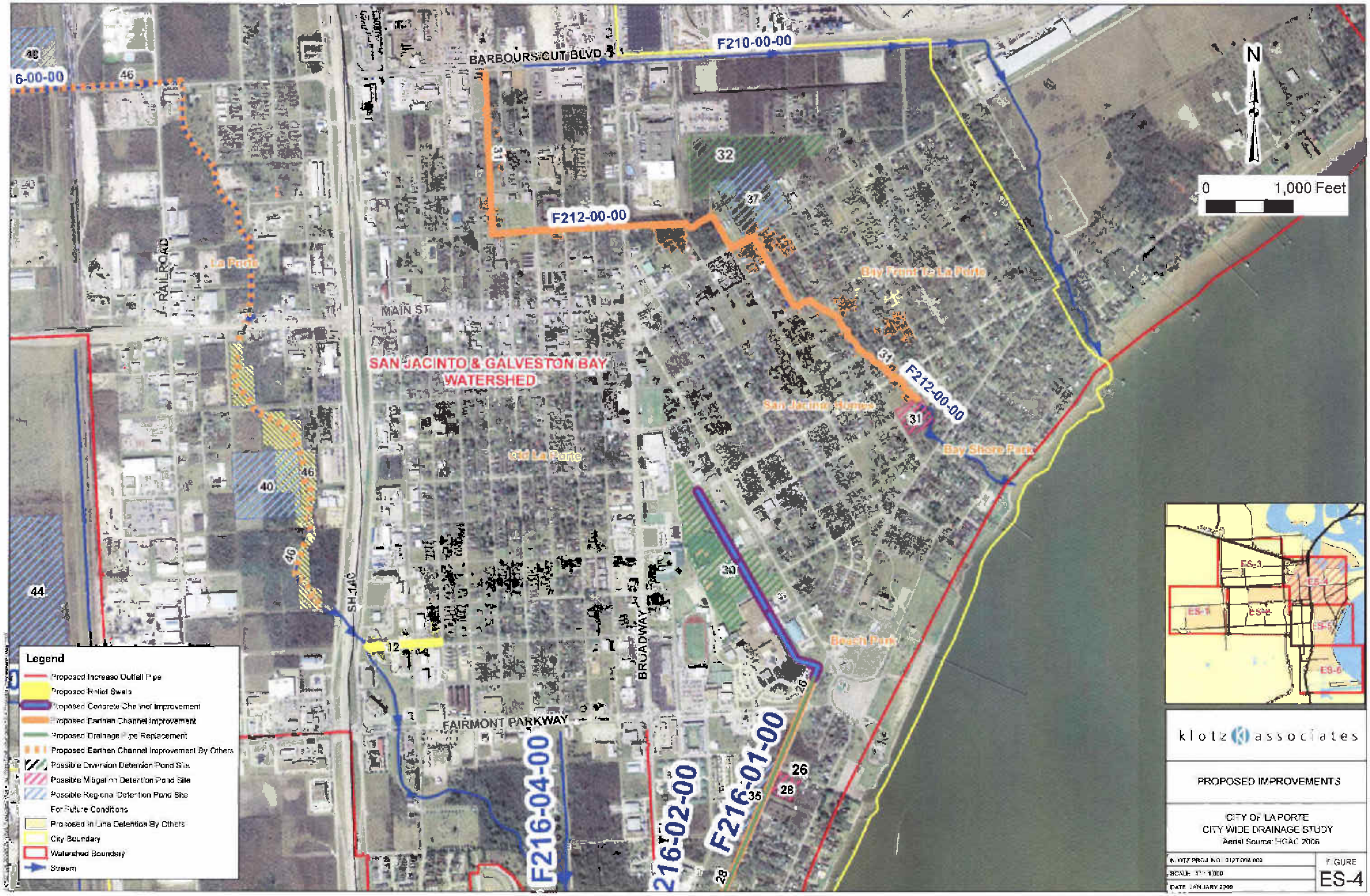
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. [illegible]	FIGURE ES-3
SCALE: 1" = 1,000'	
DATE: JANUARY 2009	



klotz associates

PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ NO. 0127.008.000
SCALE: 1" = 1,000
DATE: JANUARY 2008

FIGURE
ES-4

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PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 0127-009-000
SCALE: 1" = 1,000'
DATE: JANUARY 2008

FIGURE
ES-5

klotz associates

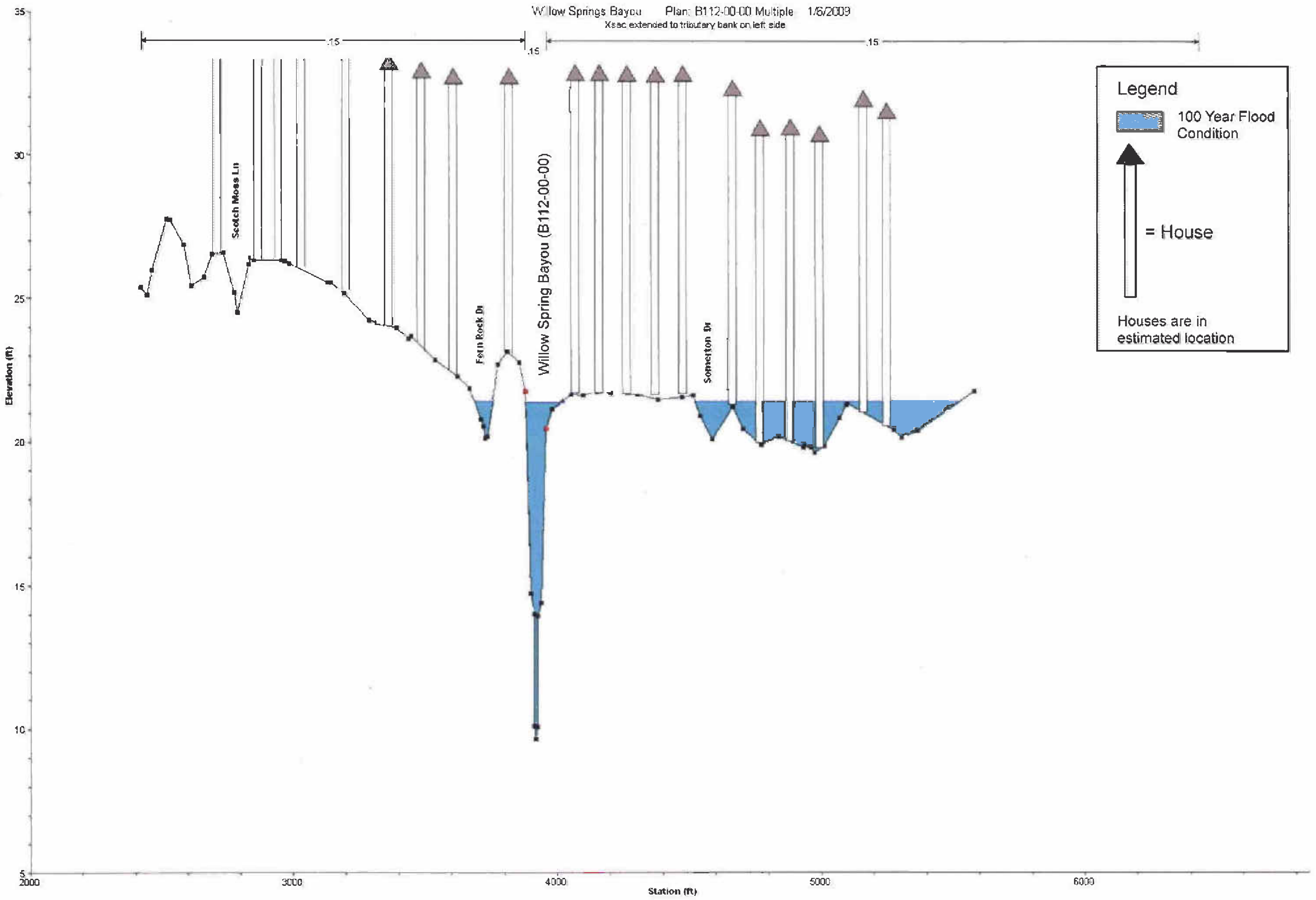
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2008

KLOTZ PROJ. NO. 0727.006.000
SCALE: 1" = 1,000'
DATE: JANUARY 2009

FIGURE
ES-6

FIGURE ES-7
CHANNEL CROSS SECTION FOR B112-00-00 IN BROOKGLEN SUBDIVISION
EXAMPLE ILLUSTRATION



ENGINEERING SUMMARY

A City Wide Drainage Study (CWDS) for the City of La Porte (City) was undertaken to identify and describe existing and future drainage and flooding problems across the City and devise solutions for the identified problems. Sources of drainage and flooding problems in the City are several and vary with location in the City. Some channels and major drainage ditches have insufficient capacity for conveyance of the runoff from severe storm events. Sometimes low lying developed areas adjacent to but beyond the boundaries of a ditch or channel can become flooded even if the channel itself is not full because water levels in the channel are above the level of the adjacent low lying areas. Ponding in low lying areas is sometimes caused by lack of surface pathways to rapidly drain away storm waters which are not captured and carried away by storm sewers. Storm sewers draining to a channel or ditch may not always have sufficient capacity to prevent collection of waters in streets and adjacent properties. Storm sewer system capacity can be limited by pipe size, insufficient numbers of inlets, debris-blocked inlets, or backup of water in the storm sewers due to high water levels in receiving channels. Storm drainage problems in the City are also in part due to natural effects common to coastal areas: Ground slopes are relatively small, making it difficult to rapidly drain away storm runoff waters. Tidal effects worsen drainage conditions, with storm tidal rises or storm surges causing rising water levels in the channels and bayous near the coast and limiting how well water can drain. The Texas coastal area is also subject to frequent but severe storm events with large amounts of rain falling in short periods of time, often overpowering drainage systems.

This planning report presents the result of the CWDS and provides recommendations for improved drainage infrastructure to reduce flooding and its impacts in the City. Three letter reports have been previously developed as part of the work leading to this CWDS report. Letter Report No. 1, dated March 10, 2008 described the City's existing drainage infrastructure and general data collection activities. The City lies in three major watersheds: Armand Bayou, Clear Creek, and San Jacinto/Galveston Bay. Assembled data and previous reports by others (see Appendix A in the main report following this summary) were used to provide a preliminary identification of apparent critical drainage problems and definition of short term solutions to the more critical problems. Sources of current drainage problems include inadequate channel capacities, lack or blockage of sheet flow outlets, and inadequate storm sewer system capacity.

Letter Report No. 2 dated May 7, 2008 also provided a description of flooding conditions using hydraulic models to provide additional evaluation of critical drainage problems, and determine potential storm sewer system limitations and possible solutions. Several short term solutions were also proposed for sewer systems in four subdivisions currently experiencing significant drainage problems; these are summarized in Table ES-2. Details of these particular solutions are described in Letter Report No. 2; Appendix C of the CWDS report following this summary provides summary tables from Letter Report No. 2 describing the proposed improvements. Other concentrated studies were used to address a current solution in Creekmont Section 2 which now nearing construction (see Project 45 in Table ES-2).

Letter Report No. 3 examined drainage criteria and standards and made recommendations for their improvement. Long term flooding problems were identified and prioritized. Conceptual solutions were identified. Conceptual solutions which are considered practical for use in the City are channel widening, channel lining, more effective use of overland storm flow relief pathways, construction of diversion and detention ponds, upgrading of storm sewer systems, and use of regional detention. Potential funding sources and mechanisms for drainage and flood control infrastructure were discussed.

Drainage problems arise from high tides and surge induced by Galveston Bay storms; such tides and surge impacts cannot commonly be mitigated by drainage infrastructure improvement. To limit storm surge impacts, considerations should be focused upon such options as early flood warning systems for citizen protection for near shoreline areas, evacuation in severe storm situations, construction of finished floor slabs and roadways above predicted storm-produced high tides or surge levels, construction of coastal storage systems in conjunction with tide gates at the mouths of bayous; flood proofing of residences; and potential property buy-outs of frequently affected homes.

This CWDS report brings together pertinent information developed in the three letter reports as well as information developed subsequent to the letter reports to document both current drainage issues and anticipated drainage problems arising from future development. The conceptual strategy for addressing current and anticipated flooding and drainage problems consists of two basic evaluations: 1) Solutions to current drainage and flooding problems, and 2) potential mitigation of future drainage problems. To perform these evaluations, existing Federal Emergency Management Agency (FEMA) hydrologic (HEC-HMS) models and hydraulic (HEC-RAS) models for most major channels in the City were gathered and evaluated; these models were termed FEMA models. Limited field survey along with other data was used to construct approximate models for some bayous and tributary channels for which FEMA models had not been developed; these later models are termed non-FEMA models. Collectively, 16 different FEMA and non-FEMA models were modified or developed to evaluate flooding conditions and identify possible improvements to reduce flooding problems.

Solution of Current Drainage and Flooding Problems

To address the current flooding problems, channel improvements, development of relief swales (i.e., directed sheet flow pathways), storm sewer outfall improvements, limited storm sewer improvements, and detention ponds for flood flow diversion (termed "diversion ponds") were considered. Proposed improvements made in prior studies by others were also considered as appropriate to the drainage problems identified in this study. While detailed storm sewer network analyses were not included in this planning level study, information on storm sewer systems was utilized in defining surface drainage systems, identifying the need for storm sewer system improvements, and in some cases identifying upgrades for sewer systems.

Recommendations for drainage system improvements to address current flooding problems are summarized in Table ES-1 (located at the conclusion of the Executive Summary). Various potential projects are identified by a Project Number. Figures E-1 through ES-6 locate where the improvement projects are proposed. In some cases options for addressing the same drainage problem are provided (e.g., as in the case of Projects 14 and 20 for the Brookglen area). Table ES-1 identifies the improvement, the area it benefits, and the channel or channels for which the improvement is being made. The table provides a basic description of the improvement, its estimated cost, and its benefit in terms of estimated reduction in number of flooded (predominately residential) structures. Information for identification of previously flooded structures included repetitive loss and flooding report data provided by the City. (Flooding reports are detailed in Exhibits 2-6 through 2-11 at the end of the main text.) The potential projects are ordered according to their cost/benefit, computed as the ratio of the cost for the improvement divided by the estimated number of structures removed from flooding. This cost/benefit can be used by City leaders as a tool for defining priorities for construction of proposed improvements.

Relief Swales

Among the various improvements proposed, surface storm water relief swales are relatively inexpensive and easily implemented. Relief swales are essentially shallow, wide ditches located to carry ponded water away to larger drainage ditches or channels and are used to improve the storm sewer system drainage. Relief swales are recommended when storm drainage conditions indicate the swale will be effective and construction will be feasible. In the urban areas of La Porte, where land availability of drainage easements is typically limited, swale widths can be kept to a minimum by using concrete swales, as opposed to grass swales. The recommended swales are assumed to be concrete lined swales.

Recommended relief swales with their basic sizes are given in Table ES-1; locations of the proposed relief swales are shown in Figures ES-1 through ES-6. The swales are used to improve drainage in areas where significant amounts of flooding problems have been reported and evaluation indicates lack of overland drainage for sheet flow discharge.

Some proposed relief swales are proposed to be located in a storm sewer system outfall easement; in these cases, the outfall pipe will require replacement in addition to construction of the swale (e.g., see Project 2 in Table ES-1). Storm sewer system capabilities can also be improved by increasing the outfall pipe size and thereby reducing the "chocking" effect it has on upstream storm sewers during extreme event storms. Such upsizing is identified when review of storm sewer system data indicated that the existing outfall was undersized.

The following table summarizes the proposed relief swale projects:

Recommended Relief Swale Projects

Project ID	Subdivision/ Area Benefiting	Type of Improvement	Project Construction Cost	COST/BENEFIT: Construction Cost Per Loss Removed[1]
1	Pinegrove Valley	Relief Swale	$6,000	$140
2	Brookglen	Relief Swales & Outfall Pipe Upgrade	$95,000	$350
3	Fairmont Park West	Relief Swales & Outfall Pipe Upgrade	$57,000	$370
4	Glen Meadow	Relief Swales & Outfall Pipe Upgrade	$30,000	$540
5	Meadow Park	Relief Swales & Outfall Pipe Upgrade	$13,000	$540
6	Fairmont Park	Relief Swales & Outfall Pipe Upgrade	$19,000	$560
7	Creekmont Section 1	Relief Swale & Outfall Pipe Upgrade	$34,000	$610
8	Fairmont Park East	Relief Swales & Outfall Pipe Upgrade	$65,000	$860
9	Spencer Highway	Relief Swale	$30,000	$1,360
10	Villa Del Rancho	Relief Swale	$24,000	$2,670
11	Battleground Estates	Relief Swale	$35,000	$17,500
12	Old La Porte	Relief Swale & Outfall Pipe Upgrade	$336,000	$21,000
		Total 12 Projects	**$744,000**	

[1] Total construction cost divided by the number of structures that have been reported in the past to have flooded and for which the recommended project will alleviate flooding in the future.

Storm Sewer Improvements

Areas where sewer system improvements are needed are listed in Table ES-2. Reasons for the needed sewer system improvements can be several, including insufficient pipe size, insufficient street inlet capacity, or high tailwater levels in the receiving channel. High tailwaters are fundamentally a problem in the receiving channel capacity, while insufficient capacity of storm sewer pipes and inlets is a true storm sewer deficiency. An identification of the likely source of the storm sewer system problem, either insufficient receiving channel capacity or insufficient storm sewer system capacity, is given. In some cases the flooding was judged to a combination of both causes.

Subdivisions where storm sewer system improvements are needed and/or more detailed investigation is needed to determine the extent of needed sewer improvements have been identified and are listed in Table ES-2 in order of estimated drainage problem severity. Of these subdivisions, Brookglen, Creekmont Section 1, Glen Meadows, Fairmont Park East, Pinegrove Valley, and Spencer Highway Estates have high drainage problem severities; and thus should be given high priority for problem solution. The Creekmont Section 2 Project is expected to constructed in the near future. Some proposed improvements have been already identified for Brookglen, Creekmont Section 1, Glen Meadows, Fairmont Park East; these improvements include relief swales as part of the project but will require further engineering investigation for defining full project details.

Channel Improvements and Ponds for Diversion of Flood Waters

Channel improvements or detention ponds to which some channel flood flow can be temporarily diverted (i.e., "diversion ponds") are recommended where the out-of-bank flow or high in-channel water levels. The latter condition may be a primary source of flooding when low lying areas at less than top-of-channel bank elevations occur beyond the channel banks and channel flood waters can move from the channel (through low points along the bank or by sewer backup) into the low lying areas, as illustrated in Figure ES-7 for Ditch B112-00-00. Out-of-bank or adversely high in-channel flooding is evaluated for the 100-year flood frequency. A 100-year design frequency criterion is used in the City as well as by other municipalities and drainage districts throughout most of the Houston area for assessing flooding impacts for severe storm events.

Channel improvements are accomplished by one of following: widening of the channel, lining the channel with concrete to reduce flow resistance, or a combination of these two methods. Table ES-1 lists the proposed widening projects while Figures ES-1 through ES-6 show where channel widening is proposed. Widening is accomplished by generally excavating the soil in mid and lower portions of the channel to make full use of the channel right-of-way as approximately defined by the existing approximate top width of the channel. Slopes for non lined channels are set to a maximum of 3:1 (i.e., 3 horizontal to 1 vertical) as defined by City design criteria. In many locations, current land use will preclude significant channel widening and improvement in the channel capacity will require lining of the channel, as currently exists in many of the major ditches and channels in the City. The data of Table ES-1 indicates which channels are recommended for actual widening and those channels which, because of limited space for channel widening, would be recommended for concrete lining. In some instances, large drainage pipes might be used as an alternative to channel widening (e.g., see Project 28 in Table ES-1).

Increase in downstream flows is an adverse impact from channel improvements; this impact can be mitigated with detention ponds (i.e., "mitigation ponds") specifically designed to capture the flow increase and temporarily detain the increase until it can be released without adverse impact. All channel widening or lining projects include as part of the project a detention pond to mitigate (hence the name "mitigation pond") the adverse downstream impacts arising from the enhanced discharge capabilities of the improved channel. Potential sites for the mitigation detention ponds are shown in Figures ES-1 through ES-6. In some cases, optional locations for a mitigation pond for one particular channel improvement are shown; in such cases, the actual mitigation pond would be either at one of the two sites, or, possibly smaller ponds would be used at each of the optional sites. Detailed engineering analyses would be required to identify the optimal number, configuration and sizes of individual ponds. In all situations, the pond configurations, locations, and sizes shown are only approximate.

In special situations, mitigation may be avoided if it can be demonstrated that adverse impacts or are absent or of very little consequence. An example of this possibility is provided by the improvements for Ditch F216-01-00, for which three alternatives have proposed (Projects 26, 28, and 30 in Table ES-1). Project Options 26 and 28 include a mitigation pond; however, the channel improvement extends to the confluence of F216-01-00 and F216-00-00, which lies quite close to Galveston Bay. Thus locations downstream of the channel improvements' potential impacts are quite limited in extent, and because of the relatively large flows that occur in F216-00-00, the increases in flow due to improvements along F216-01-00 may be so small, in a relative sense, that they are inconsequential. Hence, mitigation of the channel improvement may be unnecessary. Detailed engineering analysis would be required to confirm this speculation.

It is recognized that using channel lining to improve channel conveyance capacity is not desirable from an environmental or permitting perspective. On the other hand, widening of the channel with 3:1 or flatter side slopes will often result in a channel width that will significantly impact adjacent properties, including in some instances actual residences and consequent requirements for possible buy-out of affected residences.

Therefore, the option of off-channel diversion detention storage is sometimes considered. Table ES-1 identifies proposed detention ponds for diversion use while Figures ES-1 through ES-6 show approximate locations of the diversion ponds. Pond configurations, locations, and sizes shown are only approximate. When optional locations are available for a mitigation pond, the optional locations are shown.

In developing channel capacity improvements, channel widening is given preference over detention since widening is typically less expensive than other improvement options. However, in some instances, diversion to a detention pond may become the preferred choice or part of a preferred choice because of either its relative cost, the potential use of the detention site to serve multiple uses, or other special characteristics of the project.

Thus, for example, two alternatives (Projects 23 and 25) are proposed for Ditch B106-00-00 (also know as Big Island Slough); see Figures ES-2 and ES-3. Project 25 proposes a concrete lined channel, mitigation pond, and an approximately 207 acre-foot diversion pond. Project 25 requires diversion detention in order to limit channel lining to between Spencer Highway and the confluence of B106-00-00 and B106-02-00. Estimated construction costs for this project are $11.7 million (see Table ES-1). Project 23 proposes a larger diversion pond, with 228 acre-feet of storage, in approximately the same location as that for Project 25 but no channel improvements. The cost of Project 23 is only $8.3 million. The larger pond size of Project 23 achieves the same net result as the combined channel improvement and smaller pond of Project 25. Between these two alternatives, the alternative without channel improvement is the preferred alternative; the Project 23 choice, which does not include the channel lining, is clear because the diversion ponds of both projects are located at the same approximate location.

For flooding along Ditch B112-00-00 (Willow Springs Bayou) in the western "panhandle" of the City, two alternative solutions have been identified. Flooding in this panhandle segment of B112-00-00 is due not primarily to over-bank flooding, but, rather, due in large measure to flooding of low lying areas beyond the channel banks even before the water levels rise to the top of channel. As illustrated by the representative channel section view in Figure ES-7, some areas beyond the channel bank are low relative to top of the channel. Rising flood waters in the channel can move out the channel through low points in the channel bank or by backup into sewers into these low lying areas. The widening necessary to keep channel flows low enough to prevent flow from the channel moving into low lying areas is large (some 175 feet if 30-foot channel maintenance berms are included; see Project 14 in Table ES-1). Therefore diversion of flow to detention storage to lessen the maximum flow and lower the water surface in the channel becomes a potential option to widening of the channel.

Diversion sites of sufficient size in the City that could provide sufficient storage to generally lower water levels in B112-00-00 to the point where flooding and backup of waters into residential areas is not a problem are not available. However, some open lands north of the City boundary not committed to future development are apparently currently available for a diversion pond (see pond site for Project 20 in Figure ES-1). Because of its location, coordination for development of this site would have to be pursued in close cooperation with the adjacent city and other stakeholders. The estimated cost for the channel lining project within the City limits, Project 14, is approximately $5.5 million, while the estimated cost for diversion pond construction outside of the City limits, Project 20, is $11.3 million. However, the diversion project has potential regional benefits (and does not have the undesirable environmental features of a lined channel) and thus has consequent possibilities for cost sharing with other parties. Thus, before a decision is made as to which option to pursue; discussion needs to be undertaken with the adjacent city as well as other stakeholders such as the Harris County Flood Control District (HCFCD) as to the possibilities of development of the site for a detention pond.

The estimated costs for constructing the various recommended projects (exclusive of sewer system improvement costs) to address current flooding and drainage projects are listed in Table ES-1. The cost elements include land acquisition (assumed to be developed land for channel improvements and undeveloped land for ponds), site preparation, excavation, lining (when used), culvert removal and/or installation (when part of the project), and site stabilization after construction. Because of the nature of home buy-out, buy-out as an alternative to channel improvements or diversion ponds was not specifically evaluated. The recommended priority for the various projects is based upon the cost-benefit analysis described above.

The various channel improvement and diversion pond projects range from a low of $361,000 (Project 19) to a high of $11,752,000 (Project 25). Cost/benefit ratios range from $23,000 (Project 13) to $3,078,000 per loss removed (Project 32).

Total expenditures for projects will depend, of course, upon the projects selected for construction. Total cost and cost-benefit as well as availability of construction funding and the opportunities for construction phasing will have to be considered in project selection. The cost-benefit ratio of relief swales is low, but conveyance improvements, because of the high level of protection they provide, have larger costs. Some of the construction cost impacts to the City can be lessened by using alternative, less traditional funding sources such as state or federal loans or grants, joint funding of projects in cooperation with other governmental entities, or establishing a storm water utility as an independent revenue source.

As the cost/benefit ratio rises, projects become less economically efficient. At some point, the cost/benefit ratio becomes so high as to render a project unreasonably expensive. Clearly some of the higher cost/benefit projects of Table ES-1 fall into this category. Precisely where the breakpoint lies between an acceptable and an unacceptable level of cost/benefit level is a matter of policy, availability and source of funds, and competition for funds. However, some guidelines for selecting a breakpoint can be identified, as described in the following.

If the project (Project 32) with the highest cost/benefit (and a cost of $6.2 million) is removed from consideration, the largest cost/benefit drops to $935,000. Clearly a cost/benefit of this magnitude for removal of a loss is unrealistic. If, however, only the most cost efficient options (i.e., smallest cost/benefit) are considered among the various options (while still excluding Project options 32 and 33 for Channel F212-00-000), Projects 30, 29, 28, and 27 can be removed and the largest cost/benefit drops to $161,555 (for Project 26). The largest project cost, however, still remains at $11.8 million, just as it did before any projects were dropped from consideration.

If, however, Project 26 is removed from consideration, Projects 25 and 24 can also be removed from consideration because they have more efficient options. Consequently, the largest cost/benefit drops to only $87,500 (for Project 23) and the largest project cost drops to $8.3 million (also for Project 23). The projects removed from consideration reduce the channels for which projects remain from 10 to 8. Additional removals require more comprehensive considerations that would involve City policy and funding considerations.

Recommended Channel Improvement and Detention Pond Projects to Address Flooding Problems

Project ID	Subdivision/ Area Benefiting	Type of Improvement	Project Construction Cost	Construction Cost Per Loss Removed[1]
13	Fairmont Park, Fairmont Park East	Channel Widening	$781,000	$23,000
14	Brookglen	Channel Lining	$5,494,000	$29,400
15	Meadow Park, Villa Del Rancho	Channel Widening	$1,701,000	$47,000
16	Lennox Gardens, L Street	Pond for Diversion	$1,092,000	$50,000
18	Battleground Estates, Pinegrove Valley, P Street	Channel Lining	$1,032,000	$54,000
19	Shady River	Channel Widening	$361,000	$60,200
21	Woods on the Bay, Pine Bluff, Shady River	Channel Widening	$600,000	$75,000
23	Meadow Crest, Creekmont, Glen Meadows, Fairmont Park, Fairmont Park West	Pond for Diversion	$8,314,000	$87,500
		Total 8 Projects	**$19,375,000**	

[1] Total Construction cost divided by the number of structures that have been reported in the past to have flooded and for which recommended projects will alleviate flooding in the future.

Thus, in view of project cost/benefits and total projects costs, $87,500 per loss removed appears to be a reasonable breakpoint for deciding whether channel improvements or diversion ponds are appropriate to addressing flooding problems. Projects which have higher cost/benefit levels could be considered, but warrant considerable justification.

If then the least expensive project of the various options for a particular channel which meet the $87,500 criterion is selected for implementation, the projects listed on the previous page result.

Future Drainage Issues and Regional Detention

Future drainage problems may arise from land development for residential or commercial structures which would, without mitigation, typically result in increased rates of runoff. Such increase in storm water flows could overtax existing or already improved drainage facilities.

Development is typically required by the City to provide mitigation of runoff increases, i.e., construction of facilities that eliminate the increased runoff. Two policy-based approaches are generally considered in providing necessary mitigation: on-site detention (possibly coupled with best management practices which reduce the amount of runoff generated) or regional detention. In practice, a combination of the two approaches is used. Some areas or developments may rely upon on-site detention while other areas or developments may rely upon regional detention.

Regional detention facilities were evaluated for planning purposes. Planning for regional detention requires an identification of potential detention volumes and locations where detention facilities might be located. Under the assumption that regional detention is used, Table ES-3 identifies potential regional detention projects which could mitigate future land development drainage impacts or possibly be used to address yet unidentified current drainage problems. Possible approximate locations for the various detention facilities are shown in Figures ES-1 through ES-6. For illustration purposes, pond shape is usually assumed to be square. Actual pond configuration would depend upon site specific details such as property boundaries, site topography, and necessary characteristics of inlet and outlet works.

There are a variety of pros and cons in the use of regional detention as an alternative to on-site detention for runoff control from future development: On-site development costs are the sole responsibility of the developer but potentially taxable land is lost because of pond development. On-site detention is easily implemented, while regional detention requires more coordination of interests to develop. Regional detention allows multiple uses of the detention and consequent multiple sources for funding, but land must be available in sufficient amount in proper locations. A prime concern for any detention facility is land acquisition; availability of land can often be a significant limitation in regional detention pond development. On-site mitigation does not require the single large tracts of land for a pond that a regional pond requires.

Regional detention ponds lend themselves to a variety of different funding mechanisms. Costs, all or in part, for regional detention could be borne by the City, by developers through payments to the City, or some combination of City and developer funds. If the detention system serves regional purposes beyond just mitigation of land development projects, Harris County Flood Control District (HCFCD) may participate in the detention pond development and the costs of its construction. Estimated costs for construction of the various detention facilities are given in Table ES-3. As an aid (only) for assessing these costs, a cost per acre of developable land is also listed.

The potential regional detention facilities are ordered according to estimated total cost for full development of the detention site. Phasing of pond construction to match detention needs as they develop could be used to spread costs over time. What regional facilities are actually built first will depend upon how city development patterns evolve over time, costs of on-site vs. regional detention for specific land development projects, and what detention needs other than mitigation of development runoff may be served by the pond. The listing of Table ES-3 is not intended to define which regional detention facilities should be built or which should be built first.

Concluding Remarks

To maximize the effectiveness of proposed drainage improvements and minimize future drainage problems, the City should rigorously enforce drainage criteria and standards. Future finished floor slab and critical roadway elevations should be established. Provisions for sheet flow relief pathways and assurance of adequate capacity in new sewers systems which meet upgraded City criteria should be enforced. Construction in flood hazard zones and flood-prone areas should be avoided as much as possible. And, to the extent that they are not already in place, agreements need to be developed between the City and HCFCD to assure adequate levels of channel maintenance to maintain channel conveyance.

Implementation of recommended projects can initially focus upon very cost efficient, less expensive projects such as relief swales, which can be relatively easily implemented. Larger, more complex projects to address flooding problems along channels as well as detailed analysis of some storm sewer systems should follow. The more complex flood protection projects will require more effort to implement, but will provide a high level of flood protection. Selection of the more cost efficient alternatives will usually facilitate project implementation. Impacts of recommended improvements should be recognized and appropriate mitigation implemented. Regional detention opportunities should be explored when impacts lie or have their source beyond City boundaries.

Projects can be implemented individually and are not contingent upon each other; sequencing of projects can be used to implement a series of projects over time. While guidance has been provided to assist in deciding which projects should receive priority for implementation, the decisions as to the priorities for construction of improvement projects is, in the final analysis, the responsibility of City leaders.

SECTION 1
INTRODUCTION

1.1 Purpose and Scope

Klotz Associates, Inc. has prepared a City Wide Drainage Study (CWDS) for the City of La Porte (City). This CWDS provides a plan for the City which identifies and describes existing and anticipated drainage and flooding problems in the City and develops both short and long term conceptual remedies for the identified and prioritized problems.

The general scope of the CWDS includes the assessment and detailing of drainage and flooding problems; examination of hydrologic and hydraulic conditions as a basis for characterizing problems and identifying potential remedies; characterization and prioritization of drainage and flooding problems using various hydraulic modeling methods; development of remedies for addressing the drainage problems; estimate of the cost of potential remedies; and recommendations and considerations in implementing conceptual remedies.

1.2 Authorization

Development of the City Wide Drainage Study by Klotz Associates was authorized by the City of La Porte by agreement dated January 29, 2008.

1.3 Prior Reports of Present CWDS Report

Pursuant to scope, three prior reports have been prepared as part of the development of the CWDS.

Letter Report No. 1, dated March 10, 2008, collected and assembled key data (Tasks 1.1 and 1.4 of scope), generally described the watersheds and drainage system in the City using various techniques and data including LiDAR data (Task 1.2), and conducted and documented site visits (Tasks 1.3). Key drainage reports developed prior to the present study were also summarized (Task 1.6). In addition, the assembled data was used to assess and provide a preliminary identification of apparent critical existing drainage problems (Task 1.5). This assessment led to identification of short term solutions (Task 2.3) which were communicated to the City Council and Flooding and Drainage Committee (Task 2.4).

As part of the data gathering activities documented in Letter Report No. 1, available and previous prepared hydrologic and hydraulic data and models for various bayous in the City were obtained (Task 2.1). Review and update of the models continued though preparation of Letter Report No. 2 and Letter Report No. 3 (Task 2.5). Modeling was assisted with limited survey for selected bayous (Tasks 2.6 and 3.1) so that models and identification of drainage and flooding problems could be refined for both existing and estimated future conditions (Task 2.5).

Letter Report No. 2 provided a description of flooding conditions (Task 2.2) and provided a detailed description of the available hydraulic models (Task 2.5), while update of the models continued. Letter Report No. 2 also provided additional characterization of critical drainage problems and refined improvements for addressing short term drainage problems. Letter Report No. 3 completed the development of hydraulic models for the various bayous in the City being studied. A report on key aspects of the findings documented by Letter Report 2 was presented to the City Council and Flooding and Drainage Committee (Task 2.4).

Letter Report No. 3 examined drainage design criteria and standards (Task 4.1) and made recommendations for modifications to the City's criteria. Long term drainage problems were described and prioritized (Task 4.2) with regard to the relative adverse impacts on the residential areas. Reasons for drainage system deficiencies were categorized as a preliminary to developing conceptual remedies. Conceptual remedies were generically described, and preliminary unit cost factors to use in estimating remedy costs were determined (Task 4.3). Potential funding sources for capital improvement projects addressing drainage and flooding issues were identified (Task 4.4). Information developed for Letter Report No. 3 was provided to the City Council and Flooding and Drainage Committee (Task 4.2).

Management of the execution of work leading to these letter reports as well as the CWDS Report was performed pursuant to Tasks 1.7, 2.3, 4.4 and 4.5.

1.4 CWDS Report

This CWDS Report brings together (pursuant to Task 4.5 of the study scope) the more cogent aspects of the three letter reports to quantify the character of the problems as deduced from both earlier evaluations in the three letter reports and application of the hydrologic and hydraulic models to specific bayous and channels. This application provides estimates of channel capacities and identifies where capacities are insufficient to meet capacity design goals to further define the nature of the drainage problems in the City (Task 2.2). Various workable remedies for achieving the design capacity are identified at a conceptual level and approximately sized and located (Task 4.3). Remedies include possible channel modifications and detention storage. Approximate dimensions of modified channels are presented. Potential detention pond locations are identified and storage requirements quantified. Remedies are described for the study bayous on a bayou-by-bayou basis. Estimated costs of proposed remedies are provided (Task 4.3). Potential ways to prioritize implementation of drainage improvements are suggested. Issues in implementing the potential improvements are discussed and recommendations are presented.

1.5 Data Sources

The data that was gathered was from a variety of sources, including earlier studies and reports from the City, HCFCD, and Consultants; hydraulic and hydrologic models from FEMA; plans and profiles of existing storm drainage systems; field reconnaissance; and from discussions and correspondence with residents' and City Staff input. Appendix A provides a tabulation of earlier studies and reports reviewed as part of the development of this CWDS.

1.6 Acknowledgments

Klotz Associates wishes to acknowledge the support and help of the following people in providing data, photos, or insight into the drainage systems and conditions in the City of La Porte, including the City Staff and the Department of Public Works, the Flood and Drainage Committee of the City of La Porte, Harris County Flood Control District (HCFCD), and the people of La Porte. The City Staff provided important information for this report and helped significantly in identifying current flood problems and issues reported by citizens of the City. Coordination with local communities in the area was facilitated by HCFCD and the City's Drainage Committee; monthly meetings with the Committee were important to improving our understanding to issues of concern.

SECTION 2

DRAINAGE AND FLOODING CONDITIONS

2.1 Background Information

The City lies entirely within Harris County, Texas, and encompasses approximately 19.7 square miles. It is located on the extreme east side of Harris County on the shores of Galveston Bay (see Exhibit 2-1). The City is bounded by the City of Deer Park on the west, the east-west State Highway 225 on the north, and the community of Shore Acres and properties of the Port of Houston on the south. State Highway 146, extending in a generally north-south direction approximately bisects the City. Key thoroughfares in addition to State Highways 225 and 146 are Fairmont Parkway, Spencer Highway-Main Street, and Broadway (see Exhibit 2-1).

The City has a mixture of residential, industrial and commercial land uses. The area between Fairmont Parkway and Spencer Highway is composed primarily of small residential lots. Areas north of Spencer Highway have not only typical residential medium to small lot developments (with lots commonly in the range of 0.15 to 0.25 acres) but also some large rural lot residential areas (with lot sizes typically in the 3 to 5 acre range). Areas east of SH 146 include residential lot developments, commercial areas, and industrial areas.

2.1.1 Land Use

The City has a wide variety of land use: rural, urban, industrial, and commercial. Exhibit 2-2 shows an aerial of the City. The City area lying east of SH 146 and adjacent to Galveston Bay, often referred to as "Old La Porte," is predominately residential and commercial land. The southwest side of the City east of Sens Road is predominately residential. The northern side of the City is an industrial area composed of primarily petrochemical facilities. The northeastern portion of the City is considered to be a "Large Lot District," composed primarily of large rural residential lots. The south side of the City is a rural area that is a Planned Unit Development, intermingled with some small, established residential areas. La Porte Municipal Airport is in the center of the City, north of Spencer Highway.

2.1.2 Drainage Overview

The City is drained by both storm sewers and open and roadside ditches. Storm sewered areas are commonly found in the newer developments in the west side of the City and in the Brookglen subdivision. The topography of the City is generally flat and averages about 24 feet above sea level (see Exhibit 2-3).

Drainage problems have been reported or identified in many areas of the City, but many of the drainage problem or flood prone areas are concentrated in the older areas of the City. More recently developed areas of the City typically have less reported or identified drainage problems. Tidal variations in the lower San Jacinto Bayou and Galveston Bay can significantly affect drainage in the eastern side of the City.

The city has approximately 35.1 miles of Harris County Flood Control (HCFCD) drainage channels; these named channels form the primary component of the surface drainage system in La Porte. The City also has approximately 3 miles of coast contiguous to Galveston Bay. There are seven major channels forming the primary surface drainage system of the City (see Exhibit 2-4). There are also nine major tributaries to these primary channels. Drainage conditions in and along these primary and major tributaries are the focus of the CWDS.

2.2 Watersheds and Primary Surface Drainage

The City lies in three major watersheds (see Exhibit 2-2): the Armand Bayou Watershed, the Clear Creek Watershed, and the Lower San Jacinto/Galveston Bay Watershed.

2.2.1 Armand Bayou Watershed

The Armand Bayou Watershed lies on the southern and western side of the City. The watershed drains in a generally southern direction to Clear Creek. Much of the western portions of the City watershed lie in this watershed; many of the residential areas of the City are located in this watershed as well.

The primary drainage channels and their major tributaries in this watershed are listed in Table 2-1 and shown in Exhibit 2-6. Drainage area sizes and levels of current development for these channels and tributaries are also summarized. It should be noted that these watercourses drain highly developed areas, but there are some large undeveloped tracts especially along Big Island Slough (B106-00-00). It should also be noted that the majority of Willow Spring Bayou (B112-00-00), Tributary 1.78 to Willow Spring Bayou (B112-02-00), and Spring Gully (B109-00-00) are outside of La Porte's city limits, thus affecting the available remedies for these watercourses.

There are several homes in this watershed with severe flood damage and repetitive losses. However, review of previously estimated flood plains, as published by Federal Emergency Management Agency (FEMA) flood insurance rate maps (FIRMs) for the primary channels in this area indicate major channel flood levels are within the banks of the channels throughout most of the watershed except in the Spencer Highway Estates Subdivision and the Brookglen Subdivision (see Exhibit 2-5).

2.2.2 Clear Creek Watershed

The Clear Creek watershed drains into Clear Lake which eventually outfalls to Galveston Bay. The central and southern sections of the city lie in the Clear Creek watershed.

The primary drainage channels and their major tributaries in this watershed are listed Table 2-1 and shown in Exhibit 2-7. Drainage area sizes and levels of current development for these channels and tributaries are also summarized. To be noted about these watercourses is the following: Channel A104-07-00 is characterized as a large, well-maintained, straight channel, while Taylor Bayou (A104-00-00) and A104-12-01 are mostly natural channels with heavy forested overbanks.

Flooding in some areas of this watershed has been studied in prior FEMA studies, but the studied areas in these prior studies lie generally to the south of the City. Taylor Bayou (A104-00-00) and Channel A104-07-00 (see Exhibit 2-7), which are primary City drainage channels in this watershed, have been previous modeled by FEMA but not through the City; consequently floodplains in the City within this watershed have not been previously delineated.

2.2.3 San Jacinto/Galveston Bay Watershed

The San Jacinto/Galveston Bay Watershed drains into Galveston Bay and encompasses the eastern portions of the City. Land use is predominately residential in this watershed.

The primary drainage channels and their major tributaries in this watershed are listed Table 2-1 and shown in Exhibit 2-8. Drainage area sizes and levels of current development for these channels and tributaries are also summarized. Little Cedar Bayou (F216-00-00) and Deer Creek (F212-00-00) are mostly characterized as natural, meandering channels with either heavy forested overbanks or dense residential/commercials areas.

This area has experienced structural flooding. The San Jacinto/Galveston Bay Watershed has been partially studied by FEMA as part of the Tropical Storm Allison Recovery Program (TSARP). However, Little Cedar Bayou (F216-00-00), the most significant channel in the watershed within the City (see Exhibit 2-8), was the only channel in the watershed that was specifically studied in this program. The City has plans to construct a linear detention pond on F216-00-00 to reduce flooding in the area. Exhibit 2-8 shows stream locations, FEMA delineated floodplains, and locations of flooded structures.

2.3 Drainage and Flooding Problems

2.3.1 Base Flood Maps and Regulatory Floodplains

The City's current Base (100-year) Flood Maps (also identified as FIRMs, i.e., flood insurance rate maps) were developed as a consequence of hydrologic and hydraulic studies done for the FEMA-sponsored Tropical Storm Allison Recovery Program (TSARP); these maps became effective on June 18, 2007. These Base Maps were developed using particular hydrologic and hydraulic models (conveniently referred to here as the FEMA models since they have been formally adopted by FEMA) to delineate the extent of potential floodplains along various larger streams, bayous, and channels in a watershed for base flood conditions in the area drained by the watercourse in question; these floodplains define regulatory floodplains (i.e., officially recognized by FEMA and used for defining flood insurance rates). Exhibit 2-6, 2-7, and 2-8 shows the locations of the floodplains delineated on the FEMA base maps for bayous and streams studied under the TSARP program that lie in the City. The delineated floodplains identify areas where potentials for flooding are high during severe storm events.

Examination of the delineated floodplains in Exhibits 2-6, 2-7, and 2-8 shows that out-of-bank floodplain areas, while present in some areas, are not extensively spread across the City for those bayous and streams studied with the FEMA hydrologic and hydraulic models under the TSARP program. Recognize, however, not all bayous and streams in the City were studied under the TSARP program for the purpose of base floodplain delineation; watercourses for which neither in-channel nor out-of-bank flooding conditions are shown are watercourses (or portions of a watercourse) for which no FEMA hydraulic model has been developed.

2.3.2 Drainage and Flooding Problem Identification

While FEMA-delineated floodplains and the models used for such delineation can be used to estimate or identify areas of potential flooding problems, other techniques can and were also used to identify flooding and drainage problem areas. These latter methods included direct inspection and observation, discussion with knowledgeable persons on the City staff and City Council, citizen reports to the City on severely damaged structures, drainage and flooding problems arising from Tropical Storm Allison and Tropical Storm Erin, flooding data documented by citizens, and formal repetitive loss reports (i.e., multiple reports of flood damage to structures made for flood insurance claim purposes). These latter reports define what are termed repetitive loss data.

The City's repetitive loss data were obtained for this study at the request of the Floodplain Administrator for the City and used to approximately locate where structural losses (e.g., residential houses) were occurring. Repetitive loss data help not only identify the location of the flooding problems but are important to identifying recurring and long term problem areas.

The agglomeration of these locations in combination with other information on flood damage locations can be used to identify areas (referenced by the subdivision in which the flood damage is concentrated) of significant drainage or flooding problems. Exhibit 2-6, 2-7, and 2-8 shows locations of drainage and flooding problems defined by these damage and flooding reports.

2.3.3 Subdivision Areas with Significant Drainage or Flooding Problems

Based upon the data gathered on drainage and flooding problem locations, general locations (identified by subdivision areas) of significant drainage or flooding problems were identified. These are listed in Table 2-2.

To assist in identifying the level of severity of the drainage and flooding problems in the identified subdivision areas, each flood damage report (arising from Tropical Storm Allison, Tropical Storm Erin, severe structural damage reports, and repetitive loss reports, discussed above) was assigned a weighting factor (selected in consultation with City staff and listed in Table 2-3) so that a severity index could be computed from the sum of the weighted reports in the general vicinity of the subdivision where the flooding problem was reported. The details of the process of generating this severity index are discussed at length in Letter Report No. 3. The computed severity index, termed the flood problem "intensity" is listed in Table 2-4.

The computed flood problem intensities can be used to graphically display the severity of flooding problems across the various watersheds, as illustrated in Exhibits 2-9, 2-10, and 2-11. Since the intensity values should be considered only as approximate, the exhibits use only broad classifications to display the problem severities in various subdivision areas.

Note that it is the relative magnitude of the flood problem intensity parameter that is of importance, not its absolute magnitude. Consequently, for assistance in decision making about remedies for drainage and flooding problems, the intensity values can be used to rank the various problem areas on a scale of 1 to 10, 10 representing the most severe problem area. The ranks for the various subdivisions are given in Table 2-4.

The subdivision ranking of Table 2-4 is a ranking based upon flood problem severity as reflected in drainage and flooding reports, as discussed above. Improvement in drainage, as discussed at length in Letter Report No. 3, will improve drainage conditions across a large area of a subdivision, not just for those residences for which flooding reports have been made. The estimated number of lots (in lieu of detailed information on number of people in a residence) generally benefiting from drainage improvements in the general vicinity of a subdivision have been also estimated; these estimates are listed in Table 2-4. The number of lots likely to directly benefit from drainage improvements provides an alternative method by which to judge the relative merit of drainage improvements.

2.3.4 Problem Areas with Short Term Drainage Project Remedy

Initial work in development of the CWDS examined drainage problems and potential remedies developed by the City because of conditions conducive to severe flooding; these problem and remedies have been detailed in Letter Report No. 1. Five critical areas were identified in this initial identification of drainage and flooding problems by the City (for convenience these problem areas are identified as City-Identified Drainage Problem Areas. These are listed in Table 2-5 and shown in Exhibit 2-12.

Potential remedies for reduction or elimination of localized drainage problems in these City-Identified Drainage Problem Areas had been identified by the City, the distinctive feature of the remedies being their ability to be quickly and relatively cheaply implemented. These drainage problems, the proposed remedies, and the evaluation of the proposed remedies are summarized in Table 2-5. The particular drainage problem remedies for these initially identified problem areas are localized and consisted of the following strategies applied in the immediate vicinity of the identified problem area:

- Improvement of sheet flow paths by reduction of blockages
- Introduction of a new or emergency sheet flow path
- Lowering of street elevations to promote drainage by reducing obstruction to flow
- Adding capacity to existing ditches or introducing drainage swales
- Improving or realigning a key existing storm sewer to provide increased capacity
- Addition of street inlets

2.4 Probable Causes and Potential Remedy of Drainage and Flooding Problems

Subdivision areas (and areas in close proximity) with significant drainage problems have been identified above (see Table 2-2). Evaluation of these problems based upon information provided by the City, review of information in previous drainage reports, site inspection, proximity to potential flooding sources (i.e., bayous and channels), and hydrologic and hydraulic modeling to identify the probable cause of flooding.

Identified potential causes for reported or otherwise identified drainage or flooding problems are the following: lack of overland flow path, prohibitive flow path elevations, insufficient storm sewerage, and lack of channel capacity.

Remedy of problems are intended to address the root cause of the problem but could consist of a combination of various techniques for remedy.

2.4.1 Sheet Flow Ponding and Paths

Ponding in localized areas (such as at street intersections or at the end of a cul-de-sac) due to inability of accumulating runoff waters to drain away from the accumulating area because of the lack of a overland flow path: If a sheet flow pathway (or a drainage relief structure, such as a relief storm sewer or relief swale, which achieves the same effect) can be provided to drain away accumulating runoff waters, a localized drainage problem can be possibly resolved. Improved sheet flow pathways were identified for use in the five City-Identified Drainage Problem Areas discussed in Section 2.3.4 above.

2.4.2 Flow Path Elevation Adjustment

Sheet flow drainage is sometimes prohibited by the elevation of a street, parking lot, or other large open area. Lowering of such areas can promote more effective sheet flow. This strategy was used in addressing some of the drainage problems in the City-Identified Drainage Problem Areas listed in Table 2-2. Table 2-6 and Exhibit 2-13, 2-14, 2-15 and 2-16 shows the cost and locations of possible sheet flow paths. Detail information on elevation and flow path direction is required to implement this improvement strategy.

2.4.3 Storm Sewerage Improvements

Storm Sewerage, the set of pipes and appurtenances composing a system, may be inadequate because of several causes:

- Insufficient inlet capacity, which may be the result of insufficient size or type of inlet, insufficient number or spacing of inlets, inadequate street grading toward the inlet, or shifting of the elevation of a street or inlet which inhibits flow into the inlet.
- Inadequate sewer pipe capacity, which may be the result of insufficient size, too shallow of a pipe slope, or excessive energy losses due to pipe material or junction conditions.
- Outfall limitations which limit the maximum discharge from a sewer, due to outfall pipe material, size, or slope.
- Incorporation of sheet flow options to provide addition drainage capabilities and prevent excessive ponding can be considered a particular type of sewerage

improvement since it has the net effect of moving runoff away to a point of discharge just as an inlet into sewer pipe does.

Any one or more of these adequacies can be addressed by sewer or sewer system appurtenance replacement or upgrade. In addition to storm sewer or storm sewer appurtenance replacement, capacity improvement options include addition of parallel sewers, addition of new inlets, realignment of sewers, and introduction of bypass sewers.

For planning purposes, sewerage improvements are only categorically identified as sewerage improvements since the choice of a particular improvement technique will depend upon the details of the current sewerage system which are not available for the planning purposes of the study.

2.4.4 Channel Capacity Increase

Inadequate capacity of an open channel (ditch, bayou or other watercourse) has two important consequences: potential overflow of the channel during flood conditions; and creation of high tailwaters at storm water sewer outfalls, which in turn reduces storm sewer capacity. Potential methods for channel capacity improvement include the following:

- Deepening of a channel: Deepening possibilities will generally be limited, because of flat topography and flowline connection levels at junctions and culvert crossing structures.
- Adjustment of the channel bottom slope: Channel slope adjustment will typically be limited for the same reasons as those limiting deepening of a channel.
- Channel straightening to reduce energy losses and increase bottom slope: Straightening has limited application in the City because most channels are already quite straight.

- Lining of channel bottom and side slopes to increase channel conveyance by reducing frictional losses: Lining, while sometimes necessary as the only viable option, is not a preferred technique because of costs and environmental impacts.
- Channel berming at low points: Berming of a channel to form, in effect, a local levee at locals where the top of bank elevation is low can be used to help contain high flood waters, but in fact may not function as intended in an urban environment because of crossings beneath the berm by sewer pipe.
- Widening of a channel: Widening a channel to improvement its capacity is a preferred feasible technique provided adequate right-of-way is available so that adjacent properties are not adversely impacted.
- Improvement of hydraulic structure capacity: Bridges, to some extent, and culverts, often to a considerable amount, can significantly reduce the capacity of a channel. If data are available for estimating the impact of hydraulic structures on channel capacity, improving structure capacity, or at least significantly reducing the constrictions that hydraulic structures like culverts introduce, can be considered.

2.4.5 Detention

Detention is used for several primary purposes in drainage and flood control:

- On-site Mitigation of Runoff: On-site detention for mitigation of increased runoff due to development of an area.
- Diversion of Channel Flow: Off-line detention for diversion purposes to reduce existing channel flows by diverting flow to the diversion pond and reducing flow and stages in the channel from which the diversion occurs.
- Off-site Mitigation of Runoff: Off-line regional detention for mitigation due to increased runoff from several sites simultaneously.

- Mitigation of Flow Impacts from Channel Improvements: Off-line or in-line detention for mitigation of increased discharge from other improvements, such as channel widening.

SECTION 3
METHODS FOR EVALUATION OF ALTERNATIVE REMEDIES

3.1 Purpose and Scope of Evaluation

Various methods are used to determine the characteristics of various remedies, i.e., potential solutions, proposed to address identified drainage and flooding problems. The previous section identified problem areas; the following section applies the methods of this section to size, dimension or otherwise define the key features of proposed remedies.

Basic characteristics of remedies to be determined include channel geometries and detention pond sizes. The information required to determine these characteristics are storm water runoff and channel flow depth, i.e., hydrologic and hydraulic behavior.

3.1.1 Drainage Criteria

Characteristics of remedies are determined in light of City drainage criteria. Key drainage criteria from the City of La Porte Design Criteria Manual, Chapter 5 used in the development of drainage and flooding problem remedies are the following:

3.1.1.1 Design Frequencies

Design frequencies, expressed as return period, for various infrastructure elements are the following:

Sewers:	3-year
Road side ditches and Culverts:	3-year
Ditches and Culverts draining more than 100 acres:	25-year
Bridges:	100-year
Creeks:	100-year

Since drainage improvements proposed for watercourses are all major drainage ways (bayous, channels, and creeks), the 100-year design frequency was used to determine needed infrastructure improvements. Currently, the City staff is in the process of updating the storm sewers design frequencies requirements to a 5-year design. While the 3-year design is consistent or even slightly more stringent than some other surrounding communities, the City does experience continuing flooding and drainage problems with smaller storm events so a 5-year level of protection is warranted.

3.1.1.2 Detention Requirements

When storm water detention is required, the following criteria are used to specify minimum detention:

0 to 3 acres	0.20 ac-ft/ac
3 to 10 acres	0.45 ac-ft/ac
10 to 50 acres	Per HCFCD criteria
Greater than 50 acres:	City and HCFCD approval

Since the detention systems considered for addressing drainage and flooding problems in this CWDS deal with areas typically greater than 50 acres, detention volumes were determined using hydrologic methods based upon comparison of hydrograph volumes. It should be noted that the City staff is currently in the process of updating the detention requirements for the City. The staff is recommending that a minimum 0.2 ac-ft/ac detention rate be applied to development areas ranging in size from 0 to 1 acre, while the 0.45 ac-ft/ac detention rate is to be used for areas ranging from 1 to 10 acres. These detention rates should provide an additional level of protection to the City.

3.1.1.3 Street Ponding Levels

Ponding levels in local public streets used as drainage facilities when the 100-year storm event occurs are not to exceed the minimum of top curb and top of roadway crown for new roadways or new developments.

3.2 Classification of Watercourses

To conduct various hydraulic and hydrologic analyses with the available data, three types of watercourses were recognized, as follows:

- Primary Channels: Larger channels and bayous and similar watercourses which form the backbone of the City's drainage system. These channels are all owned by HCFCD.
- Major Tributaries: Channel, ditches, bayous and similar watercourse of moderate size which are tributary to primary channels. These tributaries are all owned by HCFCD.
- Other Channels: Small to moderate channels and ditches which are tributary to primary channels or major tributaries. All channels and ditches which are not classified as primary channels or major tributaries are classified as "other channels."

Hydraulic analysis in the development of this CWDS was performed only for primary channel and major tributaries. Primary channels and major tributaries are identified in Table 3-1 and shown in Exhibit 3-1.

3.3 Hydrologic Models

Hydrologic models were used to describe runoff magnitudes and flow in channels. For evaluation of primary channels and major tributaries, hydrologic models were available from TSARP studies or were developed for evaluation of primary channels and major tributaries.

3.3.1 HEC-HMS Hydrologic Models for Primary Channel Drainage Areas

HEC-HMS hydrologic models for entire drainage areas defined by most of the primary channels are available as a consequence of the TSARP program (these models are available online from HCFCD). These models use the Tc+R method (a specialized version of the Clark unit hydrograph method) developed and used by HCFCD. Key parameters in these models are drainage area, time of concentration Tc, storage parameter R, channel length L, and level of development as characterized by the DLU parameter, the latter affecting Tc, R, and imperviousness values. Each watershed for which a HEC-HMS model was available has a separate HEC-HMS model with its own set of parameters.

These models are used to define not only peak discharge for the storm event frequency of interest but also the entire shape (i.e., discharges) of the runoff hydrograph.

3.3.2 Hydrologic Models for HEC-HMS Sub-Areas

For drainage areas within a drainage area with a HEC-HMS model but of lesser size than the full drainage area for which a HEC-HMS model is available, the peak discharge and hydrograph discharges were determined by prorating discharges according to drainage area size.

3.3.3 Correlation Models

For drainage areas not covered by nor included in the available HEC-HMS models, a correlation model was developed. Data from the HEC-HMS models were used to compute the unit runoff (peak cfs per acre of drainage area) as a function of channel L and level of development DLU; see Figure 3-1, 3-2, and 3-2 for the 10-, 50-, and 100-year event correlations developed, respectively.

These correlations, with a different correlation for different storm event frequencies (e.g., 10-, 50-, and 100-year storm events), were used to compute peak discharges for areas which did not have a HEC-HMS model. Discharges at frequencies other than 10-, 50-, or 100-year levels were computed by interpolation.

3.3.4 Hydrograph for Correlation Models

The complete hydrograph for a drainage area with peak discharge described by a correlation model was approximated by the Malcom hydrograph used in the HCFCD small watershed method. The discharges defining the Malcom hydrograph are determined by three parameters: time to peak T_p, total volume of runoff V, and peak discharge Q_p. Only two of these three parameters are independent, the three parameters being defined by the following equation:

$$Q_p = V/(1.39\ T_p)$$

In application of this method for the present study, Q_p is determined by the peak discharge correlation (discussed above) and the volume of runoff. The volume of runoff is determined from the intensity-duration-frequency behavior for a 100-year 24-hour duration rainstorm event and an imperviousness determined by the land development parameter DLU. The fraction of rainfall which becomes runoff is set equal to the imperviousness, while the percentage imperviousness is approximated by the DLU percentage.

3.4 Hydraulic Models

3.4.1 FEMA Hydraulic Models

Hydraulic models (specifically HEC-RAS models) for most primary watercourses are available as a result of the TSARP program. These hydraulic models were used to delineate what are now officially designated as FEMA base floodplains along major watercourses, such as most of the watercourses defined as primary watercourses in this CWDS report. These HEC-RAS models are termed for his study as FEMA models and channels for which such FEMA models are available are termed FEMA channels. Table 3-1 tabulates the FEMA channels; these channels are also shown in Exhibit 3-2.

The FEMA models are used in the following ways:

To determine existing channel capacity in a FEMA channel: This is accomplished by executing the FEMA model and by determining at what points the 100-year storm event rises above the lower of 1) the top of bank or 2) the ground levels in areas immediately beyond the berms forming the banks of the channel. This latter condition may occur when the natural ground is below the bank level due to depressed topography beyond the channel. Top of bank elevations were determined from the HEC-RAS cross section data (which in turn are based upon survey data) while ground levels beyond the channel banks were determined from LiDAR-determined topography.

To determine necessary channel widening to increase the channel conveyance to handle the 100-year flood: This is accomplished by a trial and error process which gradually increases the channel width until the required discharge is conveyed within a channel water level which is the lower of the top of bank or ground levels in areas immediately beyond the berms forming the banks of the channel.

3.4.2 Non-FEMA-Modeled Channels

When a FEMA model is not available for a primary channel or major tributary, an approximate model is created by assuming the flow in the channel to be at normal depth. Available data, including field survey data collected for this study, are used to define the in-channel cross sectional shape of the channel in question. Representative bottom slope is obtained from field survey data. With representative channel shape and slope determined, the depth versus discharge relation for the channel can be determined using the Manning equation.

The hydraulic model, therefore, for a non-FEMA models station is the set of data defining channel shape and slope and the Manning equation which uses these data.

3.5 Evaluation of Storage Requirement

Storage is determined when a detention pond is to be sized to reduce peak discharge in a channel. Depending upon the available model for the channel, the information available to compute storage, and the purpose of the detention storage, somewhat different methods are used to compute required storage volumes.

3.5.1 Mitigation Storage for Channel Widening

For mitigation of channel improvements involving channel widening, the mitigation storage was estimated as the volume of excavation for the widening.

3.5.2 Diversion Storage

The volume of diversion storage for FEMA channels was estimated as the volume of the hydrograph before diversion for those values of discharges in excess of the peak discharge after diversion. For non-FEMA channels, diversion volume was estimated as the difference in before- and after-diversion hydrographs assuming hydrographs were described by the Malcom hydrograph (see Section 3.3.4) with peak discharge determined from the runoff calculations using a runoff correlation (see Section 3.5.4 below).

3.5.3 Mitigation of Excess Runoff Due to Development

The volume of runoff for FEMA channels before- and after-detention is computed as the difference in the HEC-HMS hydrographs as predicted by the HEC-HMS model with a peak discharge equal to the peak discharge before and after detention is used. The volume for non-FEMA channels is computed in the same manner except that the hydrograph is described by the Malcolm hydrograph model (see Section 3.3.4).

3.5.4 Correlation Models

For drainage basins with correlation models (basins with non-FEMA model channels), the hydrographs before and after detention are determined by the Malcom hydrograph with peak discharge determined from the correlation of runoff with area and level of development (see Section 3.3.3) and runoff volume equal to the design rainfall multiplied by the estimated imperviousness fraction for the land development condition being evaluated.

SECTION 4
IDENTIFIED DRAINAGE AND FLOOD CONTROL REMEDIES

4.1 Approach

Remedies for addressing identified drainage and flooding problems incorporated improvements identified directly as a consequence of the modeling and analysis methods discussed in Section 3 of this CWDS report, review of prior drainage studies for the City and abstraction of recommended drainage improvements from those studies that are appropriate to the problems identified in this study, and inclusion of some term remedies identified and described in Letter Report No. 1.

4.2 Identified Types of Remedies for Existing Conditions

Within the limits of information available for the development of the CWDS, identified drainage and flood control problems fall into three broad categories: Problems arising from flooding of primary or main tributary channels, as evidenced by estimated out-of-bank conditions; significant numbers of reports (of different types, as shown on Table 2-2) on flooding when nearby out-of-bank conditions do not occur or a channel is at considerable distance from the problem area; or various reports, site inspection, and review of topographic information indicates a condition conducive to or arising from significant localized ponding because lack of drainage pathways.

4.2.1 Remedies for Insufficient Channel Capacity

Primary or major tributary channel flooding was concluded to be the primary flooding problem source when either delineated floodplains more or less encompassed the drainage problem area or the existing channel in the vicinity of the problem area did not have the capacity to convey the design discharge. While this evaluation used the channel design flow (of 100-year frequency; see discussion of Section 3 regarding design criteria), the evaluation of extreme event flows was used as the guideline to assess the likelihood of channel overflow as a significant problem source. For FEMA channels, the 100-year flow was evaluated to determine in- or out-of-bank conditions, while non-FEMA channels were examined for the 100-year flow and less severe flood levels as well.

Four basic options were considered in addressing flooding due to channel overflow:

- *Channel widening*, selected as the most feasible and desirable channel modification technique if channel modification is to be used to increase channel capacity. The channel reach length where widening was proposed could be limited in channel length to areas where actually needed. For planning purposes, the widening was assumed, when based upon FEMA model analysis, to generally extend the length of the channel reach between FEMA model sections in the vicinity of where the current floodplain was out of banks and structures were being adversely impacted by flooding, such that the reaches to be improved were contiguous. For non-FEMA model analysis dealing with tributaries, the widening was assumed to occur in the channel reaches between model sections (with section locations based upon field survey) where the downstream end of a reach did not have adequate existing capacity to carry the 100-year discharge. The upstream end of non-FEMA model channel improvements were, based upon professional judgment, sometimes not included because improvements in the excluded reaches were judged not to have significant potential for reduction in structural flooding.

  In addition, the widening for which cost estimates were made was done so as to approximately 1) maintain the widened channel within its current top width and 2) using side slopes which approximated existing side slopes. In many instances, the existing slide slopes were steeper than a 3:1 horizontal to vertical side slope. The width of right-of-way for this channel improvement thus consisted of two parts: 1) the approximate existing top width (i.e., bank-to-bank); and 2) an assumed maintenance berm of 20-feet on each side of the channel.

Widening of channels to the point of significant encroachment upon adjacent properties was not considered to be a viable option. Table 4-2 shows the estimated additional channel width that would be required if channel widening with using a 3:1 side slope were used rather than a slope approximately matching the existing side slope . It is noted that significant encroachment upon adjacent properties could be expected if a 3:1 channel slope were consistently used for channel widening.

- *Channel lining*, which is used as a channel modification when widening, because of adjacent structures or similar limitations, was not feasible. The lining was evaluated as being concrete, which would allow steeper side slopes (1 to1) as well as reduced channel roughness. It is recognized that concrete lining is not a preferred option from an environmental perspective, but it was found to be necessary in some situations. Furthermore, detailed design could consider alternative materials, such as flexible concrete mats of interlocking blocks, partial lining, and geo-cell systems, which typically are more aesthetically pleasing than solid concrete lining (but note, side slope steepness on some of these types of alternatives are quite limited). Right-of-way requirements for the lined channels are similar to widened channels, i.e., existing width at top-of-bank plus a 20-foot maintenance berm of each side of the channel.

- *Hydraulic structure modification*, in which bridges and culverts are modified to reduce significant channel restrictions and consequent water level impacts: For FEMA-modeled channels, the structures along the channel are virtually all bridges. For bridges along the FEMA-modeled channels, review of computed water surface profiles for the design discharge for the FEMA-modeled channels indicated no significant (in comparison to channel widening) impacts on water surface levels. Thus for FEMA-modeled channels, reduction of structure impact by bridge or culvert improvement was not considered as an improvement option.

For non-FEMA-modeled channels for which channel and structure information was limited, it was concluded that bridges, if any, as in the FEMA-model channels, were not a significant factor in estimating channel capacity.

On the other hand, culverts might be a significant constriction in the non-FEMA-modeled channels. To assess whether culverts might or might not be a significant factor in the capacity of the channel, the estimated capacity of the existing channel was determined using the approximate methods discussed in Section 3. The capacity of any culvert system along the channel was assumed to be roughly the same as the capacity of the channel. If, then, the estimated existing channel capacity were in excess of an approximately 100-year frequency storm event, it was concluded that the capacity of any culvert system in the channel would not be a significant limitation on the capacity of the channel if the channel were to be improved by widening or lining.

On the other hand, if the estimated existing channel capacity was less than that for an approximately 100-year storm, it was assumed that the existing culverts would have a significant impact on the capacity if widening or lining were undertaken, and, therefore, culvert improvements would be required at all culvert systems along the channel where the widen or lining was to take place. For planning purposes (and specifically for costing purposes), the nominal improved culvert system was assumed to be a 5-foot square concrete box culvert with a typical velocity (at the design flow) of 6 feet per second, so that the capacity of a single culvert would be approximately 150 cubic feet per second. The number of barrels required would be the design discharge divided by 150 cubic feet per second (rounded upward to the nearest whole culvert number).

- *Diversion ponds* are off-line ponds potentially used when widening or lining, as discussed above, is 1) inadequate to lower water levels sufficiently to carry the design flow without bank-overflow, 2) considered unacceptable because of construction or environmental limitations; or 3) inadequate to prevent flooding in low-lying areas beyond the channel (low lying in comparison to the top-of-channel bank elevation) would require, for flooding of such areas not to occur (either directly or by backflow into sewer outfalls or bank cuts), that the water surface elevation for the design flow condition to be dropped to a very low level, so low that it could not be readily accomplished with widening or lining. A diversion pond, in essence, diverts some of the design flow out of the channel and temporally stores it so that the peak flow to be carried in the channel is lowered, and, a result, the maximum water surface is lowered. The procedure for determining the necessary storage volume to accomplish this is described in Section 3.

  It is more hydraulically-efficient that diversion ponds be located in the vicinity of areas where the flooding problems they are intended to remedy are located. Potential pond locations area discussed in regard to regional detention ponds discussed below; for effective diversion, ponds would be located in middle or downstream reaches of a channel at locations were open land were available. However, due to limited open land near the affected areas, some of the diversion ponds will have to be located in the upstream reaches of certain channels.

4.2.2 Mitigation of Channel Improvements

Channel improvements, such as widening, will usually result in increases in the peak discharge that occurs downstream during the design flood condition because the floodwaters move more effectively in the improved channel. If these increases are significant, an adverse impact to the downstream regions can result. To prevent such adverse impacts, mitigation of increases is required. In addition, if these increases are seen at downstream points outside the City, controversy over the proposed improvements might result. Consequently, construction of mitigation ponds associated with channel improvements should be expected.

For planning purposes, mitigation ponds would be expected to be located in the approximate vicinity of where the channel improvements occur. However, the mitigation volume would not necessary have to be provided in a single pond, but could be divided among several smaller ponds. Underground detention might in part be used to provide some of the required mitigation (though typically, underground detention is more expensive than surface detention unless land acquisition costs for surface detention are quite high and the surface above the underground detention can be used for high-valued purposes; such alternatives could be examined in detailed design).

For planning purposes, the required mitigation volume is estimated as the volume of excavation needed to construct the channel capacity improvement. Construction of mitigation will introduce additional cost for channel capacity improvement. Locations where mitigation ponds (or detention or diversion ponds might be located) are discussed below in regard to regional detention issues.

4.2.3 Storm Sewerage System Improvements

When the source of the drainage problem for a particular area of identified significant drainage problems is not considered to be channel flooding or a flood-related source, storm sewer system improvements should be considered. Areas of drainage problems for which inadequate storm sewerage was identified as the likely source of the drainage problems were listed in Letter Report No. 2. Sewerage improvements could involve sewer pipe replacement (with larger size pipe), addition of supplemental sewer lines, sewer pipe replacement with alternative materials, or, perhaps, sewer pipe lining. Inadequate sewer inlet capacity, because of inlet size, number, or location, may also be a root cause of inadequate sewerage. Letter Report No. 2 noted potential deficiencies in inlet spacing. Subdivision areas where conditions suggest that the underground sewers systems and/or inlets may be inadequate are listed in Table 2-2.

The CWDS is intended to address surface drainage issues. Where deficiencies in underground sewer systems or surface inlets are suspected, focused detailed study on such areas will be required. This CWDS report does not specifically address remedy of underground sewer system deficiencies.

One important factor in regard to the local drainage provided by storm sewer systems needs to be borne in mind when addressing potential sewer system improvements. The system of streets drained by a sewer system is in fact part of the sewer system. Limited accumulation of storm waters in the streets for the events larger than the design storm event (3-year storm for the City) is a planned behavior. Water accumulations at shallow depths for larger storm events do not inherently imply that a sewer system is inadequate or that there is a drainage problem to be remedied. However, if the City prefers to reduce these areas of ponding, then improving the sewerage (e.g., adding additional inlets, increasing the storm sewer pipe sizes, building a parallel line) would provide an additional level of flood-protection. Detailed storm sewer analysis is beyond the scope of this planning study, but the City should pursue more detailed sewerage drainage studies for the various subdivisions where sewer system improvements are apparently the necessary drainage problem remedy to confirm the problems with the sewerage systems (if a system exists already) and design sewerage system improvements.

4.2.4 Local Ponding Relief Using Sheet Flow Paths

Excess surface ponding in localizes areas can arise because of the interaction of two effects: lack of adequate sewer capacity (as discussed above) and the lack of a pathway that allows excess accumulated waters to drain away from the area of accumulation. The accumulation of runoff water will occur in a low spot. If the sewer system capacity (for whatever reason) is insufficient to receive and convey away the accumulating water, the water accumulates in the low spot. Similar remarks hold for drainage systems which use surface ditches rather than underground sewers. When improvement of the sewer system is not considered appropriate or feasible (because of, for example, high cost; long term delay before sewer improvements can be made, or, as is commonly the case, the rate of accumulation exceeds the properly determined-design capacity of the sewer system), then relief of the accumulated waters using either a sheet flow relief swale or an underground relief storm sewer (i.e., another sewer to increase sewer system capacity) can be considered.

Letter Report No. 1 described certain situations where new sheet flow paths were proposed to relieve excessive ponding. Because of the localize nature and consequent relatively small drainage areas in question, proposed construction of sheet flow pathways was considered as an option to alleviate drainage problems for areas drained by non-FEMA-modeled tributaries when topographic and other conditions suggested that lack of sheet flow paths was a significant contributor to drainage or flooding during large storm events. Underground relief sewers could be considered as an alternative to the surface sheet flow path, but for planning purposes all ponding relief was assumed to be provided by a surface relief swale or a combination relief swale and storm outfall pipe improvement, with typical width of 8 feet and depth of 3 feet. Detailed drainage analysis should be done before the construction of sheet flow paths and land acquisition is started.

4.3 Identified Types of Remedies for Future Conditions

Future conditions are characterized by more or less maximum development of land; details for evaluating runoff from such lands are described in Section 3. The present discussion focuses upon the rationale for selection of potential remedies for drainage and flooding when future development increases the runoff from various areas draining to either FEMA-modeled channels or non-FEMA-modeled channels.

4.3.1 Assumed Detention Strategies for Development

Future development in a watershed will, generally, increase imperviousness and consequent runoff beyond that which currently exists. The remedies for existing conditions (discussed above) are intended to resolve current drainage problems under the broad-based assumption that significant increases in runoff due to development do not occur. Increases in runoff due to development, on the other hand, can be dealt with in two ways: on-site mitigation or regional mitigation.

On-site mitigation is control of runoff from a development site in such a way that the peak discharge does not increase above the level that existed before the development of the site. City drainage criteria require that such control is achieved as part of future development. The on-site mitigation is typically accomplished using on-site surface detention, but other methods such as subsurface detention and low-impact development techniques can be used. The key factors in use of on-site mitigation are 1) that the mitigation is accomplished before runoff leaves the site so that peak discharges in channels not on the developed tract are not increased, and 2) the cost of implementing the mitigation is borne by the developer (in some manner) of the site.

Regional mitigation provides for a facility, almost invariably an off-line surface detention pond, to be constructed in the watershed where runoff control is needed, with the design of the detention pond being such that mitigation is achieved for a number of sites simultaneously. This mitigation is accomplished by two effects: 1) reduction of flows downstream of the detention site because during a storm event some flow is diverted from a channel into the pond, and 2) reduction of downstream flows lowers the tailwater effects on upstream water levels, resulting in lower maximum water levels at upstream points for similar discharges, which in net effect is as if runoff is reduced from upstream sources. Because of this latter reduction, the runoff from an upstream site does not, at least conceptually, have to be mitigated; the mitigation is provided by the regional detention pond.

In estimating needed detention, currently undeveloped land areas were assumed to become fully developed with dense residential lots of a typical size of 0.25 acre. The increased flows and runoff volume caused by the increase in development for the future conditions would be mitigated with the construction of regional detention ponds. Also, the construction of regional detention ponds assumes that the receiving streams have the needed improvements to efficiently convey the flows out of and into the receiving streams.

Several factors affect the operation of a regional detention facility and its effectiveness: 1) the runoff from an upstream development site must get to the regional detention site; if the runoff is to reach the detention site, then the channel must be sufficiently large that the increased runoff from the site does not exceed channel capacity (or, from an alternative perspective, the channel must be modified to allow extra flow because there will be more flow than would occur for existing conditions); and 2) off-line detention has hydraulic inefficiencies which could cause the required detention for the regional pond to be larger than the sum of the on-site detention. Advantages of regional detention include 1) the ability to mitigate for areas where on-site mitigation is not feasible; 2) the increase in developable land on a site; and 3) utilization of economy of scale so that the cost to developer for accessing a pro-rated portion of the regional detention is less costly than development of on-site detention by the development.

Procedures for determining necessary storage volumes for regional detention are discussed in Section 3. When applying these procedures, it is assumed that the mitigation necessary for the entire drainage basin is served by the regional detention pond. (Detailed design for the various developments in a regional drainage area might, and likely would, have a mixture of on-site and regional detention.) Exhibits 4-1, 4-2, and 4-3 shows potential detention sites. The required regional detention can be divided among various sites in view actual detailed sources of runoff and site availability.

4.3.2 Channel Improvements

For future conditions, channel improvements are not proposed as an alternative to on-site or regional detention. Development is presumed to be regulated such that increased runoff does not require additional capacity in channels, unless such capacity increase arises because of conveyance of site runoff to a regional detention pond. Channel improvements for the sole purpose of allowing increased development site runoff without use of detention is an inappropriate allocation of City resources to a single entity. Thus, channel improvement is not considered as alternative (by itself) to address future development for planning purposes.

In addition, to avoid flooding of new structures, the finished floor slab elevation of structures will have to be set at levels which will place the structures above anticipated flood levels; channel improvements should not be relied upon to allow low floor slab elevations which can only avoid inundation by channel improvements.

4.3.3 Storm Sewerage System Improvements

Future development will be required, by City criteria, to provide adequate drainage for subdivision and similar developments via surface or underground sewer systems. Storm sewer system improvements are consequently not addressed as part of the CWDS for future conditions (other than to say the sewer systems will have to be designed according to City criteria).

4.3.4 Local Ponding Relief Using Sheet Flow Paths

Future development should proceed under the condition, as reinforced by City drainage criteria, that appropriate ponding relief using sheet flow paths be present in the design of new development. Consequently, sheet flow path relief is not addressed as part of the CWDS for future conditions (other than to say that such relief should be incorporated into development design).

4.4 Identified Improvements

Proposed improvements for both existing and future conditions are summarized in Table 4-1 for each FEMA primary channel and major tributary channel, while Table 4-2 shows recommended improvements for the non-FEMA primary channel and major tributary channels. The channels for which improvements are proposed are the following:

- A104-00-00 (Existing and Future Conditions)
- A104-07-00 (Existing and Future Conditions)
- A104-12-01 (Existing and Future Conditions)

- B106-00-00 (Existing and Future Conditions)
- B106-02-00 (Existing and Future Conditions)
- B106-05-00 (Existing and Future Conditions)
- B109-00-00 (Future Conditions)
- B112-00-00 (Existing and Future Conditions)
- B112-02-00 (Future Conditions)
- F101-00-00 (Existing and Future Conditions)
- F101-03-00 (Existing and Future Conditions)
- F101-05-00 (Existing and Future Conditions)
- F101-06-00 (Future Conditions)
- F212-00-00 (Existing and Future Conditions)
- F216-00-00 (Future Conditions)
- F216-01-00 (Existing and Future Conditions)

Improvements for existing condition channels are predominately channel widening. Exhibit 4-4, 4-5, and 4-6 shows where widening or channel lining is proposed. Widened channels are presumed to be trapezoidal in section; basic dimension are given in the Tables 4-1 and 4-2. Estimated excavation for the proposed channel widening has been determined from the difference in cross sectional area of the existing channel and the proposed channel. Land acquisition acreage for channel widening assumes that only right-of-way for maintenance berms along an existing channel must be acquired. Representative land acquisition costs for undeveloped and developed land are described in Section 5. It should be noted that no channel improvements are proposed for Little Cedar Bayou (F216-00-00) for existing conditions. After reviewing the report titled "Hydraulic Analysis for Little Cedar Bayou Watershed: HCFCD Unit F216-00-00" submitted by Binkley & Barfield on January 2000, the improvements detailed in that report were determined to be adequate for planning purposes. It is recommended that the City pursue the improvements as specified in the aforementioned report to reduce the current flooding due to lack of channel capacity.

Note that regional detention for existing conditions is not proposed to remedy current conditions because of the high cost (cost estimates are discussed in greater detail in Section 5). This relative cost comparison can be readily seen if it is realized that regional detention for a channel would have to be much larger than the channel widening excavation volume. Thus, for example, for Taylor Bayou (A104-00-00), the regional detention requirement would be about 124 acre-feet (i.e., about 20 times larger than the mitigation volume). The mitigation pond has an estimate cost of about $250,000, which is approximately ten times the widening cost.

Regional detention requirements, assuming full development, with all runoff mitigation to be provided by regional detention, is provided for future development conditions. Exhibit 4-1, 4-2, and 4-3 shows undeveloped land where ponds might be located. Note that Exhibits 4-1, 4-2, and 4-3 show numerous detention sites for the watersheds; however all the identified sites are not needed. Estimated detention volume requirements identified in Tables 4-1 and 4-2 can be met by multiple sites shown on the aforementioned exhibits. A list of these potential detention sites is shown in Appendix C.

SECTION 5
COST AND IMPLEMENTATION

A key factor in implementing potential drainage remedies is the cost for construction of the project envisioned by the proposed remedy; estimated costs are presented below. Other factors, however, are important to the implementation and continued effectiveness of various drainage improvements; these are also discussed below.

5.1 Recommended Drainage Improvements

5.1.1 Costs of Feasible Remedies

Realistically feasible potential drainage improvements for addressing the underlying cause of the identified drainage problems were identified in preceding sections of this CWDS. Approximate construction costs for implementing these problems were estimated using the unit cost data of Table 5-1; these data are revisions to data developed in Letter Report No. 3.

Table 5-2 summarizes for FEMA-modeled channels the estimated costs of potential channel capacity and diversions to address current drainage and flooding problems and regional detention remedies to address future development issues. Table 5-3 provides costs for the non-FEMA channels. Non-channel solutions, i.e. relief sheet flow swales, are presented in Table 5-4 for various subdivisions in the City. It should be noted relief swales were not considered for a number of subdivisions in the City since these subdivisions are located too far away from the receiving stream to be an optimal solution.

It has been noted in prior discussion that channel improvements included in some instances channel lining when widening of a grass lined channel within estimated available right-of-way was not sufficient to provided necessary channel capacity. The drawbacks of channel lining have already been noted. Consequently, as an alternate to channel lining, diversion of flood waters was considered. Diversion alternatives are listed in Table 5-2 and 5-3. To be noted is the relative high cost of the diversion alternatives.

In making all cost estimates, a conservative but realistic approach (i.e., estimated costs were purposely overestimated rather than being underestimated) was taken because of the preliminary nature of the projects for which costs were being estimated and the fact considerable time may likely pass before actual construction of proposed improvements.

Table 5-5 presents project costs with a breakdown according to actual construction of major cost components of channel improvements (which is predominately excavation costs), detention storage, and land acquisition. Table 5-6 shows this same breakdown as a percentage. It is to be noted that detention storage, whether for mitigation or diversions to address current flooding problems, is a significant component of total cost.

Cost for regional detention to address future drainage concerns arising from development are, likewise, quite significant. It is recognized, however, that while detention for mitigation or diversion purposes would typically be a cost to be borne by the City, costs for regional detention to address future drainage concerns arising from development would typically not be borne by the City; such costs would be typically recovered by sale of detention storage to developers seeking detention to mitigation excess site runoff.

5.1.2 Establishing Priorities for Constructing Improvement Projects

Because of the recognized significant magnitude of the estimated costs of the various improvements, particularly the infrastructure improvements to address existing drainage and flooding problems, it is preferable that potential priorities be identified to help decision makers distinguish between CIP projects for near term construction and those projects that should be delayed for consideration to some future time when more funds become available or the need for a project can be more adequately justified.

Cost of a project is one consideration in establishing priorities for projects; if two projects accomplish essentially the same result, then the lesser cost project would normally be the preferred project for implementation. However, it is seldom that two projects have sufficiently similar results that would allow such a clear choice to be made. Alternatives are needed to assist in defining project priorities.

The previous discussions in Section 2 looked at drainage improvement needs for various subdivision areas from two perspectives, as summarized in Table 2-4: 1) the estimated flooding severity (as estimated from flooding reports), re-expressed in terms of flooding problem severity rank (10 being highest level of severity and 1 being the lowest level); and 2) estimated beneficial impact, as estimated by the number of properties judged to be beneficially impacted by proposed drainage improvements.

On the other hand, it is recognized that particular projects which have been proposed are intended to eliminate significant flooding in particular areas; these areas where flooding will be largely eliminated may and generally do cut across portion of different subdivisions. Exhibits 4-4, 4-5, and 4-6 show, for each of the channel improvement or diversion project needed in order to address current drainage and flooding problems, those subdivisions that will, all or in part, be beneficially impacted by a particular project. If prioritization interest were to be focused upon addressing problems in a particular subdivision, these exhibits along with Table 2-4 can be used to identify those projects which should be given a higher level of importance in project prioritization.

A more quantitative basis for establishing a potential prioritization of projects is to count the number of residents (as reflected in the total number of flooding reports) for which flooding would be generally eliminated. These flooding report numbers are listed in

Tables 5-7 and 5-8. Projects which address areas with a large number of flooding reports are projects which would be recommended as having a high priority for implementation; projects affecting areas with small numbers of flood reports should be considered to have low priority and be considered for construction only after other major problems are addressed. Generally, the lower the project cost and the higher the number of flood reports being addressed by a project, the higher the priority for construction. It should be noted that Table 5-7 orders the improvement projects based on cost, while Table 5-8 orders the improvement projects based on number of flood reports.

Depending upon the cost of projects and the number of drainage reports in an area that particular projects would address, a particular level of cost per number of reports might be considered as a basis for defining a cut-off for consideration of a project to be implemented. Such a cut-off criteria might dictate that some projects never be built; such a conclusion should be recognized as an issue in setting priorities and selecting various projects for implementation.

5.1.3 Priorities for Future Regional Detention Projects

In estimating needed detention storage, it should be noted that in order to determine the benefits of existing developable land that might become developed in the future, currently undeveloped land areas were assumed to become fully developed with dense residential lots of a typical size of 0.25 acre. The increased flows and runoff volume caused by the increase in development for the future conditions will be mitigated with the construction of regional detention ponds. These regional detention ponds are intended to address future problems. Also, the construction of regional detention ponds assumes that the receiving streams have the needed improvements to efficiently convey the flows out of and into the receiving streams.

If and when construction of regional detention projects occur, the order of their construction will be dictated by several factors which cannot at the current time be determined:

- Where and at what level development is occurring in the City and thus the magnitude of the need for having regional detention
- Whether all needed detention is to be provide by regional detention or only a portion of the needed detention would be provided by regional detention; this factor may be significant if deciding the number of actual detention projects to be developed to meet an overall detention need (because as has been previously noted, all the projected regional detention for a particular channel system does not have to constructed at one location).
- What type of funding arrangements are to be used to pay for cost for construction of a regional detention pond
- To what extent joint regional detention projects developed in conjunction with HCFCD or other cities can be relied upon to meet regional detention goals
- Whether regional detention or on-site mitigation is to be used by developers in the area potentially serviced by a regional detention facility.

In regard to use of regional detention versus on-site detention (the last issue in the above list), decisions about use of regional or on-site detention will likely in large measure be determined on a cost basis: Is it more cost efficient for a developer to pay for participation in regional detention or to develop on-site mitigation but lose developable land because of on-site pond construction? To gauge the potential choice to be made, there is included in Tables 5-2 (for FEMA modeled channels) and 5-3 (for non-FEMA modeled channels) data which presents the cost of regional detention per acre of developable land (i.e., currently open land presumed to be fully developed in the future) tributary to the regional detention site. The smaller the value of this dollars per acre of developable land, the more likely would it be that regional detention would preferred over on-site detention by a developer.

5.2 Implementation Issues

In addition to construction costs and prioritization of construction projects, other factors which are important to constructing or implementing various projects are the following.

5.2.1 Change of Information or Details of Projects

The descriptions of projects identified in this CWDS for possible implementation are based upon available information at the time the CWDS was prepared. The level of detail used in the project descriptions is appropriate to the planning level focus of this study. More detailed analysis will be required for the design of particular drainage remedies prior to actual construction. Some features of the proposed remedies may change as more information is developed as part of detailed design. In addition, changes in development patterns, land use, effects on drainage from out-of-city sources, or other similar factors affecting drainage behavior may also occur. Because of such possible changes, priorities for order of construction project may well change over time.

Consequently, drainage conditions in the City should be periodically reviewed to assess whether conditions have changed sufficiently to significantly affect the character or priority of construction of recommended drainage improvements as given in this CWDS.

5.2.2 Pre-Construction Requirements

Prior to development of a final design and construction of a particular project, various specialized studies in addition to detailed hydraulic study will be required, including detailed survey, geotechnical investigation, right-of-way investigation and delineation.

Since only preliminary estimates of available right-of-way were used in development of channel improvement alternatives, detailed right-of-way investigation will be required as part of detailed project design for some projects. Some modifications to proposed improvements may be required as a consequence of such detailed investigation.

Environmental evaluation should also be anticipated to demonstrate the absence of adverse environmental impacts for a particular project. Environmental review for potential impacts on existent wetlands will be required if wetlands are identified within the proposed project area. Furthermore, since channels may be modified by cut and fill activities, US Army Corps of Engineers (USACE) Section 404 permit is required for channel-affecting projects. In addition, for modification of channels (or portions of a channel) which are tidally affected, USACE review and approval will be required because tidal-affected waters are, by definition, waters of the United States and under the jurisdiction of the USACE. The need for significant coordination and review by the USACE to address potential environmental impacts should be expected.

Proposed modifications to HCFCD channels or modification of discharges to HCFCD channels will require review by HCFCD; of particular interest to HCFCD will be possible increases in discharges and potential resulting downstream impacts. Mitigation of discharges increases should be expected to be an approval requirement.

5.2.3 Tidal and Tropical Storm Influences

This CWDS does not specifically address surge impacts in Galveston Bay arising from tropical storms or hurricanes. Unusually high tides induced by bay storms can induce nearby shore flooding which drainage infrastructure cannot mitigate. High bay water levels will propagate up primary and major tributary channels and, depending upon their magnitude, may induce flooding. To limit adverse impacts from such effects, six primary options are available: 1) early warning to citizens; 2) construction of finished floor slabs (for new development or redevelopment) above anticipated surge levels; 3) raising of existing building; 4) construction of tide gates at the mouths of channels draining to the bay; 5) requiring new development to have appropriate flood proofing; and 6) property buy-outs of affected homes. However, it is to be recognized that even when tropical storms are the initial cause of flooding, accompanying rainstorms can often induce more flooding than the surge from a tropical storm. The proposed infrastructure in this CWDS is intended to address such severe rainstorm events.

5.2.4 Design Frequencies

Pursuant to City drainage criteria, proposed improvements to primary and major tributaries have been designed for 100-year storm events, depending upon the type of improvement and the drainage area of the proposed improvement. However, storm sewer systems, which are not specifically. except for identifying them as problematic in some areas as addressed in this CWDS, are designed, if City drainage criteria are followed, for the 3-year storm frequency event. Consequently, limited flooding of streets is to be expected for some storm events. In responding to citizen complaints about localized flooding, which can sometimes be relieved by development of sheet flow paths (as is recommended in this CWDS for some areas), it should be borne in mind that City drainage system design are intended to use the City streets for drainage for storm events more severe than a 3-year frequency.

5.2.5 Non-City Funding

Potential funding sources for drainage and flood prevention projects have been previously discussed (see Section 6 in Letter Report No. 3). In addition to alternative fee or tax-based methods for generation of additional revenue, the City should consider seeking grants or loans interest lows from either Federal or State sources. Appendix B provides a listing of websites where information on various funding source for drainage and flood protection projects can be found.

Of particular interest to the City for funding of drainage or flood protection projects would be both 1) loan programs and 2) grant programs administered by the Texas Water Development Board. Of particular interest in the loan program category is the State Loan Program (Development Fund II), which can provide low interest funds for construction of storage facilities and enlargement of channels, both of which are some of the options that have been identified for addressing some of the City's drainage problems. In the latter category are grants administered by TWDB for drainage facilities and related activities such as focused drainage studies. While the competition for such grant funds is significant, demonstration of a clear need for the funds and a sound technical approach for use of the funds can go a long way toward being selected for distribution of such funds.

Also of significant interest are grant funds from the Governor's Division of Emergency Management which administers grants for hazard (e.g., flooding) mitigation and pre-disaster mitigation. Grants under these programs can be used for acquisition of flood-prone structures, retrofit of facilities to increase the flood protection, small scale structural hazard control projects, and preparation of mitigation action plans.

Another important source of funding for drainage projects could be joint development of a project between the City and other parties, such as the Harris County Flood Control District. Such joint funding would typically be contingent upon demonstration of the mutual benefit of the propose project to both parties.

One such potential joint project is the detention pond option identified for Big Island Slough (B106-00-00) and Willow Spring Bayou (B112-00-00) (see Table 4-1). Due to the highly developed nature of the areas in the vicinity of the proposed channel improvements, the City might be hard pressed to acquire the needed acreage for building the detention ponds. However, there are available undeveloped tracts south of the City along these channels that could be used as detention sites.

5.2.6 Drainage Interaction with Other Cities

The recommended drainage improvement projects are within the boundaries of the City. This constraint on selection of projects was purposely made in order that implementation of projects could be pursued at the City's own discretion and without potentially delaying or undesirable encumberment. However, two factors should be borne in mind in dealing with drainage issues extending across city boundaries.

Mitigation of increased runoff due to drainage improvements within the City may often be required to prevent adverse impacts upon downstream locations beyond the City's boundaries. Increasing the capacity of a channel will typically result in increased discharges to downstream reaches. To determine whether such increases will be significant will require detailed engineering analysis done as part of detailed design for a particular project. If such increases are found to be significant, detention or flow impediment will typically be required to prevent such downstream increases. If such increases are significant at points beyond the City's boundaries, special caution and application of appropriate mitigation will need to be exercised to avoid adverse impacts on downstream areas beyond the City boundaries.

On the other hand, the drainage improvements identified in this CWDS assume that drainage from sources outside of and upstream of the City will not be increased by actions of others. If the City were to become aware of anticipate changes of conditions in upstream areas which might adversely impact drainage or flooding conditions, the City should coordinate with the upstream cities to address such anticipated impacts. This coordination should provide a clear and descriptive enunciation of why adverse impacts are expected and identify potential means to mitigate the adverse impacts, either by remedy within the boundary of the upstream City or by remedy within La Porte with appropriate contribution to implementation of the remedy by the upstream City. Such coordination should be pursued where necessary.

If the City suspects that a current flooding problem within the City is the result of past unmitigated changes in an upstream, non City area, the City could undertake discussions with the upstream entity believed to be contributing to the current flooding problems. These discussions and the actions taken in support of the discussions should 1) delineate the character, location, and extent of the flooding problem believed to be the result of the upstream conditions; 2) identify, describe and demonstrate the change or set of upstream conditions which are believed to be the source of the flooding problem in question; 3) suggest potential remedies for the problem, and 4) propose a recommended plan to implement actions to institute the remedy.

5.2.7 Implementation of Drainage Criteria

Recommendations for upgrades in drainage criteria and standards currently used by the City were made in Section 2 of Letter Report No. 3. Particularly important among those recommendations in regard to recommended drainage projects are the following:

5.2.7.1 Provision of Sheet Flow Paths

Sheet flow path identification and inclusion should be a required consideration in all new or redevelopment as a typically efficient means to control excess street ponding. Proposed future development should be critically reviewed in regard to provision of ponding relief using sheet flow pathways.

5.2.7.2 Construction in Special Flood Hazard Areas

While the City does allow under certain conditions construction in known floodplain areas (i.e., special flood hazard areas), the City should allow such construction only under very special circumstances. Experience has shown construction in special flood hazard areas is an invitation to flooding if such construction is not carefully designed with flooding issues fully recognized. Critical to allowing such construction, if the City feels it essential to proceed with such construction, is 1) requiring finished floor slabs to be above the 100-year flood level; 2) requiring flood proofing of the ground floor structures; and 3) allowing such construction only in storage areas well beyond the floodway so that flood flow velocities are quiet small; 4) mitigation of fill in the floodplain along with any needed detention.

Also to be recognized is that detailed flood flow analysis and floodplain delineation has not been accomplished for many of the smaller creeks, streams, and channels in the City. Thus locations of anticipated flooding when severe storm events occur are not accurately known at the current time. It would be to the City's benefit to conduct flood analyses that would delineate floodplain areas not currently known.

5.2.7.3 Minimum Low Chord Clearances

New bridge or bridge modifications in the future should be sure to have low chord clearances in accord with City criteria.

5.2.7.4 Capacity Improvements in Storm Sewer Systems

Review of storm sewer capacity should be considered in areas where this CWDS report has identified inadequate capacity as the likely key source of reported flooding in a particular area. In making such review, several factors should be considered: 1) what is the appropriate design frequency for the sewer system; 2) the inclusion of sheet flow relief paths to address storm events in excess of the design capacity, and 3) the capacity, spacing, and size of inlets. Temporary reduction in street inlet capacity due to inlet clogging by debris is often a root cause of localized flooding. Frequent removal of trash and debris from streets can be a key element in maintaining the capacity of storm sewer systems.

5.2.7.5 Minimal Detention Levels and Numbers of Detention Sites

The detention requirements identified for mitigation of proposed improvements, diversion of flood waters, and storage for regional detention are estimated minimal detention amounts to accomplish the intended purpose of the detention. Actual detention volumes will be somewhat in excess of these amounts in order to provide potential freeboard; estimated land acquisition for the pond will require inclusion of land for surrounding maintenance berms and inlet and outlet structures. Detailed engineering of the detention system in question will be necessary to refine these features.

One of the key issues in providing the required detention will be determination of whether one site or more than one site will be used to meet detention requirements. Detention does not necessarily have to always be provided by a pond at one site only. The present CWDS report identifies, based upon apparent availability of open land, potential detention sites. Detailed engineering can evaluate the feasibility of using one or multiple sites for meeting detention requirements.

5.2.7.6 Enforcement of Drainage Criteria

Drainage criteria as defined by City policy should be rigorously enforced. Letter Report No. 2 recommended certain modifications to the City's drainage criteria manual. Irrespective of whether these recommendations are adopted, the criteria in the drainage manual should be, for the purpose of preventing the development of future drainage problems, rigorously and consistently enforced by the City.

5.2.8 Issues in Regional Pond Development for Future Development

Regional detention pond development has been proposed as a primary strategy for addressing impacts of future development. Regional detention is one component of a two prong strategy: On-site detention versus regional detention. If carefully designed and implemented, either method, or a combination of both, can effectively address potential future drainage impacts arising from development or redevelopment.

Several factors affect, however, which may make regional detention less attractive than on-site mitigation: 1) The runoff from an upstream development site must get to the regional detention site; if the runoff is to reach the detention site, then the channel conveying the site runoff must be sufficiently large that the increased runoff from the site does not exceed channel capacity; and 2) off-site detention has hydraulic inefficiencies which would typically cause the required detention for the regional pond to be larger than the sum of the on-site detention.

On the other hand, the advantages of regional detention include 1) the ability to mitigate for areas where on-site mitigation is not feasible; 2) increase in the developable land on a site; and 3) utilization of economy of scale to lower overall construction costs for detention.

Other benefits to regional detention, less apparent, are the following:

- Regional detention can be constructed to address some current drainage problems. Early construction of regional detention to address future drainage could be combined with detention to remedy current drainage.

- Regional detention can be constructed in stages (with staged construction at a single site or by use of multiple sites), thus lessening initial construction costs.
- Regional detention provides a mechanism for cost recovery; sale of detention can be established to either recover incurred costs or incurred costs with additional surcharge to recovery other drainage improvement costs.
- The availability of regional detention can be an attractor for new development.

If regional detention were to be employed, a cost recovery strategy could be based upon 1) initial funding being provided by the City to provide some detention to address certain existing drainage problems; 2) allowing early purchase of surplus detention by developers to reserve detention space in the detention system so that it is present when it is needed for the development; 3) establishing a fee for purchase which is sufficient to ultimately recovery both upfront costs and expansion costs; and 4) encouraging use of regional detention by establishing a development fee on development which uses on-site detention rather than purchasing storage in a regional facility.

5.2.9. Existing Detention Issues

Detention for remedy of existing flooding problems will generally be required as part of the mitigation of increased channel conveyance when channel improvements are made to address current flooding problems if downstream impacts are to be avoided. Potential detention pond sites have been identified for such mitigation (see Exhibit 4-1, 4-2, and 4-3).

Detention can be used to address anticipated future increases in runoff due to development, as discussed in the preceding section. Some of this regional detention could be also be constructed to alleviate some current drainage problems, but at costs which are anticipated to be more than other options selected (i.e., channel improvements). One large site currently available but undeveloped is a site located on property south of the City along B109-00-00 on land owned by HCFCD and the city of Pasadena (see Pond Site 43 in Exhibit 4-1). Joint funding arrangements could be possibly made with HCFCD which could speed the development of this site under financial conditions favorable to the City.

There is, in addition, currently a HCFCD regional detention facility (see April 1997, Wilbur Smith Associates, Consulting Engineers and Planners reference in Appendix A) along B112-02-00 in Deer Park about 2,000 feet north of Spencer Highway and north of the La Porte city boundary (see Exhibit 5-2). This pond provides mitigation of channel improvements in Deer Park north of the pond site as well as possible mitigation of runoff from future development north of the pond in Deer Park. There is a potential, albeit limited, that some surplus detention is available in this existing pond which could be allocated for regional detention needs in La Porte; discussions with HCFCD and Deer Park could be undertaken to assess this potential.

There are also four potential regional detention sites (Harris County Flood Control District, Armand Bayou, HCFCD webpage) located south of La Porte (see Exhibit 5-2) being considered for development by HCFCD. The most northern of these has a potential to provide regional detention (to address current conditions or future development impacts) that may be beneficial to La Porte. Discussions with HCFCD need to be undertaken to assess the possibility of storage allocation in these reservoirs for the benefit of La Porte drainage and flooding mitigation.

5.2.10 Easements, Right-of-Way, and Land Acquisitions

The CWDS anticipates that some easements and right-of-ways will have to be acquired. Because the CWDS is a planning level study, specific acquisition requirements were not identified. Channel widening, however, was keyed to stay within the existing bank line, thus possibly requiring only land for maintenance berms, if such easement does not already exist. Proposals for sheet flow pathways, likewise, did not address whether the City had the easement necessary to utilize the proposed sheet flow path; the sheet flow path identification was based only upon apparent need and availability of open land for the pathway. Detention ponds, likewise, assumed that acquisition of land could be accomplished at locations where ponds might be located.

However, when making cost estimates for proposed improvements, account was taken of reasonably likely cost for land acquisition. For channel widening, land acquisition for maintenance berms (20-feet on each side of the channel) was assumed. Sheet flow pathways assumed land acquisition would be required for a path 20 feet wide the full length of the proposed pathway. For ponds, estimates of pond area were provided based upon detention requirement and representative pond depth with 30-foot maintenance berms; these areas defined minimum land acquisition requirements for the ponds.

Buy-out of lands with homes was not specifically identified as alternative for addressing flooding problems. Channel widening was limited to estimated existing channel widths, sheet flow paths were selected to avoid existing residents, and detention sites were limited to currently undeveloped lands. Thus buy-out of homes is not being proposed as part of this CWDS though some solutions will require that some portion of selected nearby properties be acquired.

It is recognized that home buy-out is sometimes proposed as a flood control remedy; such buy-out may become necessary in the future, but the current plan is intended not to rely upon this strategy.

5.2.11 Ownership and Maintenance of Drainage Facilities

Within the three watersheds (Clear Creek, Armand, and San Jacinto/Galveston) which compose the City, there are numerous named bayous and ditches. Seven are in the Clear

Creek Watershed, eight are in the Armand Watershed, and fourteen in the San Jacinto/Galveston Watershed; these are listed in Table 5-8. Critical to effective function of these as well as small ditches and channels is proper maintenance. Ditches, channels and bayous need to be kept reasonably free from obstructions, debris and excessive vegetation (e.g., trees, brush, high grass) for the watercourses to function as planned.

Maintenance responsibilities, in absence of agreements stating otherwise, are normally considered the responsibility of the owner of the watercourse. Of the 29 named watercourses in the City, only nine are believed to be owned by the City. Four others have unclear ownership or joint ownership with HCFCD. The remaining are owned by HCFCD (see Table 5-9 and Exhibit 5-1). The City should be aggressive in proper maintenance of watercourses under their control.

On the other hand, if a watercourse is not owned or under the control of the City but maintenance is inadequate, the City faces a dilemma. Inadequate maintenance in such non-City watercourses adversely impacts the function of the watercourse (thus adversely affecting City drainage and flooding), but the City does not legally have the responsibilities or liabilities associated with ownership.

It is recommended that the City pursue written inter-local agreements with HCFCD (for watercourses for which such agreements may not already be in place) regarding maintenance of watercourses owned by HCFCD lying within the City. For watercourses of critical importance to adverse effects on flooding in the City, an interlocal agreement should be developed between the City and HCFCD to assure that if HCFCD does not or seeks not to maintain the watercourses in question at levels the City thinks appropriate, the City has permission under appropriate limitations and constraints to perform such maintenance for an agreed upon compensation or other considerations.

TABLE 2-1
LIST OF STREAMS

Stream	Type	Total Drianage Area	Drainage Area with in the City	Modeled
Clear Creek Watershed				
A104-00-00 (Taylor Bayou)	Primary	1999	13888	Yes, TSARP
A104-07-00 (Tributary 3.93 to Taylor Bayou)	Tributary	1445.1	370	Yes
A104-07-01	Tributary	495	495	No, Not enough data
A104-10-00 (Boggy Gully/Bayou)	Tributary	128	59	No, Not enough data
A104-10-02	Tributary	22	18	No, Not enough data
A104-12-00	Tributary	626	626	No, Not enough data
A104-12-01	Tributary	48	48	Yes
Armand Bayou Watershed				
B106-00-00 (Big Island Slough)	Primary	2812	2812	Yes
B106-02-00	Tributary	598	598	Yes
B106-05-00	Tributary	155	155	Yes
B106-06-00	Tributary	268	268	No, Not enough data
B109-00-00 (Spring Gully)	Primary	3452	646	Yes
B109-03-00 (B112-02-00 Interconnect)	Primary	203	203	Yes
B112-00-00 (Willow Springs Bayou)	Primary	3259	348	Yes
B112-02-00 (Tributary 1.78 to Willow Spring Bayou)	Tributary	143	128	Yes
San Jancinto/Galveston Bay Watershed				
F101-00-00	Primary	871	871	Yes
F101-01-00	Tributary	641	290	No, Not enough data
F101-03-00	Tributary	451	451	Yes
F101-06-00	Tributary	245	245	Yes
F101-06-02	Tributary	19.5	19.5	No, Not enough data
F101-06-03	Tributary	16.4	16.4	No, Not enough data
F101-07-00	Tributary	53	53	No, Not enough data
F101-08-00	Tributary	78	78	No, Not enough data
F210-00-00	Primary	539	241	No, Not enough data
F212-00-00 (Deer Creek)	Primary	430	430	Yes
F216-00-00 (Little Cedar Bayou)	Primary	1868	1868	Yes
F216-01-00	Tributary	364	364	Yes
F216-02-00	Tributary	5	5	No, Not enough data
F216-04-00	Tributary	73	73	No, Not enough data

TABLE 2-2
SIGNIFICANT DRAINAGE OR FLOODING PROBLEMS

Name of Flood-Affected Area (See Exhibit 7, 8, & 9 for location)	Rank (10 is Highest) Assuming Flooding Reports have Fifferent Weight	Number of Lots Likely to Directly Benefit from Drainage Improvement	Likely Significant Source/Cause of Flooding
Brookglen	10	600	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (B112-00-00)
Creekmont Section 1	10	110	Inadequate Sewerage
La Porte	9	375	Insufficient Channel Capacity (F216-00-00)
Glen Meadows	9	160	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (B106-00-00)
Fairmont Park East	8	500	Inadequate Sewerage
Pinegrove Valley	8	220	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (F101-00-00)
Spencer Highway Estates	8	100	Inadequate Sewerage
Fairmont Park West	7	390	Inadequate Sewerage
Shady River	7	154	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (A104-12-00)
Bay Colony	7	128	Inadequate Sewerage
Fairmont Park	6	330	Inadequate Sewerage
Creekmont Section 2	6	30	Inadequate Sewerage
Bayside Terrace	5	252	Inadequate Sewerage
Lomax Garden	5	160	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (F101-03-00)
Meadow Park	5	91	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (B106-05-00)
Old La Porte	4	150	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (F216-00-00)
Battle Grounds Vista	4	10	Inadequate Sewerage
Pine Bluff	3	189	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (A104-12-00)
Bay Shore Park	3	50	Data Insufficient
Beach Park	3	50	Inadequate Sewerage
Woods On The Bay	2	76	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (A104-12-00)
Villa Del Rancho	2	21	Mixture of Inadequate Sewerage and Insufficient Channel Capacity (B106-05-00)
Spencer Landings	2	10	Inadequate Sewerage
Meadowcrest	1	50	Inadequate Sewerage
Battleground Estate	1	20	Inadequate Sewerage
Bay Front To La Porte	0	40	Data Insufficient
San Jacinto Homes	0	10	Data Insufficient

TABLE 2-3
POLICY WEIGHT FACTORS FOR FLOOD PROBLEM INTENSITY

Type of Flooding Report	Policy-based Weighting Factor
Report Type 1: Reports on severely damage residences	5
Report Type 2: Repetitive loss reports on structural (residential) flooding	4
Report Type 3: Tropical Storm Allison flooding in 2001	1
Report Type 4: Tropical Storm Erin flooding in 2006	1
Report Type 5: Miscellaneous but reliable data	1

TABLE 2-4
PRIORITIZING DRAINAGE PROBLEMS

Name of Flood-Affected Area (Also Show Name on Map)	Maximum of Intensity in Affected Area Assuming All Flooding Reports of Same Weight	Maximum of Intensity in Affected Area Assuming Flooding Reports have Different Weight	Rank (10 is Highest) Assuming All Flooding Reports of Same Weight	Rank (10 is Highest) Assuming Flooding Reports have Different Weight	Number of Lots in Subdivision Area	Number of Lots Likely to Directly Benefit from Drainage Improvement
Brookglen	11.84	35.37	10	10	835	600
Creekmont Section 1	10.99	15.11	10	10	338	110
Glen Meadows	10.17	13.43	9	9	744	160
La Porte	3.31	8.68	6	9	435	375
Spencer Highway Estates	2.76	8.61	6	8	381	100
Fairmont Park East	4.04	8.15	7	8	1318	500
Pinegrove Valley	4.92	7.64	8	8	275	220
Fairmont Park West	5.44	6.79	8	7	1232	390
Bay Colony	2.40	6.69	5	7	128	128
Shady River	2.41	6.65	5	7	154	154
Creekmont Section 2	3.60	6.32	7	6	138	30
Fairmont Park	4.00	5.86	7	6	705	330
Lomax Garden	5.47	5.47	9	5	160	160
Meadow Park	4.18	5.32	8	5	91	91
Bayside Terrace	1.30	3.77	3	5	252	252
Old La Porte	1.62	3.36	4	4	1305	150
Battle Grounds Vista	1.10	2.75	3	4	55	10
Bay Shore Park	1.10	2.74	3	3	217	50
Beach Park	1.06	2.67	2	3	73	50
Pine Bluff	0.64	2.20	1	3	189	189
Villa Del Rancho	2.13	2.13	5	2	21	21
Woods On The Bay	0.73	1.84	2	2	76	76
Spencer Landings	0.71	1.78	2	2	216	10
Meadowcrest	1.52	1.52	4	3	351	50
Battleground Estate	0.55	0.55	1	1	197	20
Bay Front To La Porte	0.55	0.55	0	0	436	40
San Jacinto Homes	0.55	0.55	0	0	281	10

TABLE 2-5
SHORT-TERM PROJECTS

Project Number	Name	Progress
Short Term Project 1	Catlett lane Pavement Replacement	Completed and Constructed
Short Term Project 2	Creekmont Park Overflow Path	Design Completed
Short Term Project 3	Drainage Improvements Along Driftwood Drive	Proposed Relief Swale Path
Short Term Project 4	Fleetwood Drive Outfall Pipe Upsizing	Proposed Outfall Pipe Upsizing
Short Term Project 5	Glen Meadow Subdivision Interceptor Inlet	Proposed Interceptor Inlet with Additional Outlets

TABLE 2-6
SHEET FLOW PATHS

Channel	Subdivision Name	Possibility of Sheet Flow Path	Modification Type	Description	Number of Proposed Swales	Bottom Width (ft)	Depth (Typical) (ft)	Side Slope (H:V)	Rank (Assuming Flooding Reports have Different Weight) (10 Highest, 0 Lowest)	Land Acquisition (acres)	Excavation Volume (ft³)	Excavation Volume (ac-ft)
Clear Creek Watershed												
A104-00-00, A104-12-01	Shady River	No	-	-	-	-	-	-	7	-	-	-
A104-07-00	Spencer Landings	No	-	-	-	-	-	-	2	-	-	-
A104-10-00	Bay Colony	No	-	-	-	-	-	-	7	-	-	-
A104-10-00	Bayside Terrace	No	-	-	-	-	-	-	5	-	-	-
Armand Bayou Watershed												
B106-00-00	Creekmont Section I	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	10	0.15	9990	0.23
B106-00-00	Glen Meadows	Yes	Relief Swale	Trapezoidal (Concrete)	2	1	3	1	9	0.12	15056	0.35
B106-00-00	Fairmont Park West	Yes	Relief Swale	Trapezoidal (Concrete)	5	1	3	1	7	0.24	15838	0.36
B106-00-00	Fairmont Park	Yes	Relief Swale	Trapezoidal (Concrete)	2	1	3	1	6	0.081	5290.4	0.12
B106-00-00	Creekmont Section 2	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	6	See Creekmont Park Report		
B106-00-00	Meadowcrest	No	-	-	-	-	-	-	1	-	-	-
B106-00-00, B106-02-00	Fairmont Park East	Yes	Relief Swale	Trapezoidal (Concrete)	5	1	3	1	8	0.28	18130	0.42
B106-05-00	Meadow Park	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	5	0.058	3818.3	0.09
B106-05-00	Villa Del Rancho	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	2	0.10	6811	0.16
B109-00-00	Spencer Highway Estates	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	8	0.13	8458	0.19
B112-00-00, B112-02-00	Brookglen	Yes	Relief Swale	Trapezoidal (Concrete)	9	1	3	1	10	0.4	26416	0.61
San Jacinto/Galveston Bayou Watershed												
F101-00-00	Battleground Estate	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	1	0.15	9761	0.22
F101-00-00, F101-03-00	Pinegrove Valley	Yes	Relief Swale	Trapezoidal (Concrete)	1	1	3	1	8	0.03	1699	0.04
F101-05-00, F101-06-00	Lomax Garden	No	-	-	-	-	-	-	5	-	-	-
F212-00-00	Bay Shore Park	No	-	-	-	-	-	-	3	-	-	-
F212-00-00	Bay Front To La Porte	No	-	-	-	-	-	-	0	-	-	-
F212-00-00	San Jacinto Homes	No	-	-	-	-	-	-	0	-	-	-
F216-00-00, F216-01-00	La Porte	No	-	-	-	-	-	-	9	-	-	-
F216-00-00	Old La Porte	Yes	Relief Swale	Trapezoidal (Concrete)	2	1	3	1	4	1.44	93949	2.16
F216-00-00	Battle Grounds Vista	No	-	-	-	-	-	-	4	-	-	-
Galveston Bay	Pine Bluff	No	-	-	-	-	-	-	3	-	-	-
Galveston Bay	Beach Park	No	-	-	-	-	-	-	3	-	-	-
Galveston Bay	Woods On The Bay	No	-	-	-	-	-	-	2	-	-	-

🟨 *No sheet flow paths possible.*

TABLE 3-1
CHANNEL ANALYSIS SUMMARY

Channel Watershed and Name	HEC-RAS Status	Number of Surveyed Sections	Number of Surveyed Bridges/Culverts	Number of Missing Bridges/Culverts	Channel Type	Length of Channel	Chosen Modeling Procedure				Reason for Chosen Modeling Procedure
							Normal Depth Analysis	HEC-RAS Modeling (Non-georeferenced)	HEC-RAS Modeling (Georeferenced)	No Modeling	
Clear Creek Watershed											
A104-00-00 (Taylor Bayou)	Adding new cross section to FEMA model	2	0	1	Primary Channel	6,900 feet			X		Modeling completed
A104-07-00 (Tributary 3.93 to Taylor Bayou)	Adding new cross section to FEMA model	1	2	0	Tributary	11,000 feet				X	No problem complaints recorded along tributary
A104-12-01	Klotz New model	3	1	2	Tributary	6,500 feet	X				Limited and/or missing data, especially bridge data
Armand Bayou Watershed											
B104-00-00 (Big Island Slough)	FEMA Modeled Completed	0	0	0	Primary Channel	N/A			X		Modeling completed
B105-02-00	Klotz New model	2	1	1	Tributary	4,800 feet	X				Limited and/or missing data, especially bridge data, near problem locations
B106-35-00	Klotz New model	2	1	1	Tributary	4,500 feet	X				Shorter model (2,100 feet) can be built for area south of N P St.
B109-00-00 (Spring Gully)[3]	Revising FEMA model to reflect existing conditions	0	0	0	Primary Channel	N/A			X		Modeling completed
B109-03-00 (B112-02-00 Interconnect)[1]	Revising FEMA model to reflect existing conditions	0	0	0	Tributary	N/A			X		Modeling completed
B112-02-00 (Tributary 1.78 to Willow Spring Bayou)[1]	Revising FEMA model to reflect existing conditions	0	0	0	Tributary	N/A			X		Modeling completed
B112-00-00 (Willow Springs Bayou)	FEMA Modeled Completed	0	0	0	Primary Channel	N/A			X		Modeling completed
San Jacinto/Galveston Bay Watershed											
F101-00-00	Klotz New model	3	0	0	Primary Channel	15,000 feet	X				HEC-2 model available
F101-03-00[2]	Klotz New model	2	0	49 (driveways)	Roadside Ditch	10,300 feet	X				Limited and/or missing data, especially bridge data, also a roadside ditch
F101-06-00	Klotz New model	0	0	1	Tributary	7,000 fet				X	Not surveyed or modeled as per City's recommendation
F212-00-00 (Deer Creek)	Klotz New model	2	2	11	Primary Channel	5,200 feet	X				Important channel but with limited and/or missing data, especially bridge data
F216-00-00 (Little Cedar Bayou)	FEMA Modeled Completed	0	0	0	Primary Channel	N/A			X		Modeling completed
F216-01-00	Klotz New model	3	2	5	Roadside Ditch	1,100 feet	X				Limited and/or missing data, especially bridge data, also a roadside ditch

Note 1 Models to be combined into one model
Note 2 Major roadside ditch
Note 3 Does not include review and analysis of results

TABLE 4-1
IDENTIFIED IMPROVEMENTS FOR FEMA CHANNELS

Channel	Subbasin	Modification Type	Description	Upstream Station (ft)	Downstream Station (ft)	Length (ft)	Bottom Width (ft)	Depth (Typical) (ft)	Side Slope (H:V)	N-value	Est. Existing ROW of Channel (ft)	Est. Minimum ROW with 20' Berms (ft)	Land Acquistion Area (ac)	Excavation Volume (ac-ft)
Clear Creek Watershed														
A104-00-00	A104A	Channel	Trapezoidal, earthen channel (Grass)	34404	33196	1208	30	8	3	0.055	78	118	1.1	3.4
A104-00-00	A104A	Channel	Trapezoidal, earthen channel (Grass)	33196	32796	400	40	6	3	0.035	76	116	0.4	0.8
A104-00-00	A104A	Mitigation Pond	Dimensions: 255' x 255' (including 30' berm)	-	-	-	-	5	4	-	-	-	1.5	6.0
A104-00-00	A104A	Regional Pond	Dimensions: 1200' x 1200' (including 30' berm)	-	-	-	-	5	4	-	-	-	33.1	183.0
A104-00-00	A104A	Regional Pond	Dimensions: 540' x 540' (including 30' berm)	-	-	-	-	5	4	-	-	-	6.7	34.0
A104-07-00	A10407A	Regional Pond	Dimensions: 1630' x 1630' (including 30' berm)	-	-	-	-	5	4	-	-	-	61.0	510.0
A104-12-01	A104A	Regional Pond	Dimensions: 870' x 870' (including 30' berm)	-	-	-	-	5	4	-	-	-	17.4	93.0
Armand Bayou Watershed														
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	27400	26762	637	70	17	1	0.015	104	144	0.6	6.9
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	26762	24973	1789	70	18	1	0.015	106	146	1.6	17.3
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	24973	23766	1894	70	20	1	0.015	110	150	1.7	16.2
B106-00-00	B106C	Mitigation Pond	Dimensions: 540' x 540' (including 30' berm)	-	-	-	-	8	4	-	-	-	6.7	48.0
B106-00-00	B106A	Diversion Pond	Dimensions: 1060' x 1060' (including 30' berm)	-	-	-	-	8	4	-	-	-	25.8	207.0
B106-00-00	B106A, B106B	Diversion Pond	Dimensions: 1130' x 1130' (including 30' berm)	-	-	-	-	8	4	-	-	-	29.3	228.5
B106-00-00	B106A	Regional Pond	Dimensions: 1050' x 1050' (including 30' berm)	-	-	-	-	8	4	-	-	-	25.3	203.0
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	10792	10067	725	50	11	1	0.015	72	112	0.6	4.8
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	10067	9638	429	50	12	1	0.015	74	114	0.4	3.9
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	9638	7799	1840	80	15	1	0.015	110	150	1.6	24.8
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	7799	5616	2465	80	17	1	0.015	114	154	2.2	24.8
B112-00-00	B112A, B112B	Mitigation Pond	Dimensions: 575' x 575' (including 30' berm)	-	-	-	-	10	4	-	-	-	7.6	65.0
B112-00-00	B112A	Diversion Pond	Dimensions: 1290' x 1290' (including 30' berm)	-	-	-	-	8	4	-	-	-	38.2	313.5
B109-00-00	B109A	Regional Pond	Dimensions: 580' x 580' (including 30' berm)	-	-	-	-	5	4	-	-	-	7.7	39.0
B112-02-00	B11202A	Regional Pond	Dimensions: 390' x 390' (including 30' berm)	-	-	-	-	5	4	-	-	-	3.5	16.0
B112-00-00	B112A, B112B	Regional Pond	Dimensions: 470' x 470' (including 30' berm)	-	-	-	-	10	4	-	-	-	5.1	41.0
San Jacinto/Galveston Bay Watershed														
F216-00-00	F216A	Regional Pond	Dimensions: 680' x 680' (including 30' berm)	-	-	-	-	5	4	-	-	-	10	52.0
F216-00-00*	F216B	Regional Pond	Dimensions: 770' x 770' (including 30' berm)	-	-	-	-	5	4	-	-	-	13.6	72.0
F216-00-00	F216C	Regional Pond	Dimensions: 300' x 300' (including 30' berm)	-	-	-	-	5	4	-	-	-	2.1	9.0
F216-01-00	F21601A	Regional Pond	Dimensions: 330' x 330' (including 30' berm)	-	-	-	-	5	4	-	-	-	2.5	11.0

* This regional detention pond can be incorporated into the proposed inline detention pond by others. (Hydraulic Analysis for Little Cedar Bayou Watershed: HCFCD Unit F216-00-00)

It is presented here for preliminary sizing for planning and costing purposes

TABLE 4-2
IDENTIFIED IMPROVEMENTS FOR NON-FEMA CHANNELS

Channel	Section	Modification Type	Description	Number of Bridge/ Culvert (#)	Number of Bridge/Culvert to be Replaced (#)	Length (ft)	Bottom Width (ft)	Depth (Typical) (ft)	Side Slope[1,2] (H:V)	N-value	Est. Existing ROW of Channel (ft)	Est. Minimum ROW with 20' Berms (ft)	Land Acquisition Area (ac)	Excavation Volume (ac-ft)	Est. Minimum ROW of Channel 3:1 side slopes[3] (ft)	Est. Minimum ROW with 20' Berms 3:1 side slopes[3] (ft)
Clear Creek Watershed																
A104-12-01	Section 1	Channel	Trapezoidal, earthen channel (Grass)	-	-	2900	6	7	1.2	0.035	23	63	2.6	1.8	48	88
A104-12-01	Section 2	Channel	Trapezoidal, earthen channel (Grass)	-	-	1600	6	8	1.2	0.035	26	66	1.4	1.5	56	96
A104-12-01	Section 3	Channel	Trapezoidal, earthen channel (Grass)	-	-	2000	6	6	1.3	0.035	21	61	1.8	1.4	42	62
A104-12-01	-	Culvert	Culvert Replacement (5'x5' RCP)	4	4	100	-	-	-	0.015	23	63	0.0	0.0	-	-
A104-12-01	-	Mitigation Pond	Dimensions: 255' x 255' (including 30' berm)	-	-	-	-	5	4	-	-	-	1.5	6.0	-	-
A104-12-01	-	Diversion Pond	Dimensions: 790' x 790' (including 30' berm)	-	-	-	-	7	4	-	-	-	14.3	98.0	-	-
A104-12-01	-	Regional Pond	Dimensions: 1040' x 1040' (including 30' berm)	-	-	-	-	5	4	-	-	-	24.8	136.0	-	-
Armand Bayou Watershed																
B106-02-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	-	-	600	6	15	1.2	0.035	41	81	0.5	0.9	95	135
B106-02-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	-	-	1700	6	15	1	0.035	37	77	1.5	2.3	99	139
B106-02-00	-	Culvert	Culvert Replacement (5'x5' RCB)	2	2	50	-	-	-	0.015	39	79	0.0	0.0	-	-
B106-02-00	-	Mitigation Pond	Dimensions: 240' x 240' (including 30' berm)	-	-	-	-	12	4	-	-	-	1.3	8.5	-	-
B106-02-00	-	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	-	-	-	-	7	4	-	-	-	11.2	75.0	-	-
B106-02-00	-	Regional Pond	Dimensions: 310' x 310' (including 30' berm)	-	-	-	-	12	4	-	-	-	2.2	16.8	-	-
B106-05-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	-	-	3500	6	7	2.4	0.035	41	81	3.1	5.4	50	90
B106-05-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	-	-	1000	14	6	2.3	0.035	40	80	0.9	2.6	49	89
B106-05-00	-	Culvert	Culvert Replacement (5'x5' RCB)	4	4	100	-	-	-	0.015	41	81	0.0	0.0	-	-
B106-05-00	-	Mitigation Pond	Dimensions: 300' x 300' (including 30' berm)	-	-	-	-	6	4	-	-	-	2.1	10.0	-	-
B106-05-00	-	Diversion Pond	Dimensions: 590' x 590' (including 30' berm)	-	-	-	-	7	4	-	-	-	8.0	52.0	-	-
B106-05-00	-	Regional Pond	Dimensions: 1050' x 1050' (including 30' berm)	-	-	-	-	6	4	-	-	-	25.3	160.6	-	-
San Jacinto/Galveston Bay Watershed																
F101-00-00	Section 1	Channel	Trapezoidal (Concrete)	-	-	4000	8	5	1	0.015	17	57	3.5	3.7	-	-
F101-00-00	-	Culvert	Culvert Replacement (5'x5' RCB)	8	5	125	-	-	-	0.015	17	57	0.0	0.0	-	-
F101-00-00	-	Mitigation Pond	Dimensions: 250' x 250' (including 30' berm)	-	-	-	-	5	4	-	-	-	1.4	5.7	-	-
F101-00-00	-	Diversion Pond	Dimensions: 1010' x 1010' (including 30' berm)	-	-	-	-	5	4	-	-	-	23.4	126.4	-	-
F101-00-00	-	Regional Pond	Dimensions: 930' x 930' (including 30' berm)	-	-	-	-	5	4	-	-	-	19.9	107.5	-	-
F101-05-00	Section 1	Channel	Trapezoidal (Concrete)	-	-	5500	3	4	1	0.015	11	51	4.9	3.5	-	-
F101-03-00	Section 2	Channel	Trapezoidal (Concrete)	-	-	2500	3	5	1	0.015	13	53	2.2	4.4	-	-
F101-03-00	-	Culvert	Culvert Replacement (5'x5' RCB)	49	49	1225	-	-	-	0.015	12	52	0.0	0.2	-	-
F101-03-00	-	Mitigation Pond	Dimensions: 340' x 340' (including 30' berm)	-	-	-	-	5	4	-	-	-	2.7	11.9	-	-
F101-03-00	-	Diversion Pond	Dimensions: 450' x 450' (including 30' berm)	-	-	-	-	7	4	-	-	-	4.6	29.0	-	-
F101-05-02	-	Diversion Pond	Dimensions: 410' x 410' (including 30' berm)	-	-	-	-	7	4	-	-	-	3.9	23.0	-	-
F101-03-00	-	Regional Pond	Dimensions: 440' x 440' (including 30' berm)	-	-	-	-	5	4	-	-	-	4.4	21.3	-	-
F101-06-00	-	Regional Pond	Dimensions: 500' x 500' (including 30' berm)	-	-	-	-	5	4	-	-	-	5.7	28.3	-	-
F212-00-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	-	-	5000	6	10	3	0.035	66	106	4.4	17.0	-	-
F212-00-00	-	Culvert	Culvert Replacement (5'x5' RCB)	13	11	275	-	-	-	0.015	66	106	0.0	0.0	-	-
F212-00-00	-	Mitigation Pond	Dimensions: 340' x 340' (including 30' berm)	-	-	-	-	10	4	-	-	-	2.7	19.1	-	-
F212-00-00	-	Diversion Pond	Dimensions: 1010' x 1010' (including 30' berm)	-	-	-	-	7	4	-	-	-	25.4	167.0	-	-
F212-00-00	-	Regional Pond	Dimensions: 650' x 650' (including 30' berm)	-	-	-	-	10	4	-	-	-	9.7	83.3	-	-
F216-01-00	Section 1	Channel	Trapezoidal (Concrete)	-	-	2500	3	5	1	0.035	14	54	2.2	2.3	-	-
F216-01-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	-	-	2500	3	7	3	0.015	45	85	2.2	3.5	-	-
F216-01-00	Section 3	Channel	Trapezoidal, earthen channel (Grass)	-	-	1000	13	7	3	0.015	55	95	0.9	3.8	-	-
F216-01-00	Section 2	Pipe	Pipe Replacement (84" RCP)	-	-	2500	-	-	-	0.013	-	-	0.0	0.0	-	-
F216-01-00	Section 3	Pipe	Pipe Replacement (108" RCB)	-	-	1000	-	-	-	0.013	-	-	0.0	0.0	-	-
F216-01-00	-	Culvert	Culvert Replacement (5'x5' RCB)	3	3	75	-	-	-	0.015	38	78	0.0	0.9	-	-
F216-01-00	-	Mitigation Pond	Dimensions: 270' x 270' (including 30' berm)	-	-	-	-	7	4	-	-	-	1.7	11.1	-	-
F216-01-00	-	Diversion Pond	Dimensions: 1170' x 1170' (including 30' berm)	-	-	-	-	7	4	-	-	-	31.4	229	-	-
F216-01-00	-	Regional Pond	Dimensions: 430' x 430' (including 30' berm)	-	-	-	-	7	4	-	-	-	4.2	24.6	-	-

[1] Note: Channel stabilization measures may be required for side slopes that are less than 3 on earthen channels.

[2] Note: Proposed side slopes are set approximately the same as existing side slopes.

[3] Note: ROW required for channel improvements with side slopes 3 to 1 for earthen channels.

TABLE 5-1
PROJECT UNIT COSTS

Item Description	Unit	Total Quantity	Unit Price ($)	Total Cost ($)
Land Costs				
Land Acquisition (Undeveloped Tract)	ACRE	1	40,000	40,000
Land Acquistion (Developed)	ACRE	1	145,000	145,000
Channel Costs				
Clearing and Grubbing	LF	1	2.50	2.50
Excavation of Clay with 2.5 CY Back-Hoe and 4 20 CY Dump Trailers	CY	1	5.70	5.70
Seeding, General, Mechanical Seeding, 215lbs/Acre	ACRE	1	1,000	1,000
Concrete-Lining	SF	1	2.50	2.50
Rip-rap	CY	1	21	21
Detention Costs				
Typical Cost including Excavation, Seeding, and Outfall	AC-FT	1	25,000	25,000
Culvert Costs				
Removal of 24 inch Culvert	LF	1	$ 16	$ 16
Removal of 36 inch Culvert	LF	1	$ 22	$ 22
Removal of 60 inch Culvert	LF	1	$ 30	$ 30
Removal of 10'x8' Box Culvert	LF	1	$ 36	$ 36
Installation of 24 inch Culvert*	LF	1	$ 160	$ 160
Installation of 36 inch Culvert*	LF	1	$ 240	$ 240
Installation of 60 inch Culvert*	LF	1	$ 410	$ 410
Installation of 10'x8' Box Culvert*	LF	1	$ 845	$ 845

* Installation includes Trench Safety, Pavement Demolition, Pavement Restoration, Excavation, Selected Backfill, and the Culvert.

TABLE 5-2
COST SUMMARY OF FEMA CHANNEL IMPROVEMENTS

Channel	Subbasin	Modification Type	Description	Land Acquistion Area (ac)	Excavation Volume (ac-ft)	Construction Costs with 25% Contingencies ($)	Land Costs ($)	Subtotal Costs ($)	Total Losses Removed (#)	Cost per Loss Removed ($)	Future Developable Land (acres)	Cost per Acre of Development ($)
Clear Creek Watershed												
A104-00-00	A104A	Channel	Trapezoidal, earthen channel (Grass)	1.1	3.4	45,000	43,000	88,000	1	-	-	-
A104-00-00	A104A	Channel	Trapezoidal, earthen channel (Grass)	0.4	0.8	11,000	14,000	25,000	5	-	-	-
A104-00-00	A104A	Mitigation Pond	Dimensions: 255' x 255' (including 30' berm)	1.5	6.0	188,000	60,000	248,000	0	-	-	-
							Improvement Total =	361,000	6	60,200	-	
A104-00-00	A104A	Regional Pond	Dimensions: 1200' x 1200' (including 30' berm)	33.1	183.0	5,719,000	1,324,000	7,043,000	-	-	236	-
A104-00-00	A104A	Regional Pond	Dimensions: 540' x 540' (including 30' berm)	6.7	34.0	1,063,000	268,000	1,331,000	-	-	42	-
A104-07-00	A10407A	Regional Pond	Dimensions: 1630' x 1630' (including 30' berm)	61.0	510.0	15,938,000	2,440,000	18,378,000	-	-	612	-
							Improvement Total =	26,752,000	-	-	890	30,058
Armand Bayou Watershed												
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	0.6	6.9	289,000	82,000	371,000	53	-	-	-
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	1.6	17.3	798,000	229,000	1,027,000	39	-	-	-
B106-00-00	B106B, B106C	Channel	Trapezoidal (Concrete)	1.7	16.2	843,000	242,000	1,085,000	3	-	-	-
B106-00-00	B106C	Mitigation Pond	Dimensions: 540' x 540' (including 30' berm)	6.7	48.0	1,500,000	268,000	1,768,000	0	-	-	-
B106-00-00	B106A	Diversion Pond	Dimensions: 1060' x 1060' (including 30' berm)	25.8	207.0	6,469,000	1,032,000	7,501,000	0	-	-	-
							Improvement Total =	11,752,000	95	123,700	-	-
B106-00-00	B106A, B106B	Diversion Pond	Dimensions: 1130' x 1130' (including 30' berm)	29.3	228.5	7,142,000	1,172,000	8,314,000	95	-	-	-
							Improvement Total =	8,314,000	95	87,500	-	-
B106-00-00	B106A	Regional Pond	Dimensions: 1050' x 1050' (including 30' berm)	25.3	203.0	6,344,000	1,012,000	7,356,000	-	-	315	-
							Improvement Total =	7,356,000	-	-	1,260	5,800
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	0.6	4.8	221,000	93,000	314,000	53	-	-	-
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	0.4	3.9	146,000	55,000	201,000	27	-	-	-
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	1.6	24.8	923,000	235,000	1,158,000	107	-	-	-
B112-00-00	B112A, B112B	Channel	Trapezoidal (Concrete)	2.2	24.8	1,171,000	315,000	1,486,000	0	-	-	-
B112-00-00	B112A, B112B	Mitigation Pond	Dimensions: 575' x 575' (including 30' berm)	7.6	65.0	2,031,000	304,000	2,335,000	0	-	-	-
							Improvement Total =	5,494,000	187	29,400	-	-
B112-00-00	B112A	Diversion Pond	Dimensions: 1290' x 1290' (including 30' berm)	38.2	313.5	9,796,000	1,528,000	11,324,000	187	-	-	-
							Improvement Total =	11,324,000	187	60,600	-	-
B109-00-00	B109A	Regional Pond	Dimensions: 580' x 580' (including 30' berm)	7.7	39.0	1,219,000	308,000	1,527,000	-	-	58	-
B112-02-00	B11202A	Regional Pond	Dimensions: 390' x 390' (including 30' berm)	3.5	16.0	500,000	140,000	640,000	-	-	23	-
B112-00-00	B112A, B112B	Regional Pond	Dimensions: 470' x 470' (including 30' berm)	5.1	41.0	1,281,000	204,000	1,485,000	-	-	67	-
							Improvement Total =	3,652,000	-	-	148	24,700
San Jacinto/Galveston Bay Watershed												
F216-00-00	F216A	Regional Pond	Dimensions: 680' x 680' (including 30' berm)	10	52.0	1,625,000	400,000	2,025,000	-	-	384	-
F216-00-00*	F216B	Regional Pond	Dimensions: 770' x 770' (including 30' berm)	13.6	72.0	2,250,000	544,000	2,794,000	-	-	176	-
F216-00-00	F216C	Regional Pond	Dimensions: 300' x 300' (including 30' berm)	2.1	9.0	281,000	84,000	365,000	-	-	16	-
							Improvement Total =	5,184,000	-	-	576	9,000

* This regional detention pond can be incorporated into the proposed inline detention pond by others. (Hydraulic Analysis for Little Cedar Bayou Watershed: HCFCD Unit F216-00-00)
It is provided here for preliminary sizing for planning and costing purposes.

🟨 *Based on undeveloped land costs ($40,000 per acre)*
🟧 *Based on developed land costs ($145,000 per acre)*

TABLE 5-3
COST SUMMARY OF NON-FEMA CHANNEL IMPROVEMENTS

Channel	Section	Modification Type	Description	Land Acquistion Area (ac)	Excavation Volume (ac-ft)	Construction Costs with 25% Contingencies ($)	Land Costs ($)	Subtotal Costs ($)	Total Losses Removed (#)	Cost per Loss Removed ($)	Future Developable Land (acres)	Cost per Acre of Development ($)
Clear Creek Watershed												
A104-12-01	Section 1	Channel	Trapezoidal, earthen channel (Grass)	2.6	1.8	31,000	102,000	133,000	0	-	-	-
A104-12-01	Section 2	Channel	Trapezoidal, earthen channel (Grass)	1.4	1.5	23,000	56,000	79,000	4	-	-	-
A104-12-01	Section 3	Channel	Trapezoidal, earthen channel (Grass)	1.8	1.4	24,000	71,000	95,000	4	-	-	-
A104-12-01	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	45,000	-	45,000	0	-	-	-
A104-12-01	-	Mitigation Pond	Dimensions: 255' x 255' (including 30' berm)	1.5	6.0	188,000	60,000	248,000	0	-	-	-
							Improvement Total =	600,000	8	75,000	-	-
A104-12-01	-	Diversion Pond	Dimensions: 790' x 790' (including 30' berm)	14.3	98.0	3,063,000	573,000	3,636,000	8	-	-	-
							Improvement Total =	4,624,000	8	578,000	-	-
A104-12-01	-	Regional Pond	Dimensions: 1040' x 1040' (including 30' berm)	24.8	136.0	4,250,000	993,000	5,243,000	-	-	100	-
							Improvement Total =	5,243,000	-	-	100	52,000
Armand Bayou Watershed												
B106-02-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	0.5	0.9	90,000	77,000	167,000	32	-	-	-
B106-02-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	1.5	2.3	228,000	217,000	445,000	2	-	-	-
B106-02-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	23,000	-	23,000	0	-	-	-
B106-02-00	-	Mitigation Pond	Dimensions: 150' x 150' (including 30' berm)	0.5	4.0	125,000	21,000	146,000	0	-	-	-
							Improvement Total =	781,000	34	23,000	-	-
B106-02-00	-	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	11.2	75.0	2,344,000	450,000	2,794,000	34	-	-	-
							Improvement Total =	2,794,000	34	82,000	-	-
B106-02-00	-	Regional Pond	Dimensions: 310' x 310' (including 30' berm)	2.2	16.8	525,000	88,000	613,000	-	-	13	-
							Improvement Total =	613,000	-		13	48,000
B106-05-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	3.1	5.4	525,000	448,000	973,000	26	-	-	-
B106-05-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	0.9	2.6	159,000	128,000	287,000	10	-	-	-
B106-05-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	45,000	-	45,000	0	-	-	-
B106-05-00	-	Mitigation Pond	Dimensions: 300' x 300' (including 30' berm)	2.1	10.0	313,000	83,000	396,000	0	-	-	-
							Improvement Total =	1,701,000	36	47,000	-	-
B106-05-00	-	Diversion Pond	Dimensions: 590' x 590' (including 30' berm)	8.0	52.0	1,625,000	320,000	1,945,000	36	-	-	-
							Improvement Total =	1,945,000	36	54,000	-	-
B106-05-00	-	Regional Pond	Dimensions: 1050' x 1050' (including 30' berm)	25.3	160.6	5,019,000	1,012,000	6,031,000	-	-	119	-
							Improvement Total =	6,031,000	-	-	119	51,000
San Jacinto/Galveston Bay Watershed												
F101-00-00	Section 1	Channel	Trapezoidal (Concrete)	3.5	3.7	271,000	511,000	782,000	19	-	-	-
F101-00-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	57,000	-	57,000	0	-	-	-
F101-00-00	-	Mitigation Pond	Dimensions: 200' x 200' (including 30' berm)	0.9	5.0	156,000	37,000	193,000	0	-	-	-
							Improvement Total =	1,032,000	19	54,000	-	-
F101-00-00	-	Diversion Pond	Dimensions: 1010' x 1010' (including 30' berm)	23.4	167.0	5,219,000	937,000	6,156,000	19	-	-	-
							Improvement Total =	6,156,000	19	324,000	-	-
F101-00-00	-	Regional Pond	Dimensions: 930' x 930' (including 30' berm)	19.9	107.5	3,359,000	794,000	4,153,000	-	-	79.5	-
							Improvement Total =	4,153,000	-	-	79.5	52,000

TABLE 5-3
COST SUMMARY OF NON-FEMA CHANNEL IMPROVEMENTS

Channel	Section	Modification Type	Description	Land Acquistion Area (ac)	Excavation Volume (ac-ft)	Construction Costs with 25% Contingencies ($)	Land Costs ($)	Subtotal Costs ($)	Total Losses Removed (#)	Cost per Loss Removed ($)	Future Developable Land (acres)	Cost per Acre of Development ($)
F101-05-00	Section 1	Channel	Trapezoidal (Concrete)	4.9	3.5	254,000	703,000	957,000	6	-	-	-
F101-03-00	Section 2	Channel	Trapezoidal (Concrete)	2.2	4.4	160,000	320,000	480,000	16	-	-	-
F101-03-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	556,000	-	556,000	0	-	-	-
F101-03-00	-	Mitigation Pond	Dimensions: 280' x 280' (including 30' berm)	1.8	10.0	313,000	72,000	385,000	0	-	-	-
							Improvement Total =	2,378,000	22	108,000	-	-
F101-03-00	-	Diversion Pond	Dimensions: 450' x 450' (including 30' berm)	4.6	29.0	906,000	186,000	1,092,000	-	-	-	-
F101-05-00	-	Diversion Pond	Dimensions: 410' x 410' (including 30' berm)	3.9	23.0	719,000	154,000	873,000	-	-	-	-
							Improvement Total =	1,092,000	22	50,000	-	-
F101-03-00	-	Regional Pond	Dimensions: 440' x 440' (including 30' berm)	4.4	21.3	666,000	178,000	844,000	-	-	13	-
							Improvement Total =	844,000	-	-	13	64,000
F101-06-00	-	Regional Pond	Dimensions: 500' x 500' (including 30' berm)	5.7	28.3	884,000	230,000	1,114,000	-	-	18	-
							Improvement Total =	1,114,000	-	-	18	63,000
F212-00-00	Section 1	Channel	Trapezoidal, earthen channel (Grass)	4.4	17.0	220,000	637,000	859,000	2	-	-	-
F212-00-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	125,000	-	125,000	0	-	-	-
F212-00-00	-	Mitigation Pond	Dimensions: 340' x 340' (including 30' berm)	2.7	19.1	597,000	106,000	703,000	0	-	-	-
							Improvement Total =	1,687,000	2	344,000	-	-
F212-00-00	-	Diversion Pond	Dimensions: 1010' x 1010' (including 30' berm)	23.4	167.0	5,219,000	937,000	6,156,000	2	-	-	-
							Improvement Total =	6,156,000	2	3,078,000	-	-
F212-00-00	-	Regional Pond	Dimensions: 650' x 650' (including 30' berm)	9.7	83.3	2,603,000	388,000	2,991,000	-	-	65	-
							Improvement Total =	2,991,000	-	-	65	46,000
F216-01-00	Section 1	Channel	Trapezoidal (Concrete)	2.2	2.3	139,000	320,000	459,000	4	-	-	-
F216-01-00	Section 2	Channel	Trapezoidal, earthen channel (Grass)	2.2	3.5	51,000	320,000	371,000	4	-	-	-
F216-01-00	Section 3^1	Channel	Trapezoidal, earthen channel (Grass)	0.9	3.8	48,000	128,000	176,000	1	-	-	-
F216-01-00	Section 2^2	Pipe	Pipe Replacement (84" RCP)	0.0	0.0	2,188,000	-	2,188,000	0	-	-	-
F216-01-00	Section 3^2	Pipe	Pipe Replacement (108" RCP)	0.0	0.0	875,000	-	875,000	0	-	-	-
F216-01-00	-	Culvert	Culvert Replacement (5'x5' RCB)	0.0	0.0	34,000	-	34,000	0	-	-	-
F216-01-00	-	Mitigation Pond	Dimensions: 270' x 270' (including 30' berm)	1.7	11.1	347,000	67,000	414,000	0	-	-	-
							Improvement Total =	See Note 1 & 2	9	See Note 1 & 2	-	-
F216-01-00	-	Diversion Pond	Dimensions: 1170' x 1170' (including 30' berm)	31.4	229.0	7,156,000	1,257,000	8,413,000	9	-	-	-
							Improvement Total =	8,413,000	9	935,000	-	-
F216-01-00	-	Regional Pond	Dimensions: 430' x 430' (including 30' berm)	4.2	24.6	769,000	170,000	939,000	-	-	18	-
							Improvement Total =	939,000	-	-	18	52,000

Note 1 This improvements option for F216-01-00 consist of an earthen channel that requires purchasing ROW. Total Cost $1,454,000 Cost Per Loss Removed $161,555

Note 2 This improvements option for F216-01-00 consist of an new storm sewer. Total Cost $3,970,000 Cost Per Loss Removed $441,111

🟨 *Based on undeveloped land costs ($40,000 per acre)*

🟧 *Based on developed land costs ($145,000 per acre)*

▨ *Based on developable land within the subbasin and a residential lot size of 0.25 acre*

TABLE 5-4
COST SUMMARY OF RELIEF SWALES

Channel	Subdivision Name	Possibility of Sheet Flow Path	Modification Type	Description	Number of Proposed Swales	Land Acquisition (acres)	Excavation Volume (ac-ft)	Construction Costs with 25% Contingencies ($)	Land Costs ($)	Total Cost ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)
Clear Creek Watershed												
A104-00-00, A104-12-01	Shady River	No	-	-	-	-	-	-	-	-	9	-
A104-07-00	Spencer Landings	No	-	-	-	-	-	-	-	-	0	-
A104-10-00	Bay Colony	No	-	-	-	-	-	-	-	-	7	-
A104-10-00	Bayside Terrace	No	-	-	-	-	-	-	-	-	7	-
Armand Bayou Watershed												
B106-00-00	Creekmont Section 1	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.15	0.23	13,000	21,000	34,000	56	610
B106-00-00	Glen Meadows	Yes	Relief Swale	Trapezoidal (Concrete)	2	0.12	0.35	13,000	17,000	30,000	56	540
B106-00-00	Fairmont Park West	Yes	Relief Swale	Trapezoidal (Concrete)	5	0.24	0.36	22,000	35,000	57,000	154	370
B106-00-00	Fairmont Park	Yes	Relief Swale	Trapezoidal (Concrete)	2	0.081	0.12	7,000	12,000	19,000	34	560
B106-00-00	Creekmont Section 2	Yes	Relief Swale	Trapezoidal (Concrete)	1	See Creekmont Park Report					9	-
B106-00-00	Meadowcrest	No	-	-	-	-	-	-	-	-	10	-
B106-00-00, B106-32-00	Fairmont Park East	Yes	Relief Swale	Trapezoidal (Concrete)	5	0.28	0.42	25,000	40,000	65,000	76	860
B106-05-00	Meadow Park	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.058	0.09	5,000	8,000	13,000	24	540
B106-05-00	Villa Del Rancho	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.10	0.16	9,000	15,000	24,000	9	2,670
B109-00-00	Spencer Highway Estates	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.13	0.19	11,000	19,000	30,000	22	1,360
B112-00-00, B112-02-00	Brookglen	Yes	Relief Swale	Trapezoidal (Concrete)	9	0.4	0.61	36,000	59,000	95,000	270	350
San Jacinto/Galveston Bayou Watershed												
F101-00-00	Battleground Estate	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.15	0.22	13,000	22,000	35,000	2	17,500
F101-00-00, F101-03-00	Pinegrove Valley	Yes	Relief Swale	Trapezoidal (Concrete)	1	0.03	0.04	2,000	4,000	6,000	42	140
F101-05-00, F101-06-00	Lomax Garden	No	-	-	-	-	-	-	-	-	18	-
F212-00-00	Bay Shore Park	No	-	-	-	-	-	-	-	-	1	-
F212-00-00	Bay Front To La Porte	No	-	-	-	-	-	-	-	-	2	-
F212-09-00	San Jacinto Homes	No	-	-	-	-	-	-	-	-	1	-
F216-00-00, F216-01-00	La Porte	No	-	-	-	-	-	-	-	-	14	-
F216-00-00	Old La Porte	Yes	Relief Swale	Trapezoidal (Concrete)	2	1.44	2.16	128,000	208,000	336,000	16	21,000
F216-00-00	Battle Grounds Vista	No	-	-	-	-	-	-	-	-	1	-
Galveston Bay	Pine Bluff	No	-	-	-	-	-	-	-	-	7	-
Galveston Bay	Beach Park	No	-	-	-	-	-	-	-	-	4	-
Galveston Bay	Woods On The Bay	No	-	-	-	-	-	-	-	-	0	-

🟨	*No sheet flow paths possible*

TABLE 5-5
COST ESTIMATES BREAKDOWN

Channel	Channel Type	Solution Type	Channel/Detention Costs		Channel Mitigation Costs		Total Costs
			Construction ($)	Land ($)	Construction ($)	Land ($)	($)
A104-00-00	FEMA	Conveyance	56,000	57,000	188,000	60,000	361,000
B106-00-00	FEMA	Conveyance	8,399,000	1,585,000	1,500,000	268,000	11,752,000
B112-00-00	FEMA	Conveyance	2,461,000	698,000	2,031,000	304,000	5 494,000
A104-12-01	non-FEMA	Conveyance	123,000	229.000	188.000	60,000	600,000
B106-02-00	non-FEMA	Conveyance	341,000	294,000	125.000	21,000	781,000
B106-05-000	non-FEMA	Conveyance	729,000	576,000	313,000	83,000	1,701,000
F101-00-00	non-FEMA	Conveyance	328,000	511,000	156,000	37,000	1,032,000
F101-05-00	non-FEMA	Conveyance	254,000	703,000	-	-	957,000
F101-03-00	non-FEMA	Conveyance	716,000	320,000	313,000	72,000	1,421,000
F212-00-00	non-FEMA	Conveyance	345,000	639,000	597,000	106,000	1,687,000
F206-01-00	non-FEMA	Conveyance	3,335.000	768.000	347,000	67,000	4,517.000
					Total Conveyance Cost =		**30,303,000**
B106-00-00	FEMA	Diversion	7,142,000	1,172,000	-	-	8,314,000
B112-00-00	FEMA	Diversion	9,796,000	1,528,000	-	-	11,324,000
A104-12-01	non-FEMA	Diversion	3,063,000	573,000	-	-	3,636,000
B106-02-00	non-FEMA	Diversion	2,344,000	450,000	-	-	2,794,000
B106-05-000	non-FEMA	Diversion	1,625,000	320,000	-	-	1,945,000
F101-00-00	non-FEMA	Diversion	5,219,000	937,000	-	-	6,156,000
F101-03-00	non-FEMA	Diversion	906,000	186,000	-	-	1 092,000
F101-05-00	non-FEMA	Diversion	719,000	154,000	-	-	873,000
F212-00-00	non-FEMA	Diversion	5,219,000	937,000	-	-	6,156,000
F206-01-00	non-FEMA	Diversion	5,219,000	1,257,000	-	-	6,476,000
					Total Diversion Cost =		**48,766,000**
B106-000	FEMA	Sheet Flow	55,000	85,000	-	-	140,000
B106-02-00	non-FEMA	Sheet Flow	25,000	40,000	-	-	65,000
B106-05-000	non-FEMA	Sheet Flow	14,000	23,000	-	-	37,000
B109-00-00	FEMA	Sheet Flow	11,000	19,000	-	-	30.000
B112-00-00	FEMA	Sheet Flow	36,000	59,000	-	-	95,000
F101-00-00	non-FEMA	Sheet Flow	13,000	26,000	-	-	39,000
F216-00-00	FEMA	Sheet Flow	128,000	208,000	-	-	336,000
					Total Sheet Flow Relief Cost =		**742,000**
A104-00-00	FEMA	Regional Detention	6,782,000	1,592,000	-	-	8,374.000
A104-07-00	FEMA	Regional Detention	15,938,000	2,440,000	-	-	18.378,000
B106-00-00	FEMA	Regional Detention	6,344,000	1,012,000	-	-	7,356,000
B109-00-00	FEMA	Regional Detention	1,219,000	308,000	-	-	1,527,000
B112-00-00	FEMA	Regional Detention	1,281,000	204,000	-	-	1,485,000
B112-02-00	FEMA	Regional Detention	500,000	140,000	-	-	640,000
F216-00-00	FEMA	Regional Detention	4,156,000	1 028,000	-	-	5,184,000
A104-12-01	non-FEMA	Regional Detention	4,250,000	993,000	-	-	5,243,000
B106-02-00	non-FEMA	Regional Detention	525,000	88,000	-	-	613,000
B106-05-00	non-FEMA	Regional Detention	5,019,000	1,012,000	-	-	6 031 000
F101-00-00	non-FEMA	Regional Detention	3,359,000	79,400	-	-	3 438 400
F101-03-00	non-FEMA	Regional Detention	666,000	178,000	-	-	844,000
F106-06-00	non-FEMA	Regional Detention	884,000	230,000	-	-	1,114,000
F212-00-00	non-FEMA	Regional Detention	2,603,000	388,000	-	-	2,991,000
F216-01-00	non-FEMA	Regional Detention	769,000	170.000	-	-	939,000
					Total Regional Detention Cost =		**64,157,400**

TABLE 5-6
COST ESTIMATES PERCENTAGES

Channel	Channel Type	Solution Type	Channel/Detention Costs		Channel Mitigation Costs		Total Costs
			Construction (%)	Land (%)	Construction (%)	Land (%)	(%)
A104-00-00	FEMA	Conveyance	16	16	52	17	100
B106-00-00	FEMA	Conveyance	71	13	13	2	100
B112-00-00	FEMA	Conveyance	45	13	37	6	100
A104-12-01	non-FEMA	Conveyance	21	38	31	10	100
B106-02-00	non-FEMA	Conveyance	44	38	16	3	100
B106-05-000	non-FEMA	Conveyance	43	34	18	5	100
F101-00-00	non-FEMA	Conveyance	32	50	15	4	100
F101-05-00	non-FEMA	Conveyance	27	73	-	-	100
F101-03-00	non-FEMA	Conveyance	50	23	22	5	100
F212-00-00	non-FEMA	Conveyance	20	38	35	6	100
F206-01-00	non-FEMA	Conveyance	74	17	8	1	100
Conveyance Averages =			***40***	***32***	***23***	***5***	***100***
B106-00-00	FEMA	Diversion	86	14	-	-	100
B112-00-00	FEMA	Diversion	87	13	-	-	100
A104-12-01	non-FEMA	Diversion	84	16	-	-	100
B106-02-00	non-FEMA	Diversion	84	16	-	-	100
B106-05-000	non-FEMA	Diversion	84	16	-	-	100
F101-00-00	non-FEMA	Diversion	85	15	-	-	100
F101-03-00	non-FEMA	Diversion	83	17	-	-	100
F101-05-00	non-FEMA	Diversion	82	18	-	-	100
F212-00-00	non-FEMA	Diversion	85	15	-	-	100
F206-01-00	non-FEMA	Diversion	81	19	-	-	100
Diversion Averages =			***84***	***16***	***0***	***0***	***100***
B106-000	FEMA	Sheet Flow	39	61	-	-	100
B106-02-00	non-FEMA	Sheet Flow	38	62	-	-	100
B106-05-000	non-FEMA	Sheet Flow	38	62	-	-	100
B109-00-00	FEMA	Sheet Flow	37	63	-	-	100
B112-00-00	FEMA	Sheet Flow	38	62	-	-	100
F101-00-00	non-FEMA	Sheet Flow	33	67	-	-	100
F216-00-00	FEMA	Sheet Flow	38	62	-	-	100
Sheet Flow Averages =			***37***	***63***	***0***	***0***	***100***
A104-00-00	FEMA	Regional Detention	81	19	-	-	100
A104-07-00	FEMA	Regional Detention	87	13	-	-	100
B106-00-00	FEMA	Regional Detention	86	14	-	-	100
B109-00-00	FEMA	Regional Detention	80	20	-	-	100
B112-00-00	FEMA	Regional Detention	86	14	-	-	100
B112-02-00	FEMA	Regional Detention	78	22	-	-	100
F216-00-00	FEMA	Regional Detention	80	20	-	-	100
A104-12-01	non-FEMA	Regional Detention	81	19	-	-	100
B106-02-00	non-FEMA	Regional Detention	86	14	-	-	100
B106-05-00	non-FEMA	Regional Detention	83	17	-	-	100
F101-00-00	non-FEMA	Regional Detention	98	2	-	-	100
F101-03-00	non-FEMA	Regional Detention	79	21	-	-	100
F106-06-00	non-FEMA	Regional Detention	79	21	-	-	100
F212-00-00	non-FEMA	Regional Detention	87	13	-	-	100
F216-01-00	non-FEMA	Regional Detention	82	18	-	-	100
Regional Detention Averages =			***84***	***16***	***0***	***0***	***100***

TABLE 5-7
LIST OF PROPOSED IMPROVEMENTS (COST-SORTED)

Channel	Model Type	Modification Type	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (#)	Cost Per Acre of Development ($)
F101-00-00, F101-03-00	Subdivision	Relief Swale	6,000	42	140	-	-
B106-05-00	Subdivision	Relief Swale	13,000	24	540	-	-
B106-00-00	Subdivision	Relief Swale	19,000	34	560	-	-
B106-05-00	Subdivision	Relief Swale	24,000	9	2,670	-	-
B106-00-00	Subdivision	Relief Swale	30,000	56	540	-	-
B109-00-00	Subdivision	Relief Swale	30,000	22	1,360	-	-
B106-00-00	Subdivision	Relief Swale	34,000	56	610	-	-
F101-00-00	Subdivision	Relief Swale	35,000	2	17,500	-	-
B106-00-00	Subdivision	Relief Swale	57,000	154	370	-	-
B106-00-00, B106-02-00	Subdivision	Relief Swale	65,000	76	860	-	-
B112-00-00, B112-02-00	Subdivision	Relief Swale	95,000	270	350	-	-
F216-00-00	Subdivision	Relief Swale	336,000	16	21,000	-	-
A104-00-00	FEMA	Conveyance	361,000	6	60,200	-	-
A104-12-01	Non-FEMA	Conveyance	600,000	8	75,000	-	-
B106-02-00	Non-FEMA	Regional Detention	613,000	-	-	13	48,000
B106-02-00	Non-FEMA	Conveyance	781,000	34	23,000	-	-
F101-03-00	Non-FEMA	Regional Detention	844,000	-	-	13	64,000
F216-01-00	Non-FEMA	Regional Detention	939,000	-	-	18	52,000
F101-00-00	Non-FEMA	Conveyance	1,032,000	19	54,000	-	-
F101-03-00, F101-05-00	Non-FEMA	Diversion Pond	1,092,000	22	50,000	-	-
F101-06-00	Non-FEMA	Regional Detention	1,114,000	-	-	18	63,000
F212-00-00	Non-FEMA	Conveyance	1,687,000	2	844,000	-	-
B106-05-00	Non-FEMA	Conveyance	1,701,000	36	47,000	-	-
B106-05-00	Non-FEMA	Diversion Pond	1,945,000	36	54,000	-	-
F101-03-00	Non-FEMA	Conveyance	2,378,000	22	108,000	-	-
B106-02-00	Non-FEMA	Diversion Pond	2,794,000	34	82,000	-	-
A104-12-01	Non-FEMA	Diversion Pond	2,794,000	8	578,000	-	-
F212-00-00	Non-FEMA	Regional Detention	2,991,000	-	-	65	46,000
B112-00-00	FEMA	Regional Detention	3,652,000	-	-	148	24,700
F101-00-00	Non-FEMA	Regional Detention	4,153,000	-	-	80	52,000
F216-00-00	FEMA	Regional Detention	5,184,000	-	-	576	9,000

TABLE 5-7
LIST OF PROPOSED IMPROVEMENTS (COST-SORTED)

Channel	Model Type	Modification Type	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (#)	Cost Per Acre of Development ($)
A104-12-01	Non-FEMA	Regional Detention	5,243,000	-	-	100	52,000
B112-00-00	FEMA	Conveyance	5,494,000	187	29,400	-	-
B106-05-00	Non-FEMA	Regional Detention	6,031,000	-	-	119	51,000
F101-00-00	Non-FEMA	Diversion Pond	6,156,000	19	324,000	-	-
F212-00-00	Non-FEMA	Diversion Pond	6,156,000	2	3,078,000	-	-
F216-01-00	Non-FEMA	Diversion Pond	6,476,000	9	720,000	-	-
B106-00-00	FEMA	Regional Detention	7,356,000	-	-	1260	5,800
B106-00-00	FEMA	Diversion Pond	8,314,000	95	87,500	-	-
B112-00-00	FEMA	Diversion Pond	11,324,000	187	60,600	-	-
B106-00-00	FEMA	Conveyance	11,752,000	95	123,700	-	-
A104-00-00	FEMA	Regional Detention	26,752,000	-	-	890	30,058
F216-01-00	Non-FEMA	Conveyance	See Note 1 & 2	9	See Note 1 & 2	-	-

Note 1: This improvements option for F216-01-00 consist of an earthen channel that requires purchasing ROW. Total Cost $1,454,000.Cost Per Loss Removed $161,555.

Note 2: This improvements option for F216-01-00 consist of an new storm sewer. Total Cost $3,970,000.Cost Per Loss Removed $441,111.

TABLE 5-8
LIST OF PROPOSED IMPROVEMENTS (LOSS-SORTED)

Channel	Model Type	Location Benefiting	Modification Type	Description	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (acres)	Cost Per Acre of Development ($)	For Rapid Implementation
B112-00-00, B112-02-00	Subdivision	Brookglen	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	95,000	270	350	-	-	Yes
B112-00-00	FEMA	Brookglen	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (575' x 575')	5,494,000	187	29,400	-	-	-
B112-00-00	FEMA	Brookglen	Diversion Pond	Dimensions: 1290' x 1290' (including 30' berm)	11,324,000	187	60,600	-	-	-
B106-00-00	Subdivision	Fairmont Park West	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	57,000	154	370	-	-	Yes
B106-00-00	FEMA	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	8,314,000	95	87,500	-	-	-
B106-00-00	FEMA	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (540' x 540')	11,752,000	95	123,700	-	-	-
B106-00-00, B106-02-0	Subdivision	Fairmont Park East	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	65,000	76	860	-	-	Yes
B106-00-00	Subdivision	Glen Meadow	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	30,000	56	540	-	-	Yes
B106-00-00	Subdivision	Creekmont Section 1	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	34,000	56	610	-	-	Yes
F101-00-00, F101-03-00	Subdivision	Pinegrove Valley	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	6,000	42	140	-	-	Yes
B106-05-00	Non-FEMA	Meadow Park, Villa Del Rancho	Conveyance	Trapezoidal, earthen channel (Grass), Mitigation Pond (300' x 300')	1,701,000	36	47,000	-	-	-
B106-05-00	Non-FEMA	Meadow Park, Villa Del Rancho	Diversion Pond	Dimensions: 590' x 590' (including 30' berm)	1,945,000	36	54,000	-	-	-
B106-00-00	Subdivision	Fairmont Park	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	19,000	34	560	-	-	Yes
B106-02-00	Non-FEMA	Fairmont Park, Fairmont Park East	Conveyance	Trapezoidal, earthen channel (Grass), Mitigation Pond (240' x 240')	781,000	34	23,000	-	-	-
B106-02-00	Non-FEMA	Fairmont Park, Fairmont Park East	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	2,794,000	34	82,000	-	-	-
B106-05-00	Subdivision	Meadow Park	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	13,000	24	540	-	-	Yes

TABLE 5-8
LIST OF PROPOSED IMPROVEMENTS (LOSS-SORTED)

Channel	Model Type	Location Benefiting	Modification Type	Description	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (acres)	Cost Per Acre of Development ($)	For Rapid Implementation
B112-00-00, B112-02-00	Subdivision	Brookglen	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	95,000	270	350	-	-	Yes
B112-00-00	FEMA	Brookglen	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (575' x 575')	5,494,000	187	29,400	-	-	-
B112-00-00	FEMA	Brookglen	Diversion Pond	Dimensions: 1290' x 1290' (including 30' berm)	11,324,000	187	60,500	-	-	-
B106-00-00	Subdivision	Fairmont Park West	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	57,000	154	370	-	-	Yes
B106-00-00	FEMA	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	8,314,000	95	87,500	-	-	-
B106-00-00	FEMA	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (540' x 540')	11,752,000	95	123,700	-	-	-
B106-00-00, B106-02-00	Subdivision	Fairmont Park East	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	65,000	76	860	-	-	Yes
B106-00-30	Subdivision	Glen Meadow	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	30,000	56	540	-	-	Yes
B106-00-20	Subdivision	Creekmont Section 1	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	34,000	56	610	-	-	Yes
F101-00-00, F101-03-00	Subdivision	Pinegrove Valley	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	6,000	42	140	-	-	Yes
B106-05-00	Non-FEMA	Meadow Park, Villa Del Rancho	Conveyance	Trapezoidal, earthen channel (Grass), Mitigation Pond (300' x 300')	1,701,000	36	47,000	-	-	-
B106-05-00	Non-FEMA	Meadow Park, Villa Del Rancho	Diversion Pond	Dimensions: 590' x 590' (including 30' berm)	1,945,000	36	54,000	-	-	-
B106-00-00	Subdivision	Fairmont Park	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	19,000	34	560	-	-	Yes
B106-02-00	Non-FEMA	Fairmont Park, Fairmont Park East	Conveyance	Trapezoidal, earthen channel (Grass), Mitigation Pond (240' x 240')	781,000	34	23,000	-	-	-
B106-02-00	Non-FEMA	Fairmont Park, Fairmont Park East	Diversion Pond	Dimensions: 700' x 700' (including 30' berm)	2,794,000	34	82,000	-	-	-
B106-05-00	Subdivision	Meadow Park	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	13,000	24	540	-	-	Yes

TABLE 5-8
LIST OF PROPOSED IMPROVEMENTS (LOSS-SORTED)

Channel	Model Type	Location Benefiting	Modification Type	Description	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (acres)	Cost Per Acre of Development ($)	For Rapid Implementation
B109-00-00	Subdivision	Spencer Highway	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	30,000	22	1,360	-	-	Yes
F101-03-00, F101-05-00	Non-FEMA	Lomax Garden, Residents along L St.	Diversion Pond	2 Pond: Dimensions: (410' x 410'; 450' x 450') (including 30' berm)	1,092,000	22	50,000	-	-	-
F101-03-00	Non-FEMA	Lomax Garden, Residents along L St	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (340' x 340')	2,378,000	22	108,000	-	-	-
F101-00-00	Non-FEMA	Battleground Estates, Pinegrove, Residents along P St.	Conveyance	Trapezoidal (Concrete) Channel, Mitigation Pond (250' x 250')	1,032,000	19	54,000	-	-	-
F101-00-00	Non-FEMA	Battleground Estates, Pinegrove, Residents along P St.	Diversion Pond	Dimensions 1010' x 1010' (including 30' berm)	6,156,000	19	324,000	-	-	-
F216-00-00	Subdivision	Old La Porte	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	336,000	16	21,000	-	-	Yes
B106-05-00	Subdivision	Villa Del Rancho	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft; Increase Outfall Pipe	24,000	9	2,670	-	-	Yes
F216-01-00	Non-FEMA	Beach Park, La Porte High School	Diversion Pond	Dimensions: 1170' x 1170' (including 30' berm)	8,413,000	9	935,000	-	-	-
F216-01-00	Non-FEMA	Beach Park, La Porte High School	Conveyance	Trapezoidal, earthen channel (Grass) & Trapezoidal concrete Channel. Mitigation Pond (270' x 270')	See Note 1 & 2	9	See Note 1 & 2	-	-	-
A104-12-01	Non-FEMA	Woods On The Bay, Pine Bluff, Shady River	Conveyance	Trapezoidal, earthen channel (Grass), Mitigation Pond (255' x 255')	600,000	8	75,000	-	-	-
A104-12-01	Non-FEMA	Woods On The Bay, Pine Bluff, Shady River	Diversion Pond	Dimensions: 790' x 790' (including 30' berm)	2,794,000	8	578,000	-	-	-
A104-00-00	FEMA	Shady River	Conveyance	Trapezoidal, earthen channel (Grass). Mitigation Pond (255' x 255')	361,000	6	60,200	-	-	-
F101-00-00	Subdivision	Battleground Estate	Relief Swale	Trapezoidal (Concrete) Channel with Bottom Width: 1 ft & Typical Depth: 3 ft	35,000	2	17,500	-	-	Yes
F212-00-00	Non-FEMA	Bay Front to La Porte, San Jacinto Homes	Conveyance	Trapezoidal, earthen channel (Grass). Mitigation Pond (340' x 340')	1,687,000	2	844,000	-	-	-
F212-00-00	Non-FEMA	Bay Front to La Porte, San Jacinto Homes	Diversion Pond	Dimensions: 1010' x 1010' (including 30' berm)	6,156,000	2	3,078,000	-	-	-

Note 1: This improvements option for F216-01-00 consist of an earthen channel that requires purchasing ROW. Total Cost $1,454,000 Cost Per Loss Removed $161,555.

Note 2: This improvements option for F216-01-00 consist of an new storm sewer. Total Cost $3,970,000 Cost Per Loss Removed $441,111.

TABLE 5-9
LIST OF PROPOSED IMPROVEMENTS FOR FUTURE CONDITIONS (COST-SORTED)

Channel	Model Type	Location Benefiting	Modification Type	Description	Total Costs ($)	Total Losses Removed (#)	Cost Per Loss Removed ($)	Future Developable Land (acres)	Cost Per Acre of Development ($)	For Rapid Implementation
B106-02-00	Non-FEMA	Fairmont Park, Fairmont Park East	Regional Detention	Dimensions: 310' x 310' (including 30' berm)	613,000	-	-	13	48,000	-
F101-03-00	Non-FEMA	Lomax Garden, Residents along L St.	Regional Detention	Dimensions: 440' x 440' (including 30' berm)	844,000	-	-	13	64,000	-
F216-01-00	Non-FEMA	Beach Park, La Porte High School	Regional Detention	Dimensions: 330' x 330' (including 30' berm)	939,000	-	-	18	52,000	-
F101-06-00	Non-FEMA	Pinegrove Valleyu, Residents along L St and P St.	Regional Detention	Dimensions: 500' x 500' (including 30' berm)	1,114,000	-	-	18	63,000	-
F212-00-00	Non-FEMA	Bay Front to La Porte, San Jacinto Homes	Regional Detention	Dimensions: 650' x 650' (including 30' berm)	2,991,000	-	-	65	46,000	-
B112-00-00	FEMA	Brookglen, Spencer Highway Estates	Regional Detention	Dimensions: (470' x 470'; 390' x 390'; 580' x 580') (including 30' berm)	3,652,000	-	-	148	24,700	-
F101-00-00	Non-FEMA	Battleground Estates, Pinegrove, Residents along P St.	Regional Detention	2 Ponds: Dimensions (930' x 930'; 930' x 930') (including 30' berm)	4,153,000	-	-	80	52,000	-
F216-00-00	FEMA	Old La Porte, La Porte	Regional Detention	3 Ponds: Dimensions (680' x 680'; 770' x 770'; 300' x 300') (including 30' berm)	5,184,000	-	-	576	9,000	-
A104-12-01	Non-FEMA	Woods On The Bay, Pine Bluff, Shady River	Regional Detention	Dimensions: 1040' x 1040' (including 30' berm)	5,243,000	-	-	100	52,000	-
B106-05-00	Non-FEMA	Meadow Park, Villa Del Rancho	Regional Detention	Dimensions: 1050' x 1050' (including 30' berm)	6,031,000	-	-	119	51,000	-
B106-00-00	FEMA	Meadowcrest, Creekmont, Glen Meadow, Fairmont Park, Fairmont Park West	Regional Detention	Dimensions: 1050' x 1050' (including 30' berm)	7,356,000	-	-	1260	5,800	-
A104-00-00	FEMA	La Porte, Shady River	Regional Detention	3 Ponds: Dimensions (1200' x 1200'; 540' x 540'; 1630' x 1630') (including 30' berm)	26,752,000	-	-	890	30,058	-

Note 1: This improvements option for F216-01-00 consist of an earthen channel that requires purchasing ROW. Total Cost $1,454,000.Cost Per Loss Removed $161,555.

Note 2: This improvements option for F216-01-00 consist of an new storm sewer. Total Cost $3,970,000 Cost Per Loss Removed $441,111.

TABLE 5-10
OWNERSHIP AND MAINTENANCE

Stream	Ownership	Maintenance
Clear Creek Watershed		
A104-00-00 (Taylor Bayou)	HCFCD	HCFCD
A104-07-00 (Tributary 3.93 to Taylor Bayou)	HCFCD/City	HCFCD/City
A104-07-01	City	City
A104-10-00 (Boggy Gully/Bayou)	HCFCD	HCFCD
A104-10-02	HCFCD	HCFCD
A104-12-00	HCFCD	HCFCD
A104-12-01	HCFCD	HCFCD
Armand Bayou Watershed		
B106-00-00 (Big Island Slough)	HCFCD	HCFCD
B106-02-00	HCFCD	HCFCD
B106-05-00	HCFCD/City	HCFCD/City
B106-06-00	City	City
B109-00-00 (Spring Gully)	HCFCD	HCFCD
B109-03-00 (B112-02-00 Interconnect)	HCFCD	HCFCD
B112-00-00 (Willow Springs Bayou)	HCFCD	HCFCD
B112-02-00 (Tributary 1.78 to Willow Spring Bayou)	HCFCD	HCFCD
B112-05-00	HCFCD	HCFCD
San Jancinto/Galveston Bay Watershed		
F101-00-00	HCFCD	HCFCD
F101-01-00	City	City
F101-03-00	City	City
F101-06-00	HCFCD	HCFCD
F101-06-02	HCFCD	HCFCD
F101-06-03	HCFCD	HCFCD
F101-07-00	City	City
F101-08-00	City	City
F210-00-00	HCFCD	HCFCD
F212-00-00 (Deer Creek)	HCFCD/City	HCFCD/City
F216-00-00 (Little Cedar Bayou)	HCFCD/City	HCFCD/City
F216-01-00	City	City
F216-02-00	City	City
F216-04-00	City	City

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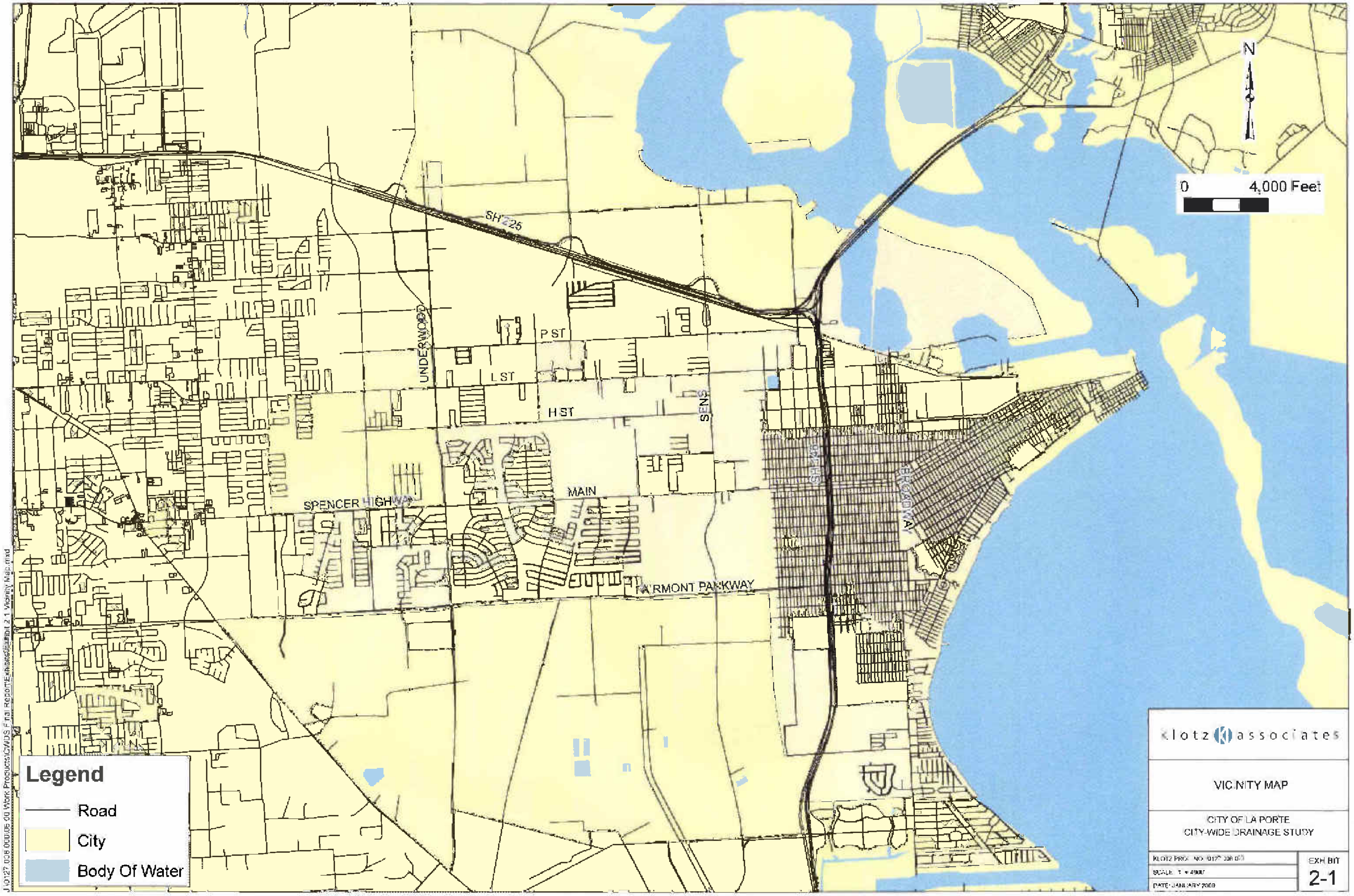


klotz associates

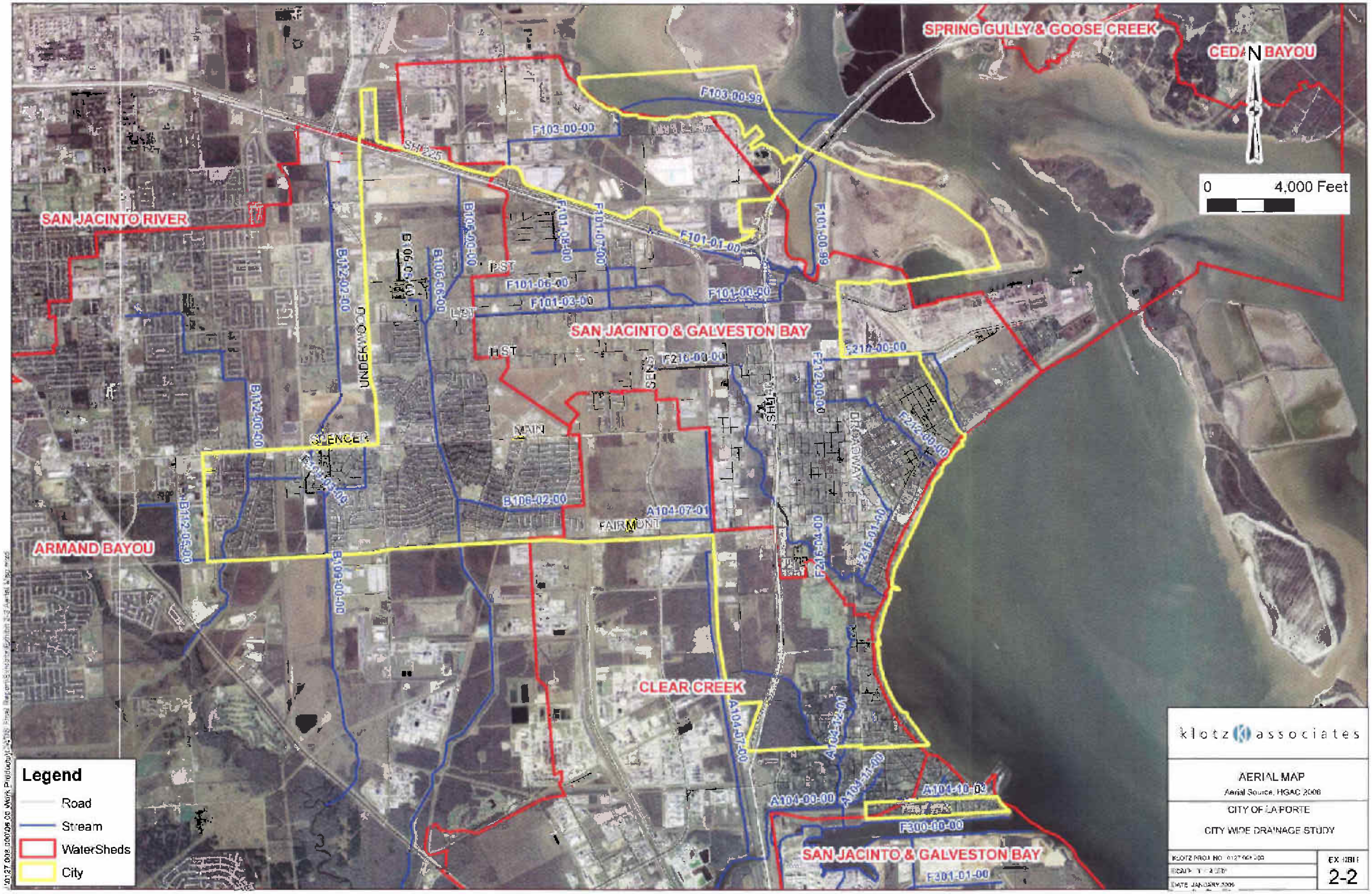
VICINITY MAP

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.006.00
SCALE: 1" = 4000'
DATE: JANUARY 2009

EXHIBIT
2-1

\0127.008.000\06.00 Work Products\CWDS Final Report\Exhibits\Exhibit 2-2 Aerial Map.mxd



klotz associates

AERIAL MAP

Aerial Source, HGAC 2008

CITY OF LA PORTE

CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.008.000	EXHIBIT 2-2
SCALE 1" = 4,000'	
DATE JANUARY 2009	

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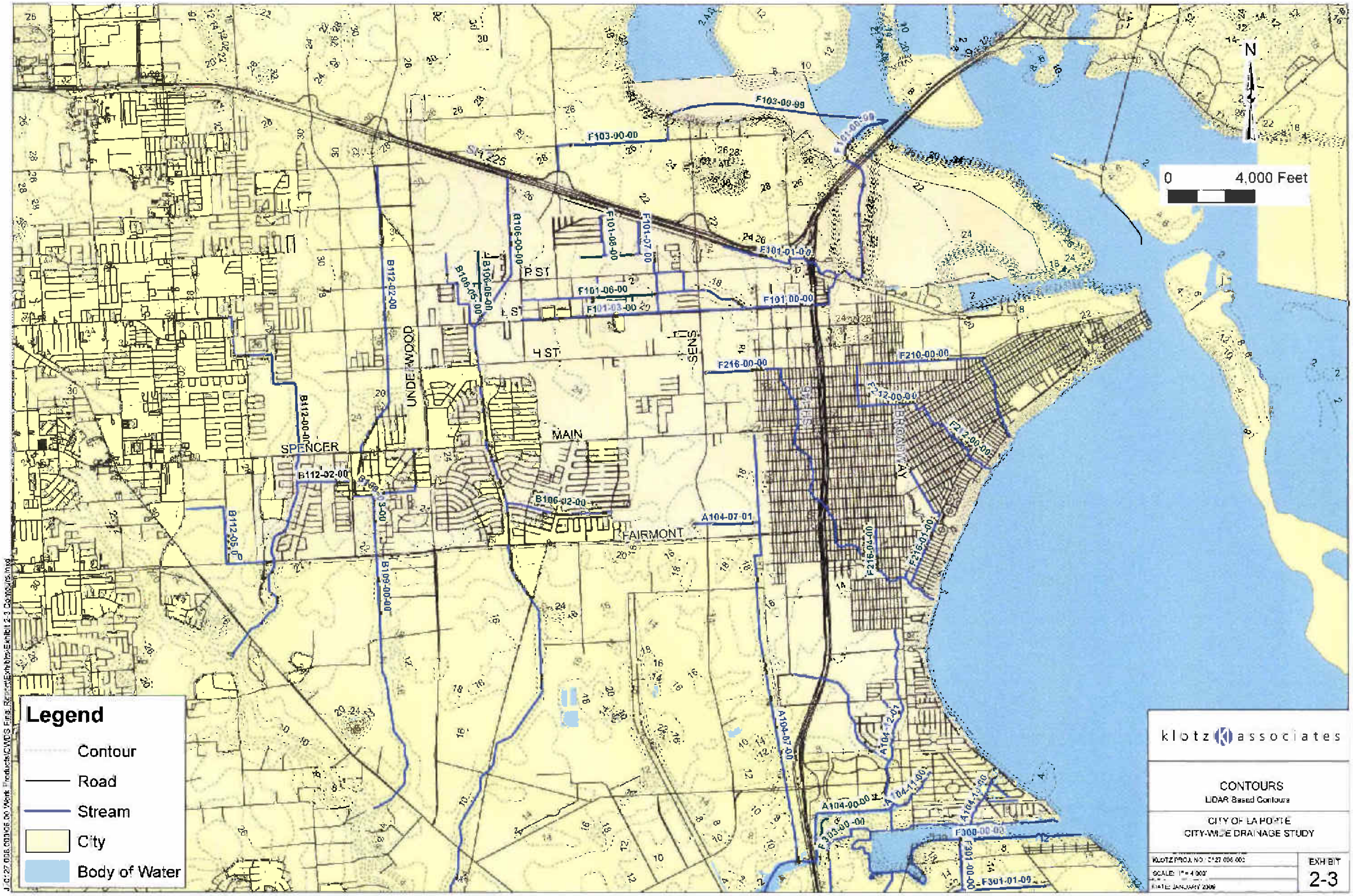

Legend

Contour
Road
Stream
City
Body of Water

klotz associates

CONTOURS
LIDAR Based Contours

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO.: 0127.006.000
SCALE: 1" = 4,000'
DATE: JANUARY 2009

EXHIBIT
2-3

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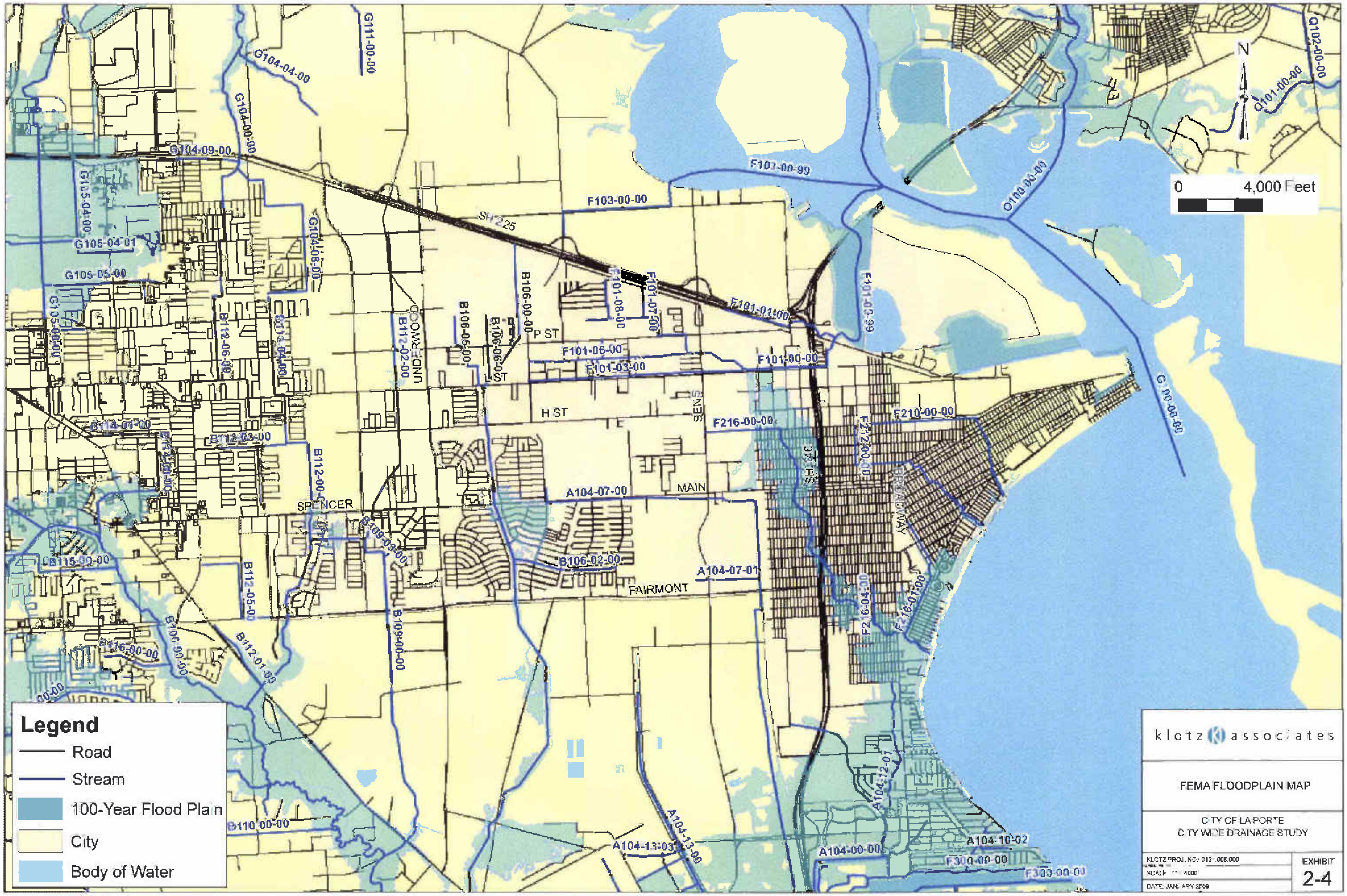


klotz associates

FEMA FLOODPLAIN MAP

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO.: 0127.008.000
SCALE: 1" = 4000'
DATE: JANUARY 2009

EXHIBIT
2-4

klotz associates

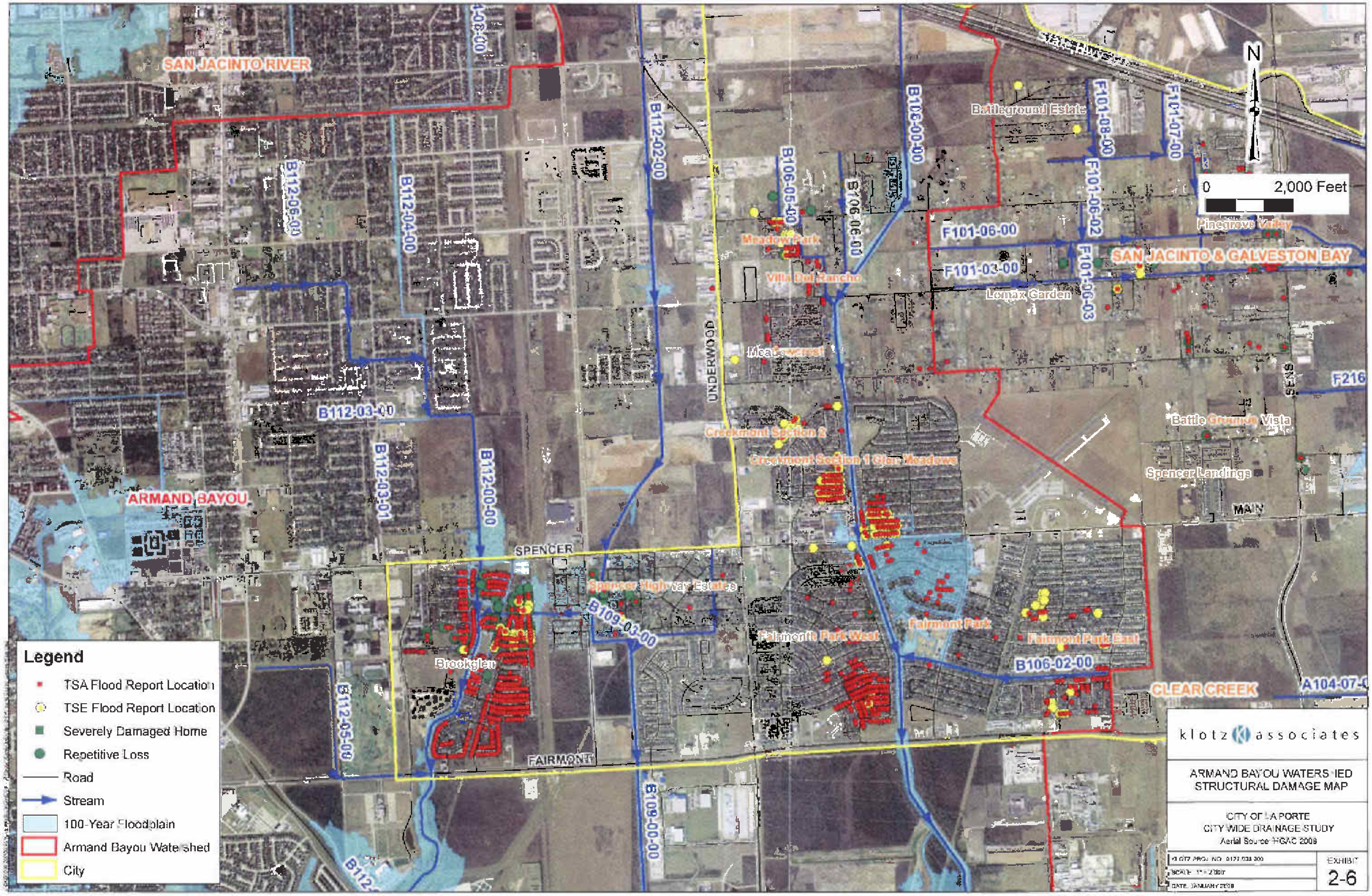
BROOKGLEN SUBDIVISION &
SPENCER HIGHWAY ESTATES
FLOODPLAIN MAP

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 0127.008.200
SCALE: 1" = 500'
DATE: JANUARY 2009

EXHIBIT
2-5



klotz associates

ARMAND BAYOU WATERSHED
STRUCTURAL DAMAGE MAP

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source HGAC 2006

KLOTZ PROJ. NO. 0127.003.300
SCALE: 1" = 2,000'
DATE: JANUARY 2008

EXHIBIT
2-6

klotz associates

CLEAR CREEK WATERSHED
STRUCTURAL DAMAGE MAP

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ NO. 0127.008.000
SCALE: 1" = 2,500'
DATE: JANUARY 2009

EXHIBIT
2-7

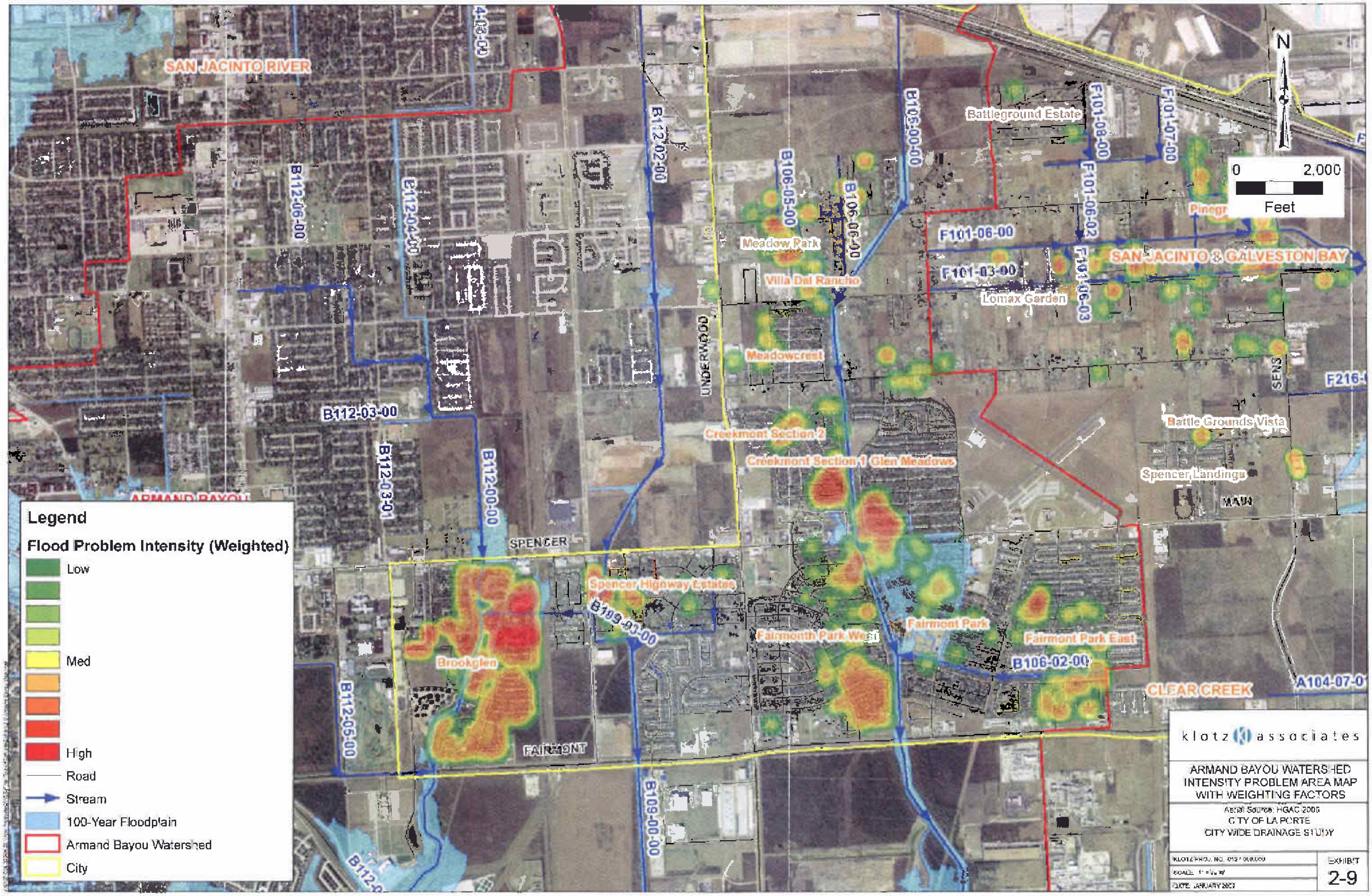
klotz associates

SAN JACINTO & GALVESTON BAY
STRUCTURAL DAMAGE MAP

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 3127.08.000
SCALE: 1" = 2,000'
DATE: JANUARY 2009

EXHIBIT
2-8



Legend

Flood Problem Intensity (Weighted)

🟩	Low
🟩	
🟩	
🟩	
🟨	Med
🟧	
🟧	
🟥	
🟥	High
—	Road
→	Stream
▨	100-Year Floodplain
🟥	Armand Bayou Watershed
🟨	City

klotz associates

ARMAND BAYOU WATERSHED
INTENSITY PROBLEM AREA MAP
WITH WEIGHTING FACTORS

Aerial Source: HGAC 2006
CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0121-008.000
SCALE: 1" = 2,000'
DATE: JANUARY 2007

EXHIBIT
2-9

klotz associates

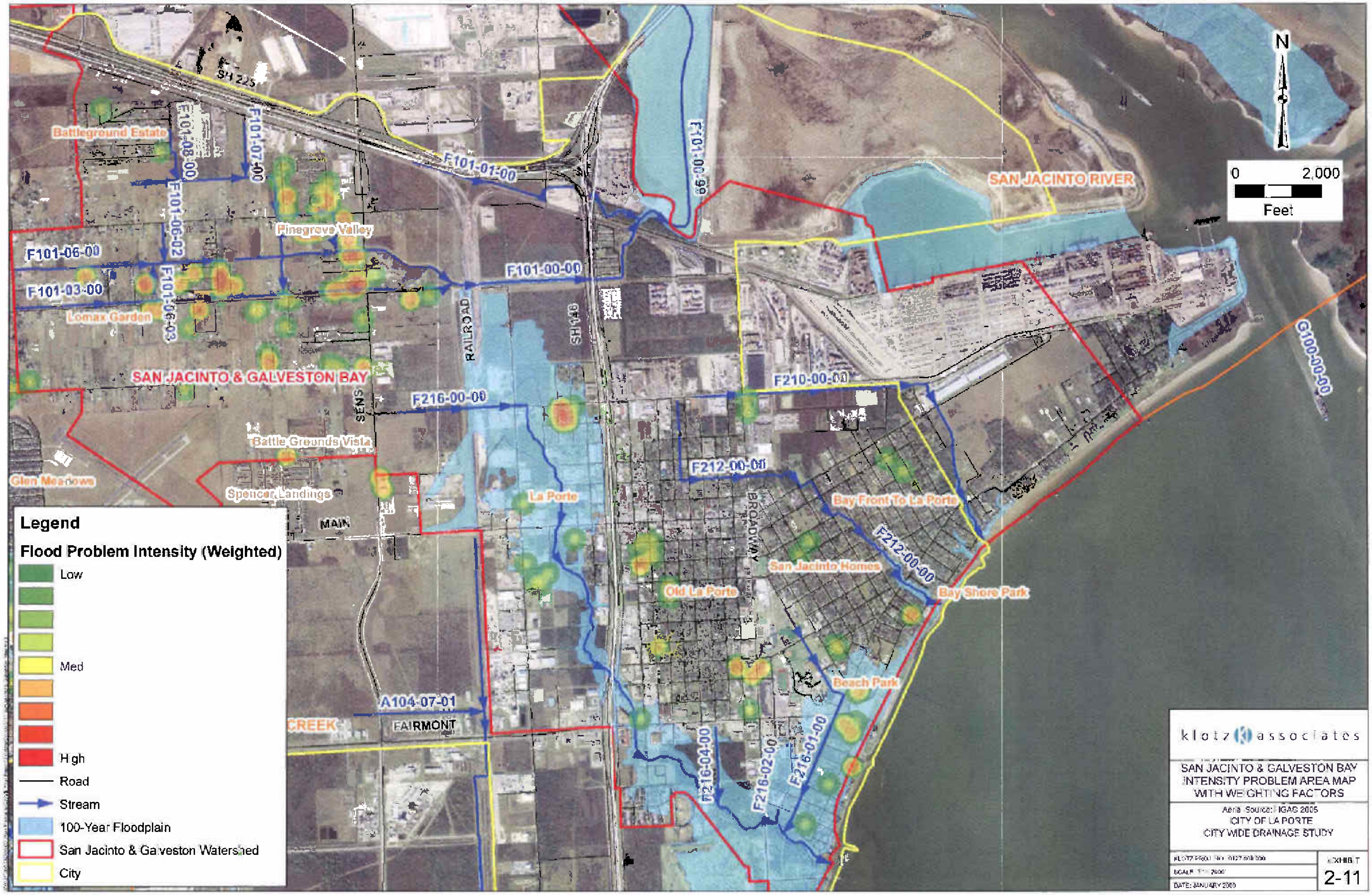
**CLEAR CREEK WATERSHED
INTENSITY PROBLEM AREA MAP
WITH WEIGHTING FACTORS**

Aerial Source: HGAC 2006

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ NO.: 0127.008.000
SCALE: 1" = 2,000'
DATE: JANUARY 2009

EXHIBIT
2-10



klotz associates

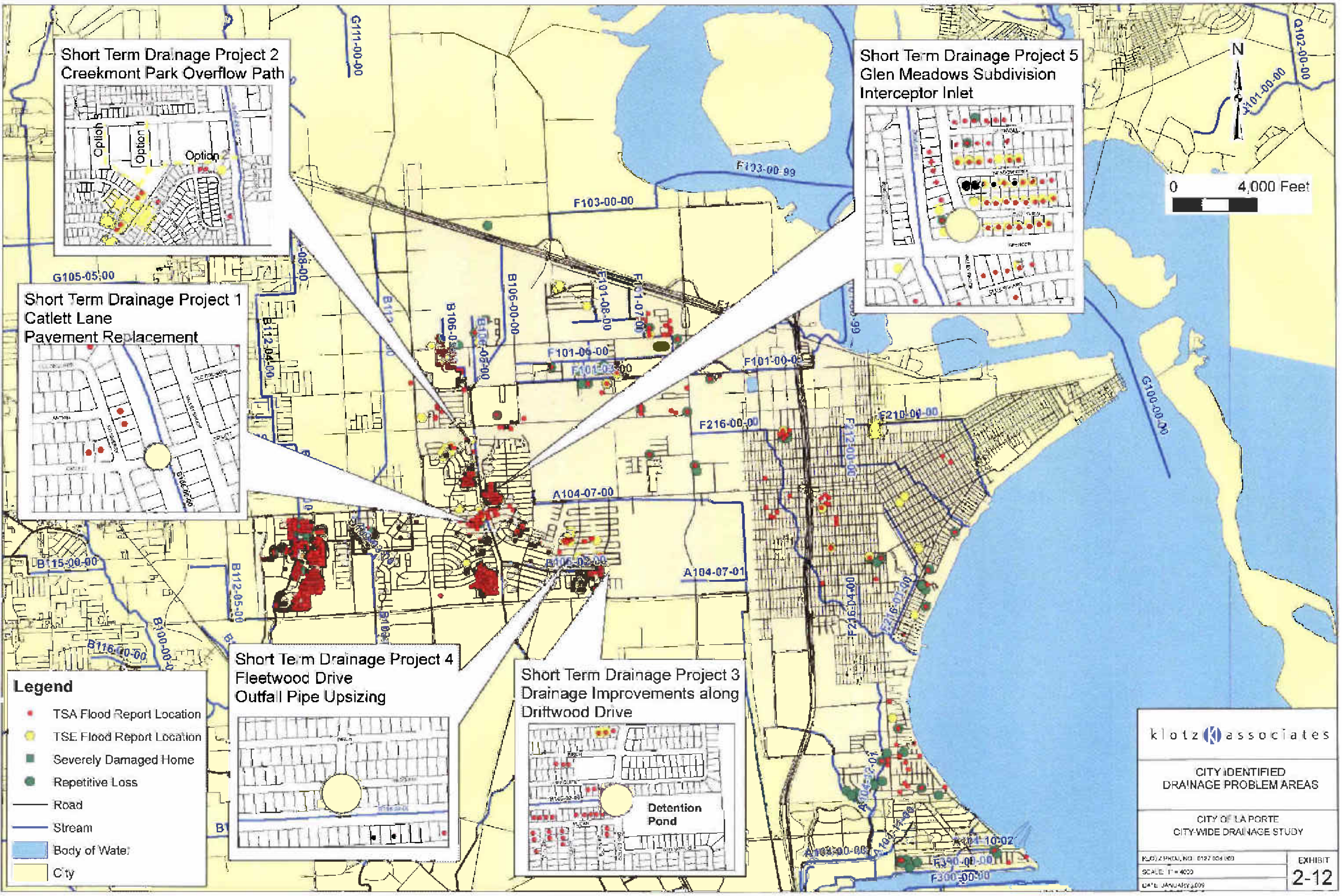
SAN JACINTO & GALVESTON BAY
INTENSITY PROBLEM AREA MAP
WITH WEIGHTING FACTORS

Aerial Source: IGAG 2005
CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.808.000
SCALE: 1" = 2000'
DATE: JANUARY 2009

EXHIBIT
2-11

J:\0127.008.000\06.00 Work Products\CWDS Final Report\Exhibits\Exhibit 2 12 City Identified Drainage Problem Areas



klotz (K) associates

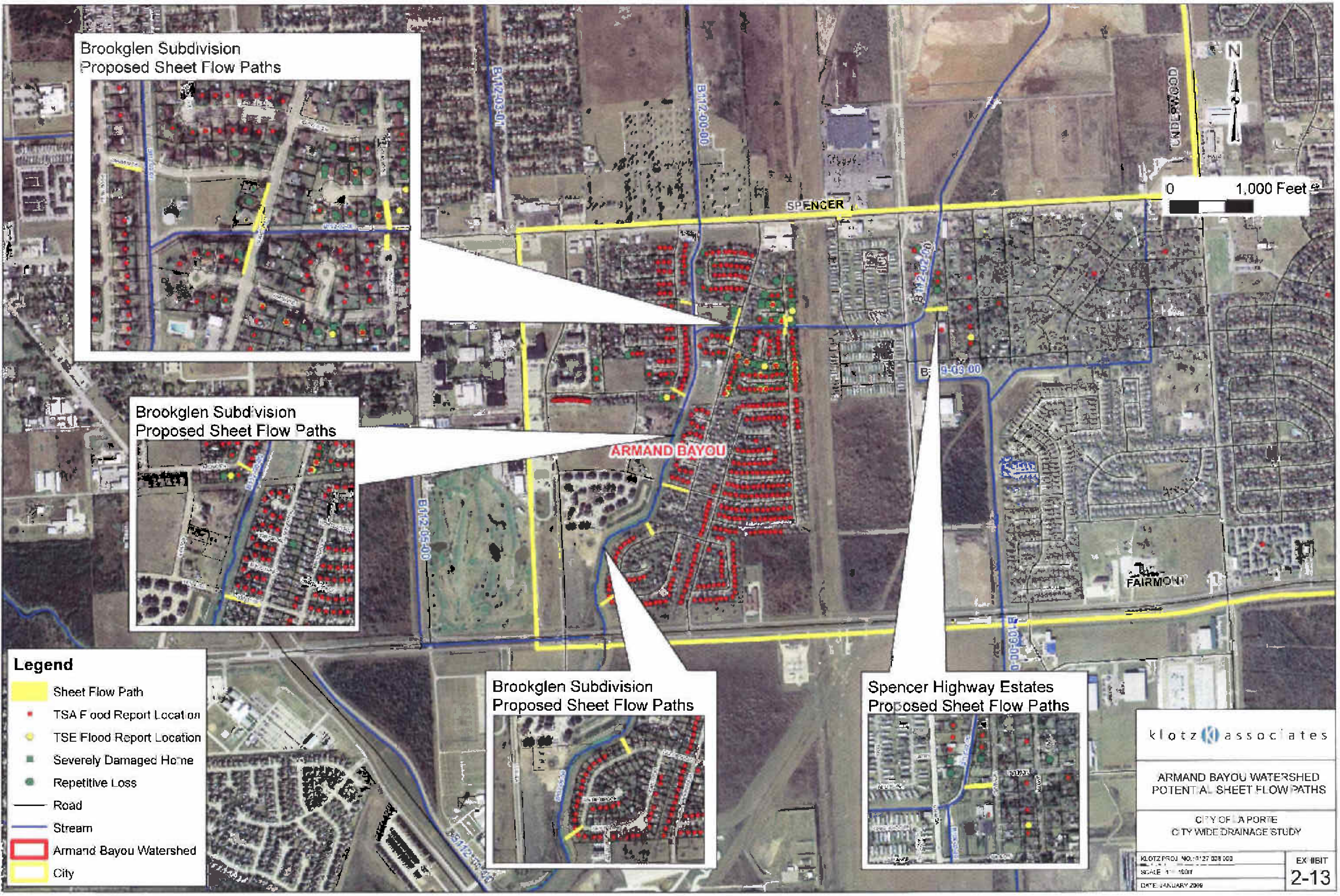
CITY IDENTIFIED
DRAINAGE PROBLEM AREAS

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.008.000
SCALE: 1" = 4000
DATE: JANUARY 2009

EXHIBIT
2-12

J:\0127.008.000\09.00 Work Products\CWDS Final Report\Exhibit 2-13 Armand Bayou Potential Sheet Flow Path.mxd



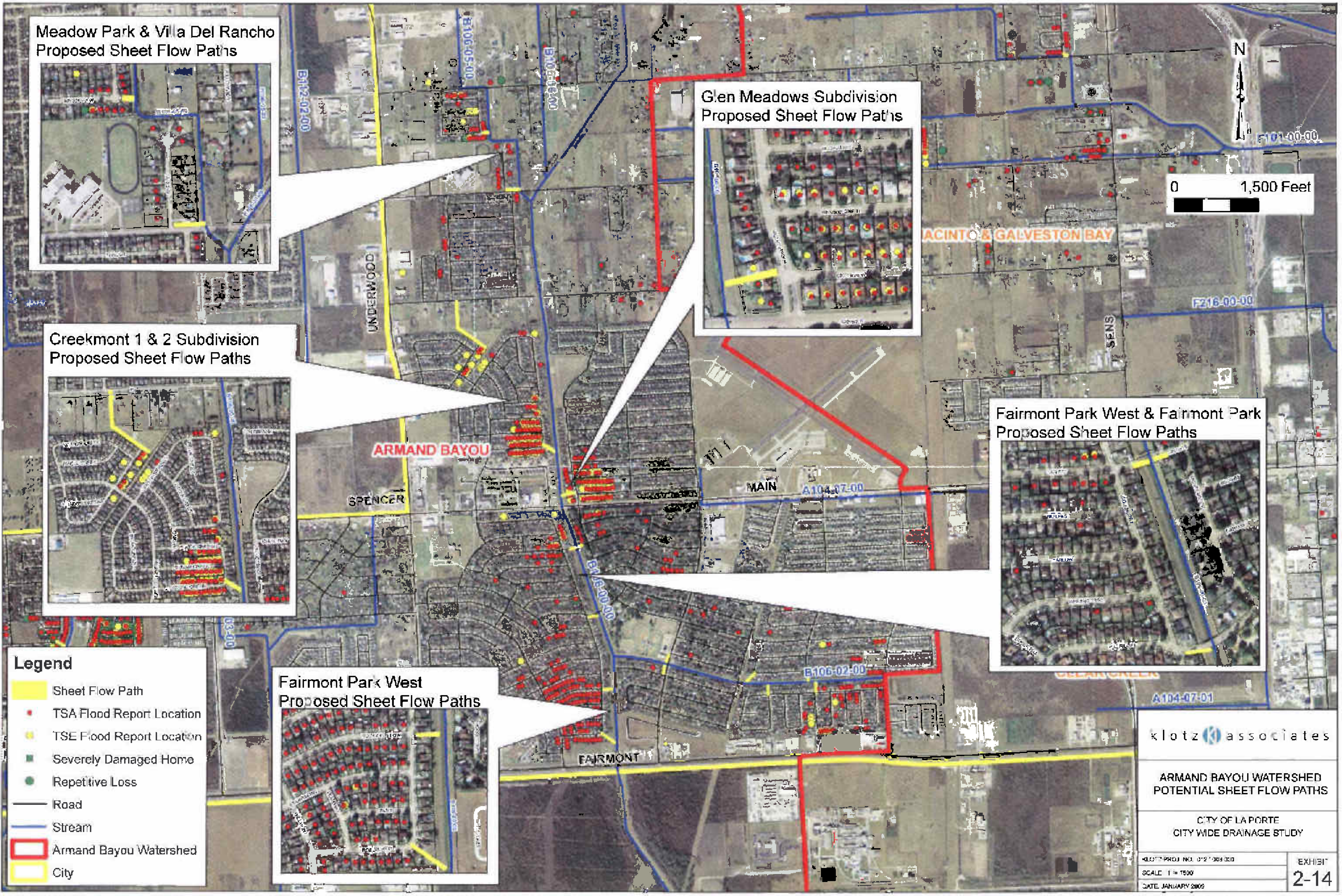
klotz associates

ARMAND BAYOU WATERSHED
POTENTIAL SHEET FLOW PATHS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO.: 0127.008.000
SCALE: 1" = 1000ft
DATE: JANUARY 2009

EXHIBIT
2-13



klotz associates

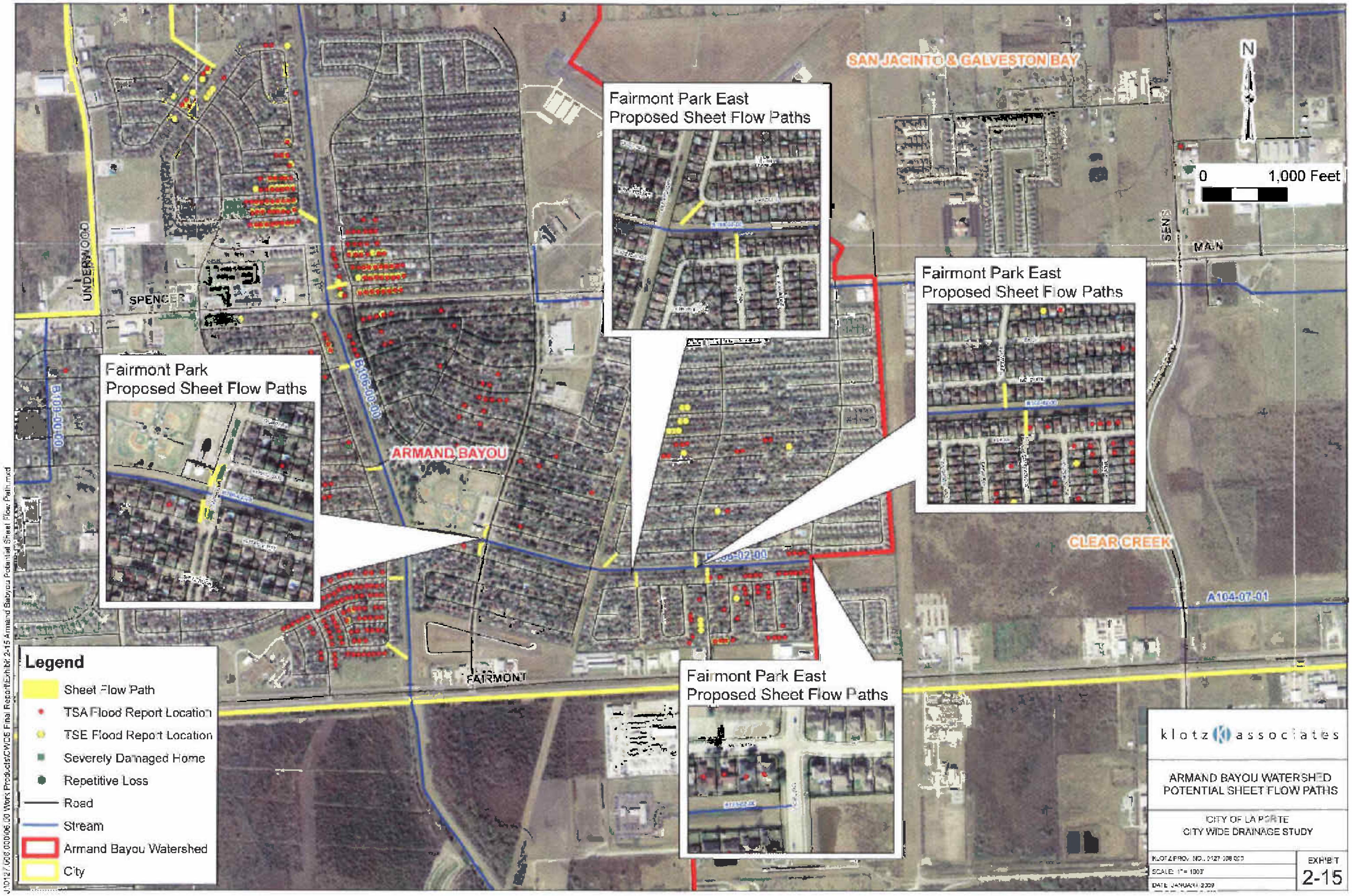
ARMAND BAYOU WATERSHED
POTENTIAL SHEET FLOW PATHS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127-008-000
SCALE: 1" = 1500'
DATE: JANUARY 2009

EXHIBIT
2-14

J:\0127.008.000\06.00 Work Products\CWDS Final Report\Exhibit 2-15 Armand Babyou Potential Sheet Flow Path.mxd



klotz associates

ARMAND BAYOU WATERSHED
POTENTIAL SHEET FLOW PATHS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO.: 0127.008.000
SCALE: 1" = 1000'
DATE: JANUARY 2009

EXHIBIT
2-15

J:\0127.006.000\06.00 Work Products\CWDS Final Report\Exhibits 2-16 SanJacinto & Galveston Potential Sheet Flow Paths.mxd

klotz associates

SAN JACINTO & GALVESTON BAY
POTENTIAL SHEET FLOW PATHS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.006.000
SCALE: 1" = 2000
DATE: JANUARY 2008

EXHIBIT
2-16

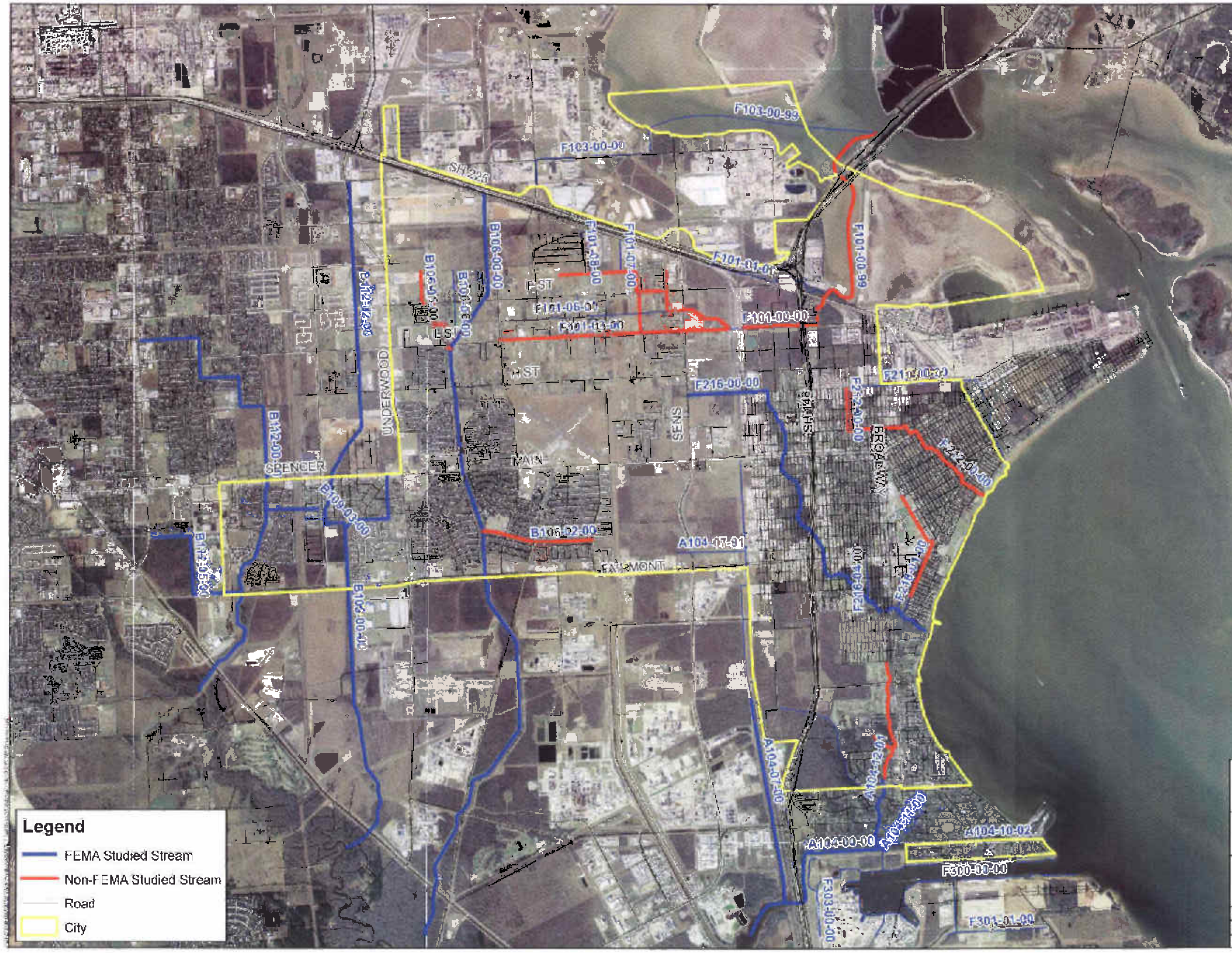
klotz associates

PRIMARY CHANNELS &
MAJOR TRIBUTARIES
Aerial Source: HGAC 2006

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.008.000
SCALE: 1" = 4,000'
DATE: JANUARY 2009

EXHIBIT
3-1



klotz associates

FEMA STREAMS

Aerial Source: HGAC 2006

CITY OF LA PORTE

CITY WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127 505.000

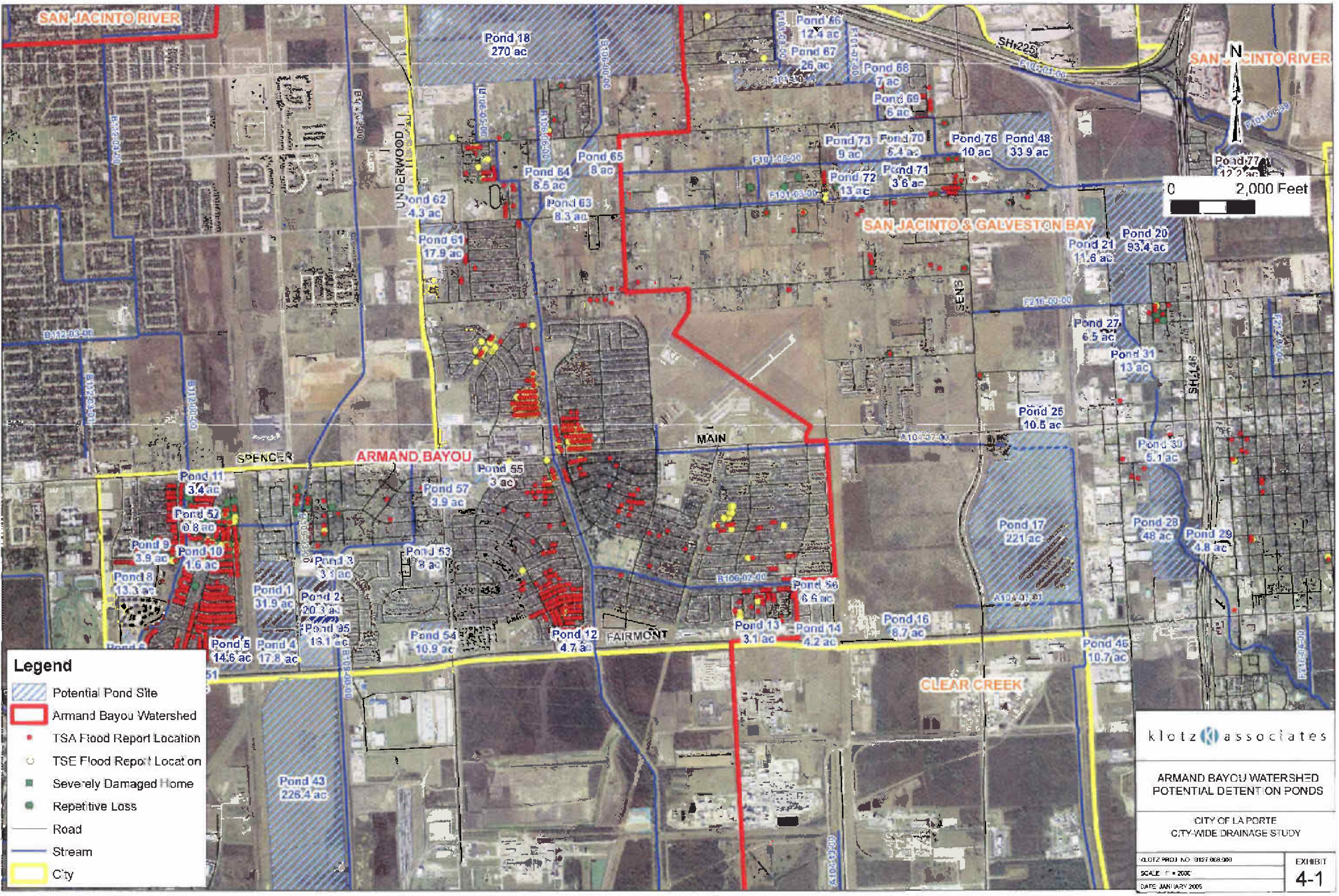
SCALE: 1" = 4,000'

DATE: JANUARY 2009

EXHIBIT

3-2

J:\0127.008.000\06.00 Work Products\CWDS Final Report\Exhibits 4-1 Armand Bayou Potential Detention Ponds



klotz associates

ARMAND BAYOU WATERSHED
POTENTIAL DETENTION PONDS

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.008.000
SCALE: 1" = 2000'
DATE: JANUARY 2005

EXHIBIT
4-1

J:\0127.008.000\06.00 Work Products\CWDS Final Report\Exhibits 4-2 Clear Creek Potential Detention Ponds

Legend

▨	Potential Pond Site
●	TSA Flood Report Location
●	TSE Flood Report Location
■	Severely Damaged Home
●	Repetitive Loss
—	Road
—	Stream
☐	Clear Creek Watershed
☐	City

klotz associates

CLEAR CREEK WATERSHED
POTENTIAL DETENTION PONDS

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO.: 0127.008.000
SCALE: 1" = 2000'
DATE: JANUARY 2009

EXHIBIT
4-2

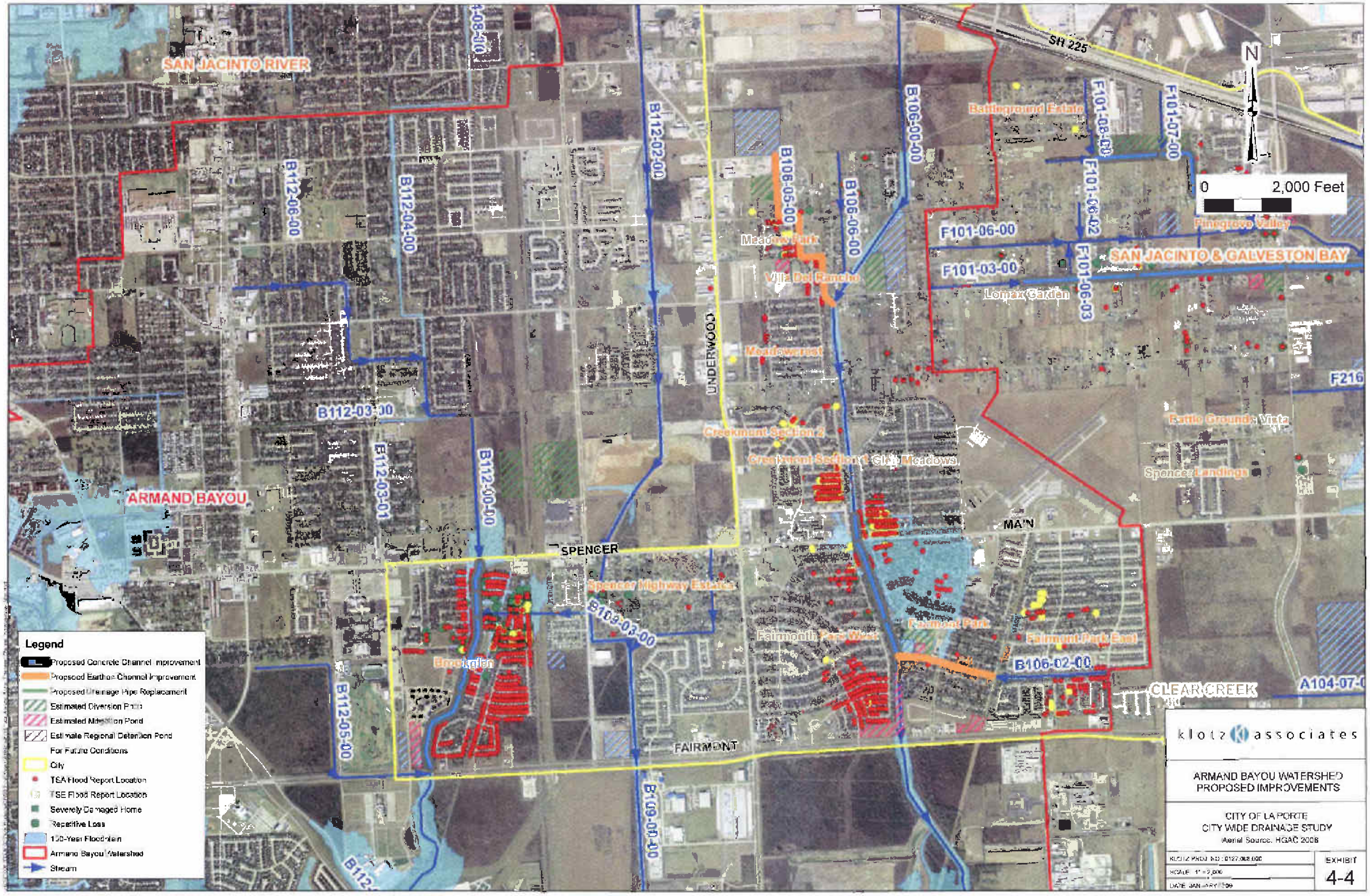
klotz associates

SAN JACINTO & GALVESTON BAY
POTENTIAL DETENTION PONDS

CITY OF LA PORTE
CITY-WIDE DRAINAGE STUDY

KLOTZ PROJ. NO. 0127.008.000
SCALE: 1" = 2000'
DATE: JANUARY 2008

EXHIBIT
4-3



klotz associates

ARMAND BAYOU WATERSHED
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO.: 0127.068.000
SCALE: 1" = 2,000'
DATE: JANUARY 2009

EXHIBIT
4-4

klotz associates

CLEAR CREEK WATERSHED
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 0127.008.002
SCALE: 1" = 2,000
DATE: JANUARY 2006

EXHIBIT
4-5

klotz associates

SAN JACINTO & GALVESTON BAY
PROPOSED IMPROVEMENTS

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 0127.008.000
SCALE: 1" = 2,000'
DATE: OCTOBER 2008

EXHIBIT
4-6

Legend

Ownership and Maintenance

Stream

🟥	City
🟦	HCFCD
▨	HCFCD/City
—	Road
🟨	City

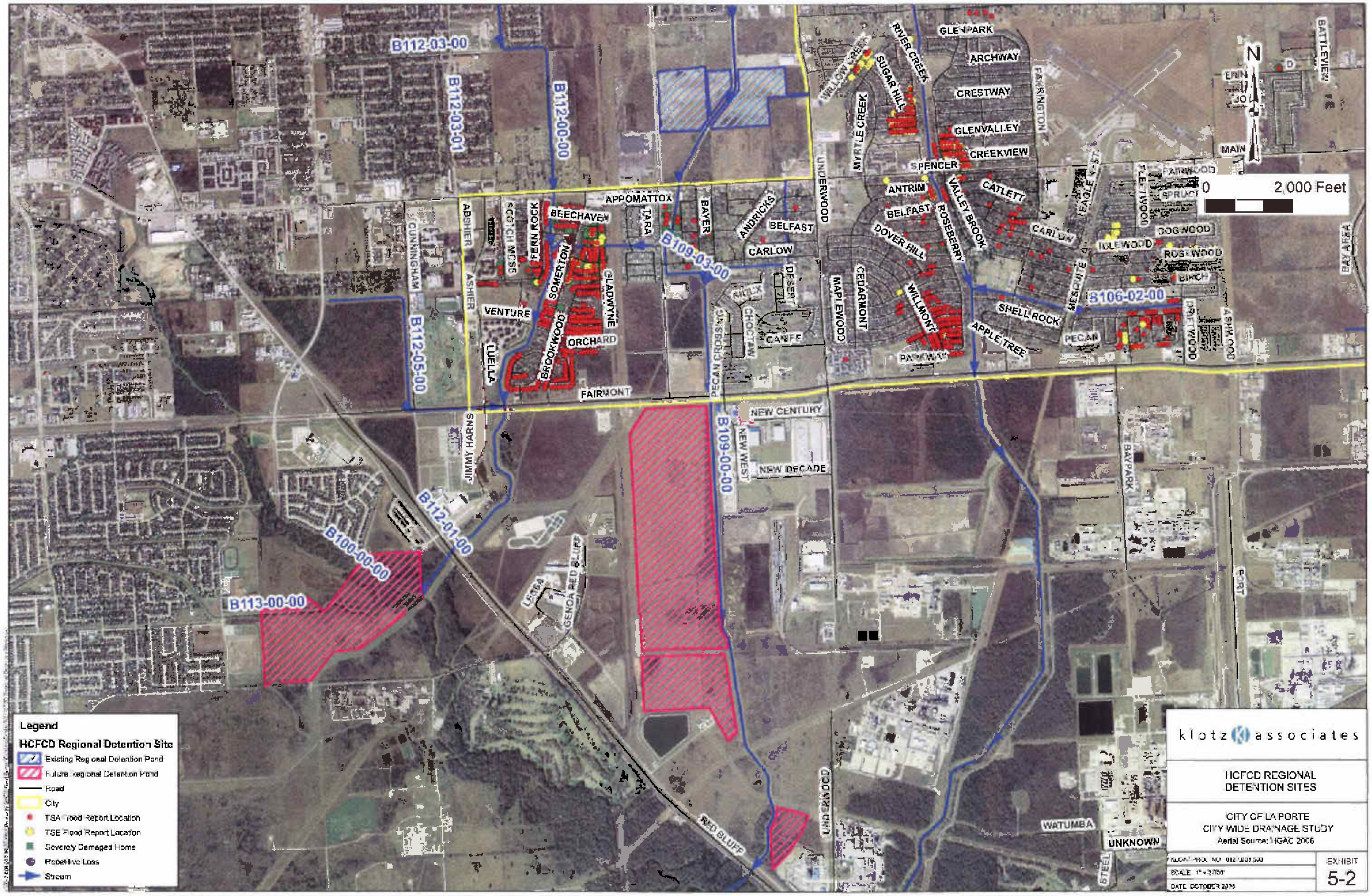
klotz associates

STREAM
OWNERSHIP AND MAINTENANCE

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 0127.006.000
SCALE: 1" = 4,000'
DATE: JANUARY 2007

EXHIBIT
5-1



Legend

HCFCD Regional Detention Site

▨ Existing Regional Detention Pond
▨ Future Regional Detention Pond
— Road
☐ City
● TSA Flood Report Location
● TSE Flood Report Location
■ Severely Damaged Home
● Repetitive Loss
→ Stream

klotz associates

HCFCD REGIONAL
DETENTION SITES

CITY OF LA PORTE
CITY WIDE DRAINAGE STUDY
Aerial Source: HGAC 2006

KLOTZ PROJ. NO. 012.003.000
SCALE 1" = 2,000'
DATE OCTOBER 2[illegible]

EXHIBIT
5-2

FIGURE 3-1
CORRELATION OF UNIT RUNOFF FOR 10 YEAR STORM EVENT

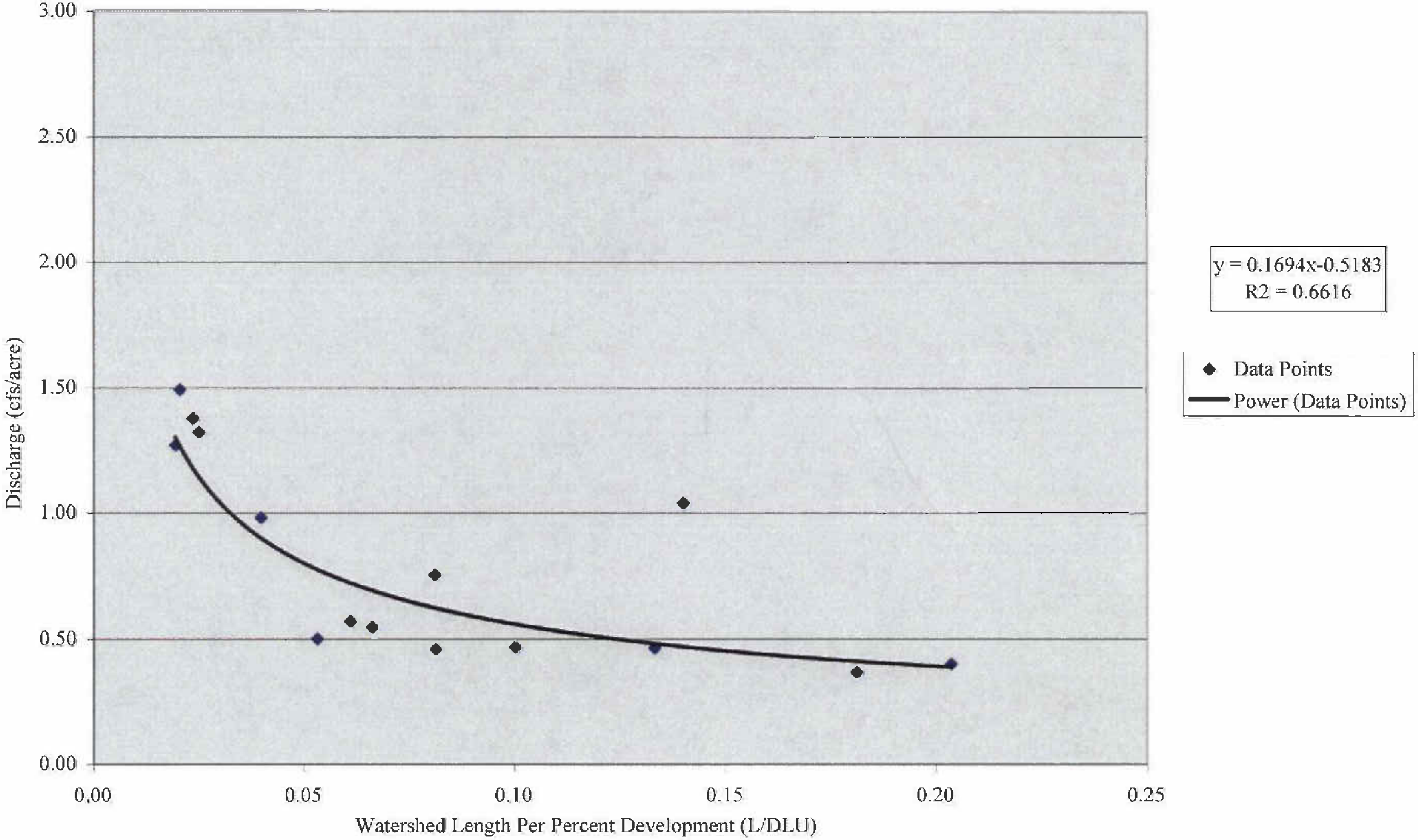


FIGURE 3-2
CORRELATION OF UNIT RUNOFF FOR 50 YEAR STORM EVENT

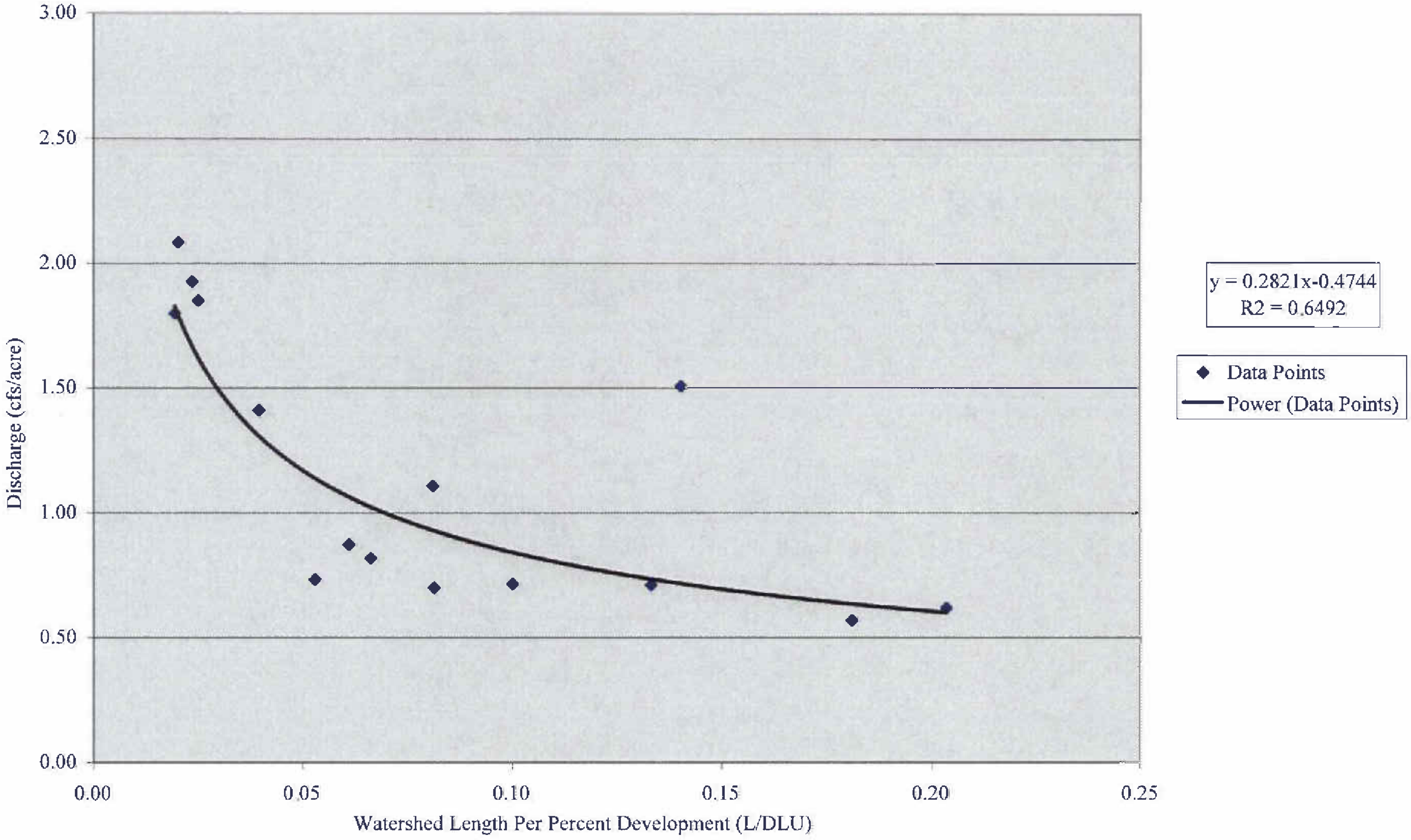
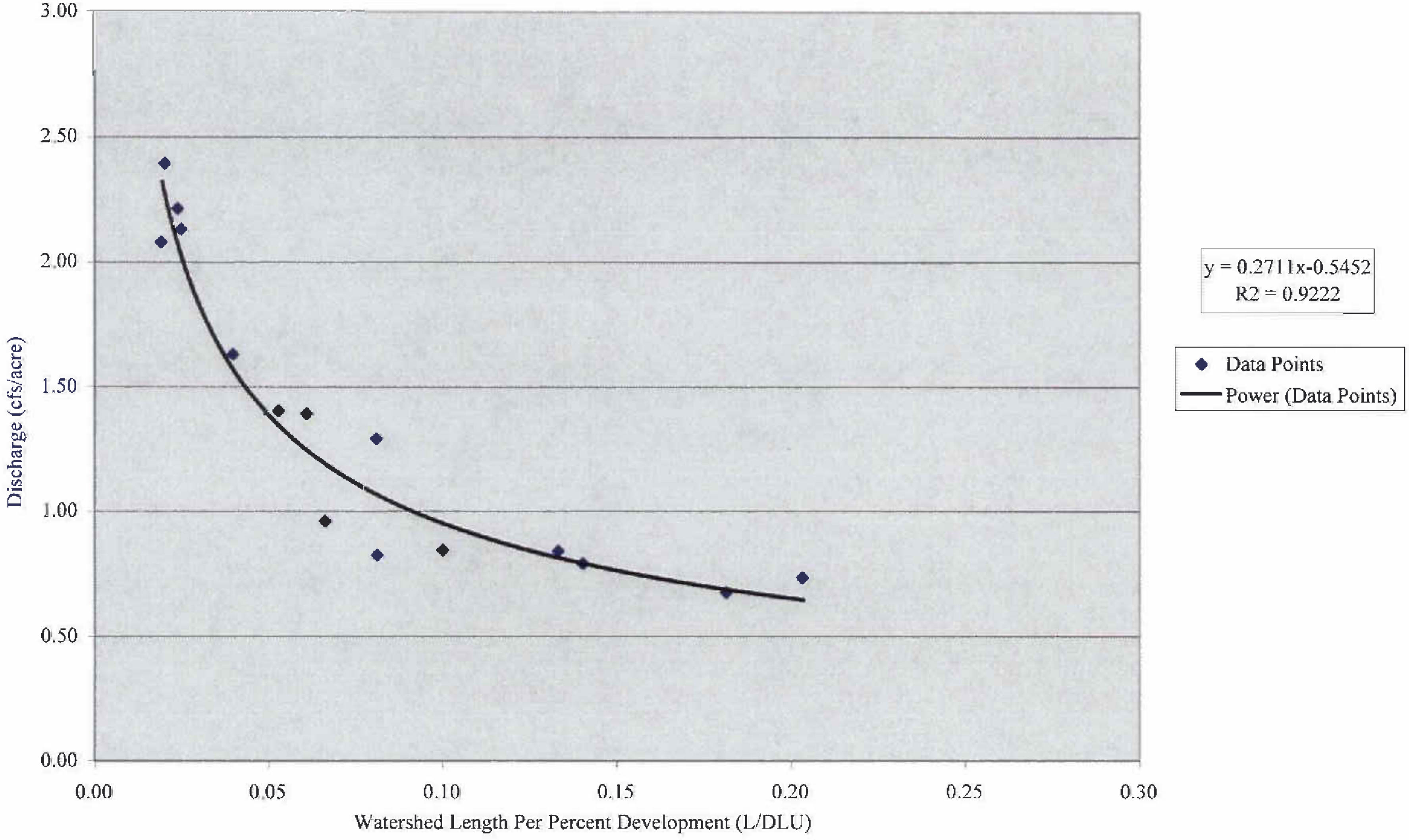


FIGURE 3-3
CORRELATION OF UNIT RUNOFF FOR 100 YEAR STORM EVENT



APPENDIX A
SOURCE DATA REPORTS AND REFERENCES

City of La Porte Master Drainage Plan (December 1982, O'Malley & Clay, Inc.)

Master Drainage Plan and Interim Improvement Recommendations for Unit F101-00-00 (September 1987, Landev Engineers, Inc.)

Clear Creek Watershed Regional Control Plan (February 1992, Dannenbaum Engineering Co.)

Hydrologic and Hydraulic Study for Interconnect of HCFC Unit B112-02-00 to Unit B109-00-00 and HCFC Regional Detention Site Unit B512-01-00 (April 1997, Wilbur Smith Associates, Consulting Engineers and Planners)

Hydraulic Analysis for Little Cedar Bayou Watershed HCFCD Unit F216-00-00 (January 2000, Binkley & Barfield, Inc. Consulting Engineers)

Hydrologic and Hydraulic Analysis of proposed Channel Improvements to Fairmont Ditch (B112-05-00) (January 1989, Dodson & Associates, Inc.)

Master Drainage Plan For The City of La Porte (July 1977, Espey, Huston & Associates, Inc. Engineering & Environmental consultants)

Master Drainage Plan Harris County Flood Control District Unit F101-00-00 (September 1987, Landev Engineers, Inc.)

Clear Creek Regional Drainage Plan (July 1989, Dannenbaum Engineering Co.)

Regional Flood Control Plan for Tributaries to Armand Bayou (May 1999, Klotz Associates, Inc.)

City of La Porte Comprehensive Plan (April 1984, Vernon G. Henry & Associates, Inc.)

Taylor Bayou Watershed Master Drainage Plan; Tax Increment Reinvestment Zone #1 (August 2003, CivilTech Engineering, Inc.)

*Tropical Storm Allison Recovery Project LiDAR QA/QC Galveston Bay, Spring Gully/Goose Creek, Luce Bayou, Cedatr Bayou & Armand Bayou (*Brown & Gay Engineers, Inc.)

Hydraulic Analysis for Sens Road From 300' North of Spencer HWY. to 300' North of Avenue "H" HCPID Pin CI/102/1002/005 VOL 2 (December 2003, Binkley & Barfield, Inc. Consulting Engineers)

Driftwood Drive Drainage Study, City of La Porte Pond to Park Project (June 2004, CivilTech Engineering, Inc.)

Preliminary Analysis for F216-00-00 Linear Detention (November 2004, Binkley & Barfield, Inc. Consulting Engineers)

Drainage Report – Impact and Mitigation Analysis San Jacinto and Galveston Bay Watershed; Proposed Fairmont Parkway Improvements From 16th Street to State HW 146 (December 2005, TSC Engineering Company)

Hydraulic Analysis for Sens Road From 300' North of Spencer HWY. to 300' North of Avenue "H" HCPID Pin CI/102/1002/005; Little Cedar Bayou (F216-00-00) & HCFCD Channel A104-07-00 (February 2005, Binkley & Barfield, Inc. Consulting Engineers)

Hydrologic & Hydraulic Analysis Port Crossing Development (June 2006, Goldston Engineering, Inc.)

APPENDIX B
SOURCES FOR FUNDING INFORMATION

Harris County Flood Control District Partnerships: www.hcfcd.org/partnerships.html

Texas Parks and Wildlife: www.tpwd.state.tx.us/business/grants/

Texas Water Development Board: www.twdb.state.tx.us/assistance/assistance_main.asp

Governor's Division of Emergency Management: www.txdps.state.tx.us/dem/pages/index.htm

Federal Emergency Management Agency: Repetitive Flood Claims Grant Program www.fema.gov/government/grant/rfc/index.shtm

"Financial Assistance." 2005. Texas Water Development Board. March 14, 2007. <http://www.twdb.state.tx.us/assistance/financial/financial_main.asp>

Colley, Jack.. Letter to Emergency Management Colleagues. January 29, 2007. Repetitive Flood Claims Grant Program Guidance for FY 2007. Emailed to firm 3.1.07.

Colley, Jack.. Letter to Emergency Management Colleagues. January 29, 2007. Pre-Disaster Mitigation (PDM) Grant Program Guidance for FY 2007. Downloaded from website 3.14.07. < http://www.txdps.state.tx.us/dem/pages/downloadableforms.htm#hmgpgrants>

"Hazard Mitigation Grant Program (HMGP)." August 30, 2005. Texas Division of Emergency Management. March 14, 2007 <http://www.txdps.state.tx.us/dem/pages/downloadableforms.htm#hmgpgrants>

Texas Statutes Local Government Code Chapter 395.015. Added by Acts 1989, 71st Leg., ch. 1, § 82(a), eff. Aug. 28, 1989. Amended by Acts 2001, 77th Leg., ch. 345, § 3, eff. Sept. 1, 2001. <http://tlo2.tlc.state.tx.us/statutes/lg.toc.htm>

APPENDIX C
Potential Detention Sites

Identification Number	Area (ft^2)	Area (acre)	Volume square (acre-feet)	Volume with SS (acre-feet)
Pond 1	1389368	31.9	159.5	118.8
Pond 2	884527	20.3	101.6	75.7
Pond 3	136547	3.1	15.7	11.7
Pond 4	776445	17.8	89.1	66.4
Pond 5	633733	14.6	72.8	54.2
Pond 6	314673	7.2	36.1	26.9
Pond 7	55348	1.3	6.4	4.7
Pond 8	580338	13.3	66.6	49.6
Pond 9	170270	3.9	19.6	14.6
Pond 10	71651	1.6	8.2	6.1
Pond 11	148457	3.4	17.1	12.7
Pond 12	204209	4.7	23.5	17.5
Pond 13	135920	3.1	15.6	11.6
Pond 14	182605	4.2	21.0	15.6
Pond 16	380896	8.7	43.7	32.6
Pond 17	9625848	221.0	1104.9	823.2
Pond 18	11761833	270.0	1350.1	1005.8
Pond 20	4069052	93.4	467.1	348.0
Pond 21	506749	11.6	58.2	43.3
Pond 25	458129	10.5	52.6	39.2
Pond 27	281953	6.5	32.4	24.1
Pond 28	2089535	48.0	239.9	178.7
Pond 29	209962	4.8	24.1	18.0
Pond 30	221175	5.1	25.4	18.9
Pond 31	564684	13.0	64.8	48.3
Pond 33	1054877	24.2	121.1	90.2
Pond 34	569349	13.1	65.4	48.7
Pond 38	1344930	30.9	154.4	115.0
Pond 39	1928957	44.3	221.4	164.9
Pond 40	787407	18.1	90.4	67.3
Pond 43	9863737	226.4	1132.2	843.5
Pond 46	467361	10.7	53.7	40.0
Pond 48	1477836	33.9	169.7	126.4
Pond 49	27300	0.6	3.2	2.3
Pond 50	123901	2.8	14.2	10.6
Pond 51	129252	3.0	14.9	11.1
Pond 52	37145	0.9	4.3	3.2
Pond 53	346481	8.0	39.8	29.6
Pond 54	476617	10.9	54.7	40.8
Pond 55	130723	3.0	15.0	11.2
Pond 56	286803	6.6	32.9	24.5
Pond 57	170004	3.9	19.5	14.5
Pond 61	781202	17.9	89.7	66.8
Pond 62	187784	4.3	21.6	16.1
Pond 63	363486	8.3	41.7	31.1
Pond 64	372049	8.5	42.7	31.8
Pond 65	350345	8.0	40.2	29.9
Pond 66	540400	12.4	62.1	46.2
Pond 67	1132392	26.0	130.0	96.9
Pond 68	306196	7.0	35.2	26.2

APPENDIX C
Potential Detention Sites

Identification Number	Area (ft^2)	Area (acre)	Volume square (acre-feet)	Volume with SS (acre-feet)
Pond 69	261528	6.0	30.0	22.4
Pond 70	280733	6.4	32.2	24.0
Pond 71	159129	3.7	18.3	13.6
Pond 72	564068	13.0	64.8	48.2
Pond 73	394306	9.1	45.3	33.7
Pond 74	221538	5.1	25.5	19.0
Pond 75	135911	3.1	15.6	11.6
Pond 76	436912	10.0	50.2	37.4
Pond 77	533094	12.2	61.2	45.6
Pond 78	427067	9.8	49.0	36.5
Pond 79	103915	2.4	12.0	8.9
Pond 80	29140	0.7	3.4	2.5
Pond 81	181381	4.2	20.8	15.5
Pond 82	18516	0.4	2.2	1.6
Pond 83	123037	2.8	14.1	10.5
Pond 84	30119	0.7	3.5	2.6
Pond 85	103245	2.4	11.9	8.8
Pond 86	161328	3.7	18.5	13.8
Pond 87	91992	2.1	10.6	7.9
Pond 88	55094	1.3	6.3	4.7
Pond 89	196168	4.5	22.5	16.8
Pond 91	97307	2.2	11.2	8.3
Pond 92	201082	4.6	23.1	17.2
Pond 93	245530	5.6	28.2	21.0
Pond 94	141337	3.2	16.2	12.1
Pond 95	703239	16.1	80.7	60.1

Volume is an approximation based on a 5 foot pond with side slope of 3:1

Appendix D

Storm Sewer Upgrade Identify in Letter Report No. 2

Appendix E

Data CD
(To be provided upon final delivery)

TABLE 2
CONCEPTUAL COST ESTIMATE
BROOKGLEN SUBDIVISION

OPTION	DESCRIPTION	UNIT	UNIT COST	AMOUNT	TOTAL COST
1	Upgrade Storm Sewer to 48" @ Gladwyne	LF	$ 210.00	400	$ 84,000.00
2	Upgrade Storm Sewer to 48" @ Bandridge	LF	$ 210.00	600	$ 126,000.00
3	Concrete Flume	SY	$ 40.00	540	$ 21,600.00
4	Excavation	CY	$ 10.00	180	$ 1,800.00
5	Property Buy Outs (House) **	EA	$ 135,000.00	2	$ 270,000.00

** Average Value per House 2 SAMPLES

Cost does not include easement costs if required

TABLE 3
CONCEPTUAL COST ESTIMATE
CREEKMONT SUBDIVISION

OPTION	DESCRIPTION	UNIT	UNIT COST	AMOUNT	TOTAL COST
1	Upgrade Storm Sewer to 48"	LF	$ 210.00	250	$ 52,500.00
2	Concrete Flume	SY	$ 40.00	1,111	$ 44,440.00
3	Excavation	CY	$ 10.00	370	$ 3,700.00
4	Property Buy Outs (House) **	EA	$ 135,000.00	2	$ 270,000.00

** Average Value per House 2 SAMPLES

Cost does not include easement costs if required

TABLE 4
CONCEPTUAL COST ESTIMATE
GLEN MEADOWS SUBDIVISION

OPTION	DESCRIPTION	UNIT	UNIT COST	AMOUNT	TOTAL COST
1	Upgrade Storm Sewer to 48"	LF	$ 210.00	180	$ 37,800.00
2	Concrete Flume	SY	$ 40.00	800	$ 32,000.00
3	Excavation	CY	$ 10.00	270	$ 2,700.00
4	Construct New 48" Stm Swr	SY	$ 210.00	400	$ 84,000.00
5	Property Buy Outs (House) **	EA	$ 135,000.00	2	$ 270,000.00

** Average Value per House 2 SAMPLES

Cost does not include easement costs if required

TABLE 5
CONCEPTUAL COST ESTIMATE
FAIRMONT PARK EAST SUBDIVISION

OPTION	DESCRIPTION	UNIT	UNIT COST	AMOUNT	TOTAL COST
1	Concrete Flume	SY	$ 40.00	540	$ 21,600.00
2	Excavation	CY	$ 5.00	180	$ 900.00
Reconstruct Roadway up to Linwood Street					
3	Upgrade Storm Sewer to 72"	LF	$ 330.00	2,100	$ 693,000.00
	Upgrade Storm Sewer on Side Streets to 48"	LF	$ 210.00	4,200	$ 882,000.00
	Inlets	EA	$ 2,000.00	26	$ 52,000.00
	Concrete Pavement	SY	$ 40.00	19,600	$ 784,000.00
	Water, Sanitary and Private Utility Relocation	LF	$ 30.00	2,100	$ 63,000.00
Reconstruct Roadway up to Main Street					
4	Upgrade Storm Sewer to 72"	LF	$ 330.00	3,300	$ 1,089,000.00
	Upgrade Storm Sewer on Side Streets to 48"	LF	$ 210.00	6,600	$ 1,386,000.00
	Concrete Pavement	SY	$ 40.00	30,800	$ 1,232,000.00
	Inlets	EA	$ 2,000.00	44	$ 88,000.00
	Water, Sanitary and Private Utility Relocation	LF	$ 30.00	3,300	$ 99,000.00
5	Construct New Parallel 60" Stm Swr at Outfall	SY	$ 220.00	120	$ 26,400.00
6	Property Buy Outs (House) **	EA	$ 135,000.00	1	$ 135,000.00
7	Detention pond excavation	CY	$ 8.00	1,613	$ 12,904.00

** Average Value per House 2 SAMPLES

Cost does not include easement costs if required