9. DRAINAGE

One of the consequences of land use is the alteration of surface water runoff and drainage. Runoff from rainstorms is a natural hydrologic process. Urban development both affects and is affected by this process. Some land areas, such as floodplains along streams, are more prone to flooding than are others. Urban development in these areas should be avoided or be designed so that the risk of damage by flooding, including loss of life, is limited. Conversely, urban development increases runoff by increasing the amount of impervious surface within a drainage basin. This increased impervious area results in higher rates of runoff, and thus larger flood flows downstream.

As in most developed areas, flooding has been a problem in Benbrook in the past. Large floods occurred on Mary's Creek in April 1922 and May 1949. The creek reportedly is named after Mary Criswell, who lost her life in a flash flood. Flooding along Timber Creek was common until the City constructed a new concrete channel in 1982. Plantation East Creek flooded in August 1974, July 1975, May 1989, March 1990, and May 1990, but large storms subsequently have been contained by the new channel and culvert. More recently, heavy thunderstorms in June 2004 caused flooding along Plantation West Creek in North Benbrook.

Prior to 1990, only one previous comprehensive drainage study had been prepared for the City of Benbrook. In 1965, the City retained Gregory, Knowlton & Ratliff, consulting engineers, to evaluate proposed drainage improvements for the City. An $886,000 system of drainage improvements was proposed, but the bond election to fund these improvements was defeated by the voters in 1969. Some of these projects ultimately were built later at a much higher cost. The remainder of this 1965 report is now outdated, since the City has subsequently increased in population four-fold and the engineering criteria used then were less stringent than are required today.

From 1991 to 1994, the City's engineering firm (Teague Nall and Perkins, Inc.) prepared a comprehensive update with different watershed being studied during different fiscal years. The results of that study identified numerous projects totaling over $21 million that were incorporated into the Drainage element of the Comprehensive Plan. The projects included in the Drainage Plan were also used to develop projects for the Capital Improvement program and to assure that private development was incorporating the necessary drainage facilities. In 2004 and 2005, the Drainage Plan was updated to reflect more recent construction costs and to reflect those projects that had been built since the mid 1990s. The Plan has also been revised in some cases to reflect a change in philosophy by the City and U.S. Army Corps of Engineers to use natural channels and gabion-lined channels instead of concrete lined channels.

This Drainage element of the Comprehensive Plan seeks to minimize damage caused by flooding by identifying areas of higher flooding risk, establishing standards for protecting new development from causing or suffering from flooding, and to identify drainage improvement projects to better protect existing residents from flood events. The goal of the drainage improvements is to remove structures from the 100-year floodplain and to minimize localized flooding that may cause property damage.

9.1 DRAINAGE PROBLEMS

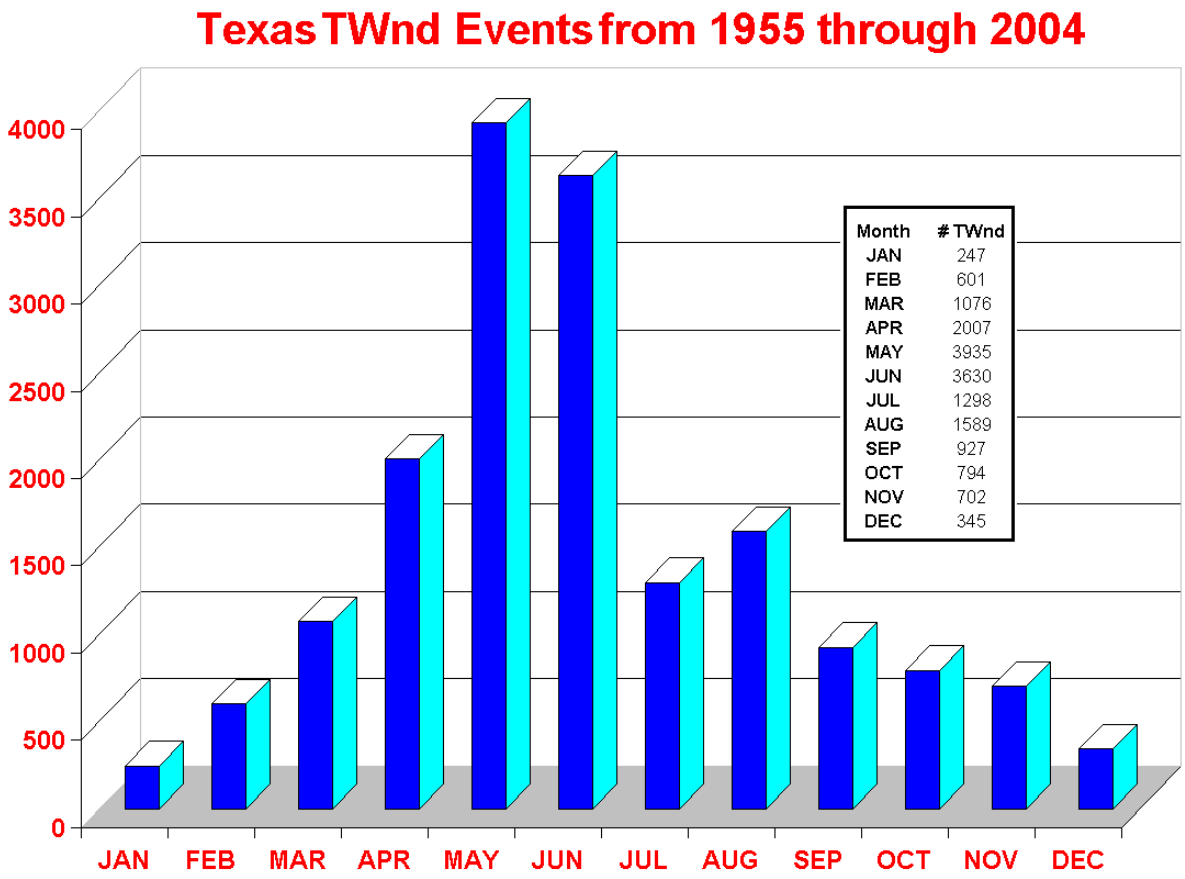
9.1.1 Rainfall

Benbrook's climate is classified as temperate. There is an official weather station at Benbrook Dam (NWS Station 410691) that has collected precipitation data since 1950 and temperature data since 1953. Normal annual rainfall is approximately 34.01 inches (based on 1971-2000). The wettest

year on record was 1991, when 55.42 inches of rain was recorded. The driest year was 1954 when only 17.43 inches fell. Recent monthly rainfall for Benbrook Dam is presented in Table 9.1.

Most rainfall occurs during frontal-type storms or thunderstorms. Most of these storms occur during the Spring and Summer, but thunderstorms can occur at any time of the year. The maximum rainfall in a 24-hour period was 9.57 inches in September 1932. An average thunderstorm event lasts 7.5 hours and drops 0.60 inches of rain. A graph showing the distribution of severe thunderstorms by month in Texas is shown in Figure 9.1.

Figure 9.1



Because most rain falls within a relatively short period of time, annual or monthly precipitation is not indicative of the type or magnitude of flooding that may occur. Therefore, individual storms are classified by the intensity, duration, and probability of occurrence. The probability of occurrence is often presented as a recurrence interval of a given number of years. For example, a storm with a 20 percent probability of occurring in a given year is called a 5-year storm, while a storm with only a one percent probability of occurring in a given year is called a 100-year storm. It is a common misunderstanding, however, that only one 100-year storm may be expected in a 100-year period. In fact, there is a 37 percent chance that there will not be a 100-year storm in any given 100-year period, a 37 percent chance that there will be only one, and a 26 percent chance that there will be more than one 100-year storm in any given 100 year period.

Table 9.1
Official Monthly Rainfall Records
Benbrook Dam (in inches)

Month	Normal	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
Jan	1.70	1.25	2.03	0.69	0.84	2.50	1.42	2.06	2.87	3.96	0.41	2.05	3.62
Feb	2.19	1.22	0.48	0.47	7.46	3.47	0.00	1.42	4.89	1.15	3.68	4.19	2.26
Mar	2.67	2.48	4.47	1.48	2.31	5.26	2.89	3.18	5.92	6.72	1.12	1.55	2.37
Apr	3.17	3.53	4.02	2.64	5.02	0.81	2.34	1.55	0.55	7.05	1.35	3.75	0.18
May	4.58	5.61	6.19	0.85	5.79	1.81	8.54	2.39	3.36	5.64	1.98	3.85	2.81
Jun	3.56	0.78	2.97	2.92	3.76	0.92	2.21	8.86	1.70	1.24	3.90	10.96	1.20
Jul	2.29	2.52	1.78	2.91	2.08	0.11	0.76	0.02	2.57	2.33	0.21	2.36	3.28
Aug	2.03	0.99	5.11	2.46	2.62	1.66	0.00	0.00	4.06	3.32	2.47	2.77	
Sep	2.86	4.17	5.03	3.21	0.62	1.37	2.45	0.00	3.05	1.52	5.31	0.13	
Oct	4.14	6.85	0.60	3.21	5.68	5.89	1.95	5.07	1.62	5.90	1.28	4.38	
Nov	2.35	5.04	0.85	6.71	1.50	4.49	0.38	6.00	2.04	0.60	1.85	8.65	
Dec	2.47	2.61	1.85	0.22	6.33	3.75	2.09	1.94	2.67	4.19	1.01	0.57	
Total	34.01	37.05	35.38	27.77	44.01	32.04	25.03	32.49	35.30	43.62	24.57	45.21	

Source: National Weather Service, National Climatic Data Center

The total rainfall expected for various storm events is presented in Table 9.2. These rainfall figures are based on records from Fort Worth from the 1890s to the present and are used to represent values for Tarrant County.

9.1.2 Runoff

Once rainfall reaches the ground, a portion infiltrates into the soil and vegetation while the remainder runs off into natural and man-made drainage-ways. The amount of water that runs off is a function of the duration and intensity of rainfall, the size of the contributing drainage area, the amount and type of pervious and impervious surface, and the length of time since the last rainfall.

Runoff and stream flow is generally measured in cubic feet per second. A cubic foot is equivalent to 7.48 gallons and a cubic foot per second is equivalent to 450 gallons per minute.

For small watersheds (i.e. less than 200 acres), the most common method of determining runoff is the Rational Method, expressed by the equation:

$$Q = CIA$$

where Q = storm flow in cubic feet per second (cfs)
C =runoff coefficient (ratio of runoff to rainfall)
I = rainfall intensity in inches per hour
A = drainage area in acres.

The runoff coefficient ranges from 0.3 in flat grassy areas to 0.90 in commercial areas with large areas of pavement. Table 9.3 presents the adopted runoff coefficient values for land uses typically found in Benbrook.

For drainage areas larger than 200 acres, the rational method is less useful. For these larger areas, runoff is calculated using various Soil Conservation Service or Corps of Engineers methods. The Federal Emergency Management Agency has calculated various flood flows for the major creeks in Benbrook, as shown in Table 9.4.

9.1.3 Drainage Areas

Benbrook has rolling topography with elevations ranging from a low of 580 feet above mean sea level to a high of 865 feet msl. To assist in analysis, the City has been divided into seven major watersheds as shown in Figure 9.2. The watersheds are drained by the following streams:

Watershed A	Mary's Creek
Watershed B	Walnut Creek
Watershed C	Clear Fork Trinity River
Watershed D	Dutch Branch
Watershed E	Benbrook Lake
Watershed F	Benbrook Lake
Watershed G	Benbrook Lake

Each of these watersheds is further divided into drainage areas and subdrainage areas.

Table 9.2
MAGNITUDE OF STORM EVENTS
Tarrant County, Texas
(in inches)

Storm Duration	Return Frequency (years)					
	2	5	10	25	50	100
0.5 hours	1.32	1.70	1.94	2.30	2.58	2.88
1 hour	1.65	2.19	2.52	3.02	3.40	3.84
2 hours	2.00	2.68	3.10	3.76	4.26	4.84
6 hours	2.52	3.42	4.08	4.98	5.70	6.54
12 hours	2.88	3.96	4.80	5.76	6.72	7.68
24 hours	3.36	4.56	5.52	6.72	7.92	9.12

Source: NCTCOG, 2005. Design Manual for Site Development, Appendix A.

Table 9.3
RUNOFF COEFFICIENTS "C"

Land Use	Coefficient
Open Space	0.30
Single Family Residential	0.50
Apartments	0.75
Industrial	0.70
Commercial	0.80-0.90

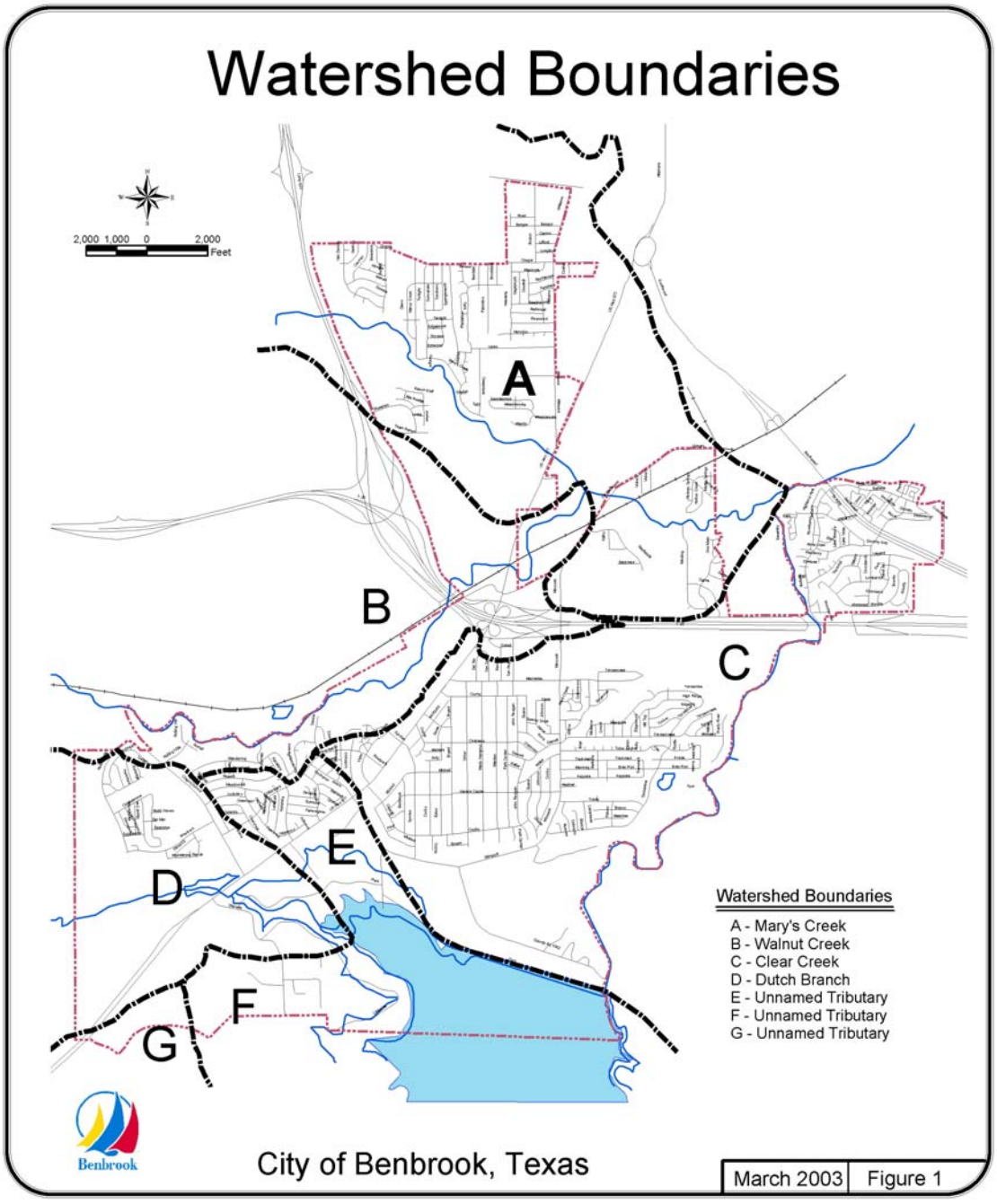
Table 9.4
SUMMARY OF 100-YEAR FLOOD FLOWS
(in cubic feet per second)

Stream and Location	Flow
Clear Fork Trinity River Downstream of confluence of Mary's Creek	25,400
Dutch Branch at Benbrook Lake	10,900
Mary's Creek at confluence with Clear Fork	42,800
Plantation East Creek 500 feet upstream of confluence with Mary's Creek	3,300
Plantation West Creek (MSC-1A) At confluence with Mary's Creek	2,630
Stream CF-5 at confluence with old Clear Fork streambed	6,800
Timber Creek Upstream of confluence with Clear Fork	5,590
Walnut Creek 2 500 feet upstream of confluence with Mary's Creek	12,600
Willow Bend Creek At confluence with Mary's Creek	2,535

Source: FEMA, 2000. Flood Insurance Study for Tarrant County and Incorporated Areas.

Specific drainage plans are being prepared for each watershed and are included in Section 9.4 of this Drainage element. As new development is constructed, that development must accommodate the designated drainage plan, or devise an alternate plan with similar performance. Drainage requirements in previously developed areas have been included in the Capital Improvements Program for future funding and construction by the City.

Figure 9.2 Watershed Boundaries page 1



9.1.4 Floodplains

Floodplains in Benbrook have been identified by the Federal Emergency Management Agency (FEMA) since May 1974 and the City entered the National Flood Insurance Program in July 1979. FEMA delineates the 100-year floodplain for flood insurance purposes, but also provides information on the 10-year, 50-year and 500-year floods as well. The 100-year floodplains in Benbrook are shown in Figure 3.6.

Natural floodplains have developed over many centuries as a result of the types and frequencies of floods which have occurred. Streams typically will scour a channel to a capacity of a 2-year storm, with an adjacent larger floodplain which will carry a 10-year to 100-year flood on a more infrequent basis. Problems occur when urban development is allowed to encroach into the floodplain. Most people have short concepts of time, and are often surprised at the magnitude of flooding which may occur in an area on a relatively infrequent basis. The second problem occurs when urban development in a watershed increases runoff, by increasing the amount of impervious area (rooftops, streets, etc.) This increases the quantity of water in a flood and the speed it travels.

There are approximately 1,561 acres of 100-year floodplain in Benbrook, including 944 homes and other buildings. Based on average household size, it is estimated that about 2,171 residents of Benbrook are at risk of flooding by the 100-year flood.

Since 1979, the City has adopted increasingly stringent regulations over new development within floodplains. The City joined the Community Rating System in 1990 to obtain credit for the additional requirements that are being used. New residences or buildings are not permitted within the floodplain unless the lowest floor is raised two-feet above the 100-year flood level. Since 2002, no new residential lots are allowed to be created in the 100-year floodplain. Unfortunately, almost all of the 944 homes and buildings at risk were constructed prior to these newer regulations. The City is attempting to correct flooding in these areas through implementation of capital projects included in this Drainage element of the Comprehensive Plan.

9.1.5 Runoff Water Quality

Recently, the issue of water quality in storm water has become more important. When storm water flows across the ground, it picks up and transports a number of pollutants, including sediment, oil and grease from roadways, fertilizers and pesticides from lawns, and other contaminants from various sources. For the past several decades, water pollution control has focused on 'point sources', such as sewage treatment plants and industrial waste treatment plants. In recent years, it has become evident that 'nonpoint source pollution' from runoff is now much more of a problem to water quality than point sources. As a result, the U.S. Environmental Protection Agency is implementing regulations designed to improve the quality of storm water.

In October 1992, the EPA promulgated storm water permit requirements for certain industrial and construction activities to protect storm water quality. Cities with populations greater than 100,000 (known as Phase 1 cities) also were required to implement certain storm water quality management programs. Benbrook participated with the North Central Texas Council of Governments to develop regionwide storm water programs. Any new construction covering more than five acres is required to obtain a storm water permit from the U.S. EPA. The Texas Commission on Environmental Quality is expected to issue their General Permit for municipal storm water discharges for Phase 2 cities in early 2006. The City prepared a Storm Water Management Plan in 2003 in anticipation of this permit.

There is little data on water quality in streams in Benbrook. The Tarrant County Water Control and Improvement District maintains three monitoring stations in Benbrook Lake. All samples collected have been within normal ranges. The nearest continuous automated river monitoring station is near downtown Fort Worth and is not representative of conditions in Benbrook. There are few known problems with water quality in streams and waterways in Benbrook.

The U.S. Environmental Protection Agency has identified the pollutants of concern to be biochemical oxygen demand (BOD), sediment (or total suspended solids), pathogens, oil and grease and any pollutant that has been identified as causing impairment of the receiving waters for their designated uses. Sampling data from the NCTCOG's stormwater program indicates the following parameters to be of concern for various land use types:

Land Use Type	Parameter
Residential	Arsenic
	Chlordane
	Diazinon
	Chemical oxygen demand
	Fecal coliforms
	Fecal streptococcus
	Total and dissolved Phosphorus
	Total and Kjeldahl nitrogen
Commercial	Fecal coliform
	Fecal streptococci
	Lead
	Diazinon
	Oil and grease
	Arsenic
	Chromium
Industrial	Cadmium
	Chloride
	Chromium
	Copper
	Lead
	Mercury
	Nickel
	Zinc
	Oil and grease
	Phenols
	Sulfates
	Total suspended solids

The City is continuing to work with various agencies to identify existing water quality in Benbrook streams and threats to that quality. Among the agencies that have been contacted are the Benbrook Water Authority, City of Fort Worth, Tarrant County Health Department, Tarrant Regional Water District, Texas Commission on Environmental Quality, U.S. Army Corps of Engineers and U.S. Environmental Protection Agency.

9.2 Drainage Standards and Regulations

9.2.1 City of Benbrook

A. Comprehensive Plan: Drainage is addressed in various parts of the Comprehensive Plan in addition to this Drainage element. Protection from flooding is specifically addressed in Principle 1.6 and its two related strategies:

> **PRINCIPLE 1.6: The City should protect homes and businesses from flooding.**
>
> > **Principle 1.6.1: The City should restrict and regulate development within floodways and floodplains to minimize future flooding.**
> >
> > **Principle 1.6.2: Existing development within floodprone areas should be relocated or protected to the degree practical.**
> >
> > Principle 1.6.3: Existing development along stream channels should be periodically evaluated for potential structural damage from stream bank erosion and mitigation actions explored.

Floodprone areas are identified on Figure 3.6. Floodways are designated for no development, while the floodway fringe is delineated to show those areas which require floodproofing or flood protection. In 2002, the City's Subdivision Ordinance was revised to prohibit the creation of new residential lots in the floodway fringe as well.

Finally, Principle 7.1.1 of the Comprehensive Plan states:

> **Principle 7.1.1: The City should plan for future street and drainage needs and formulate the mechanism to construct them.**

This is accomplished in the Capital Improvements Program, which is included as Section 17 of the Comprehensive Plan. Drainage projects to reduce flooding are included in the Capital Improvements Program and in future funding cycles.

B. Floodplain Management Regulations: The City has adopted Flood Hazard Protection regulations (Chapter 15.40 of the Benbrook Municipal Code) that establish policies and procedures for development within flood hazard areas, codified as Chapter 15.40 of the Benbrook Municipal Code. This ordinance meets or exceeds the requirements established by the Federal Emergency Management Agency.

The Flood Hazard Protection ordinance adopts the Federal Flood Insurance Maps for regulatory purposes and establishes standards for construction within these areas. The 100-year floodplain is divided into two zones (see Figure 9.3). The floodway is the area that must be kept clear of obstructions and encroachments so that the 100-year storm flow can be conveyed with no more than a one-foot rise over predevelopment conditions. The floodway fringe is that portion of the floodplain that could be developed (according to FEMA) if adequate floodproofing is provided.

Development within the floodway is generally prohibited unless it can be demonstrated by a hydraulic engineering study that no adverse impacts will occur. In subdivisions that existed prior to 2002, residential development within the floodway fringe is only permitted by special authorization and the minimum finished floor elevation must be at least two feet above the base flood elevation. Non-residential development must be elevated two feet above the base flood elevation, or have the walls floodproofed below the base flood elevation. Builders in these areas must certify this elevation on an elevation certificate, which is kept on file at the City. In addition, to the elevation requirements, foundations must be protected from erosion by the 100-year flood event.

The Flood Hazard Protection regulations also prohibit dumping of material into streams or creeks. Residents living adjacent to creeks will be notified of the prohibition, which includes dirt, rock, construction debris, rubbish, refuse, tree and brush cuttings, grass clippings or other waste or material which may obstruct flow. State and Federal regulations prohibit the discharge of unauthorized wastewater or other wastes, such as used motor oil.

The Flood Hazard Protection regulations prohibit the location of critical facilities within the 500-year floodplain. Critical facilities include facilities such as emergency centers, hospitals, fire stations, power stations, and hazardous material storage sites. This criteria is also addressed in the Comprehensive Plan's siting of new critical facilities.

The Flood Hazard regulations require that erosion control measures be implemented on all construction projects larger than 10,000 square feet. The City uses the erosion control specification promulgated by the North Central Texas Council of Governments. In the Fall of 1992, the U.S. Environmental Protection Agency began requiring erosion control on all construction projects exceeding five acres.

C. Subdivision Regulations The Subdivision ordinance and regulations require certain drainage improvements as a condition to plat approval. The Subdivision Ordinance, codified as Title 16 of the Benbrook Municipal Code, establishes as policy that "land to be subdivided shall be of such character that it can be used safely for building purposes without danger to health or peril from ... flood ... and land shall not be subdivided until proper provision has been made for drainage..." In addition, Section 16.04.050.F states "any land which, in its natural state, is subject to a one-hundred-year flood or which cannot be properly drained shall not be subdivided, resubdivided or developed until it is demonstrated to the satisfaction of the Planning and Zoning Commission that the construction of specific improvements by the developer can be expected to yield a usable building site." Section 16.28.015 states that any land within the 100-year floodplain shall not be developed and that such areas should be set aside by floodplain easements (Section 16.28..020.D.9).

Most of the specific regulations for subdivisions and platting are contained within the Planning and Zoning Commission's Rules, Regulations and Procedures, as ratified by the City Council. These regulations require the submittal of a drainage study with each plat submittal that identifies drainage considerations and needs. It also must show what drainage improvements are proposed to protect buildings from flooding. This drainage plan is then reviewed by both the City Engineer and the Planning and Zoning Commission. Section 15 of the Rules, Regulations and Procedures establish specific requirements for drainage systems, including conformance to the Comprehensive Plan, drainage easements and minimum capacities for drainage facilities.

In early 2006, the City plans to adopt new drainage criteria called Integrated Storm Water Management (iSWM) established by the North Central Texas Council of Governments. The new criteria require that storm drainage be a part of the subdivision process from its initial concept plan. The new design criteria encourage the set aside of natural floodplains and requires detention over the whole hydrograph rather than just for the 100-year storm event.

D. Design Standards and Criteria: The Subdivision Ordinance authorizes the City Manager to establish design criteria and standards for the construction of public improvements, including drainage facilities. These are contained in the Design Standards and Criteria for Streets, Drainage, and Other Public Improvements, with the storm drainage addressed in Section III. The design criteria provide specific requirements for the submittal of drainage plans, the calculation of storm flows, and design standards for facilities. Among the more salient requirements are the requirement for 7-inch curbs on streets, concrete lining of channels to the 100-year level, and the requirement for access points to allow routine maintenance. The Design Criteria also establish requirements for storm water detention facilities and grass-lined swales.

9.2.2 Federal Emergency Management Agency

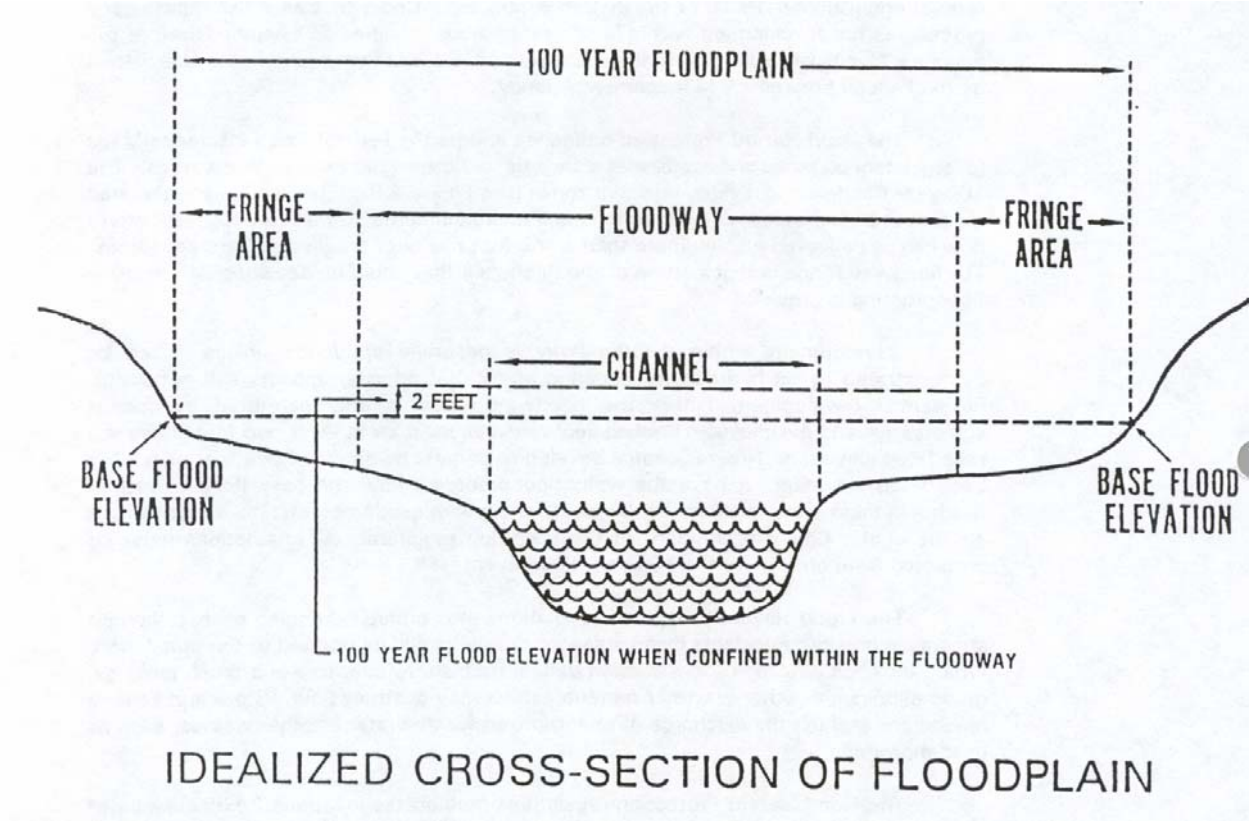
The Federal Emergency Management Agency does not directly regulate floodplains, but indirectly requires municipalities to regulate floodplains for eligibility in the National Flood Insurance Program (NFIP). The flood insurance program requires that cities restrict development in floodways and floodway fringes, establish a permitting process, and require floodproofing in floodprone areas. In return, the Federal Government underwrites flood insurance policies with differential premiums based on the risk of flooding.

Benbrook entered the flood insurance program on July 2, 1979 and the Flood Hazard Protection regulations in the Benbrook Municipal Code meet or exceed the minimum requirements of FEMA for participation.

More recently, FEMA has begun a new program to recognize cities that have gone beyond the minimum requirements for participation in the NFIP. The Community Rating System (CRS) provides discounts on flood insurance premiums based on a rating system that recognizes programs that are expected to reduce the risk of flooding. Benbrook applied for the CRS rating in December 1990, and was granted an initial rating of '9'. By 2002, the City had improved its CRS rating to “7”, which provides a 15 percent reduction on flood insurance premiums. The City applied for credit for the following activities:

Maintenance of Elevation Certificates
Map Determinations
Outreach Projects
Flood Protection Library
Flood Protection Assistance
Open Space Preservation
Higher Regulatory Standards
Flood Data Maintenance
Repetitive Loss Projects
and Drainage System Maintenance

Figure 9.3 Idealized Cross-Section of Floodplain



The City is continuing to review and consider programs that will improve the rating, and thus lower flood insurance premiums.

9.2.3 Corps of Engineers

While the U.S. Army Corps of Engineers does not directly regulate floodplains, it undertakes three programs that indirectly affect flooding and floodplain management in Benbrook. First, the Corps of Engineers is the federal agency which initially determined the floodplains for the Federal Emergency Management Agency. As such, it determines which properties are subject to direct regulation by the City. It also determines the flows which must be addressed to meet FEMA requirements.

The second program is the dredge and fill permits issued under authority of Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act. Under this program, any dredge or fill activities that affect waters of the United States, or their associated wetlands, must first obtain a permit from the Corps of Engineers. Since waters of the United States have been broadly defined by the courts, and the associated wetlands occur in floodplains, some development projects must obtain Corps of Engineers' permits before they can proceed.

Recently, the Corps of Engineers has expanded their permit program within the Trinity River drainage basin. Under this program, affected development projects must obtain a development certificate which demonstrates that the project will not cause a rise in the downstream flood elevation. The certificate review process will be coordinated by the North Central Texas Council of Governments and downstream cities will have an opportunity to comment on applications in other cities. While Benbrook is not a direct participant in this process at the present time, it may become a participant in the future.

The third program of the Corps of Engineers which affects flooding is its flood control programs, including flood control reservoirs and levees. Benbrook Dam and Reservoir was constructed, in part, for flood control purposes. As a result, flooding on the Clear Fork downstream of the dam is significantly reduced from preimpoundment conditions. The Corps of Engineers is also responsible for construction of the Fort Worth floodway, which starts just downstream of the city limits of Benbrook.

The Corps of Engineers has evaluated the potential for flood control along Mary's Creek. In a 1990 Reconnaissance Report, a 150 to 225-foot wide channel was proposed to extend from the confluence to U.S. 377. This channel would contain the 25-year flood only. A cost-benefit analysis indicated the costs would exceed the benefits, and therefore the project is not feasible under federal guidelines. Recently, the Corps of Engineers has agreed to reevaluate potential flood control projects on Mary's Creek. The reevaluation indicates that channels can be constructed which have a positive benefit-cost ratio. The project was not continued because of funding limitation.

9.3 CITYWIDE DRAINAGE ACTIVITIES

Although most elements of the Drainage Plan involve specific structural improvements that affect a specific geographic area, there are some programs undertaken by the City which benefit the community as a whole. Most of these involve general flood management and regulatory programs, public outreach and assistance and plans for repetitive loss properties.

9.3.1 Management Activities

One of the most important activities of the City is the day-to-day management and regulation of development within the floodplain. All development within the 100-year floodplain must obtain a special floodplain development permit from the City prior to starting work. To accomplish and enforce this requirement, the City's Community Development Division has added the FEMA floodplain maps onto the City geographic information system. While there is still some error in these maps, they provide a quick screening method to identify properties that may be affected by the floodplain. By the end of 2006, the City expects to receive digital flood insurance rate maps (dfirm) for use in its GIS. These more detailed maps are updated as map revisions and new development occurs. This information is also overlain upon the City's Land Use Plan and Zoning maps for quick reference.

Any new construction that is permitted within the floodplain must submit an elevation certificate demonstrating that the finished floor elevation meets the minimum elevations required for flood-proofing. The City maintains these elevation certificates on file and in a FEMA developed database.

The City also maintains the drainage ways to assure efficient conveyance of water. The City's

Public Works Department inspects all drainage facilities at least twice annually, and often more frequently depending on the degree of flooding potential. Debris is removed from channels and inlets that might obstruct the free flow of water. Permanent drainage improvements are also inspected for structural integrity and erosion and repairs are made accordingly.

9.3.2 Public Outreach

In addition to the direct management activities, the City also performs a number of public information and outreach programs to inform the public of flood hazards. The Community Development Division routinely responds to 10 to 20 inquiries per month from residents regarding floodplain boundaries. The City and City Engineer also perform technical evaluations of specific flooding or erosion problems for residents.

The City has provided a number of reference books on floodplain management to the Benbrook Public Library for use by the general public. These references are also available at City Hall. The City staff will issue press releases from time to time on various flood management topics to the local newspapers. The City publishes at least one article citywide in it Community Newsletter describing flood hazards and the benefits of flood insurance. The City also sends s an annual letter to all residents whose property lies within the 100-year floodplain.

9.3.3 Repetitive Loss Properties

Among the existing flooding problems are two unique areas that require special consideration. These are properties for which multiple flood insurance claims have been filed and are known as repetitive loss properties. Repetitive losses are those which have had two or more claims of $1,000 or more since 1978. Benbrook has five such properties: 4100 Plantation Drive (see Figure 9.4), 913 Timberline Drive (see Figure 9.5), 8616 Elmwood Drive, 4300 Twilight Drive South, and 8620 Mary's Creek Drive (see Figure 9.6.) All five properties are located within the designated 100-year floodplain.

The City completed structural drainage improvements that should reduce the flooding risk at 4100 Plantation Drive. This property was flooded by Plantation East Creek, which escaped the channel and caused street flooding along Plantation Drive. During 1990 and 1991, the City constructed a $1.7 million drainage project that diverts 70 percent of the 100-year flood into an underground culvert under Tara Drive while the remaining 30 percent is handled by the natural channel. In addition, curb inlets were constructed in front of 4100 Plantation Drive to divert additional water from the street. This project lowered flood levels of the 100-year flood by 50 percent, and the City is continuing work to remove the remaining risk, pending the acquisition of necessary drainage easements.

The repetitive loss property at 913 Timberline Drive is flooded by both street flooding along Timberline Drive and overflow of Dry Branch, a tributary of Timber Creek. This drainage plan has identified that the flooding risk for this property is not from Dry Branch itself, but from backwater effects downstream on Timber Creek. The City plans to purchase and elevate this property above the 100-year flood elevation.

The remaining three repetitive loss properties are subject to flooding from Plantation West Creek. The City is planning improvements to this creek in 2006, pending acquisition of necessary drainage easements.

Figure 9.3 Repetitive Loss Property on Plantation East Creek

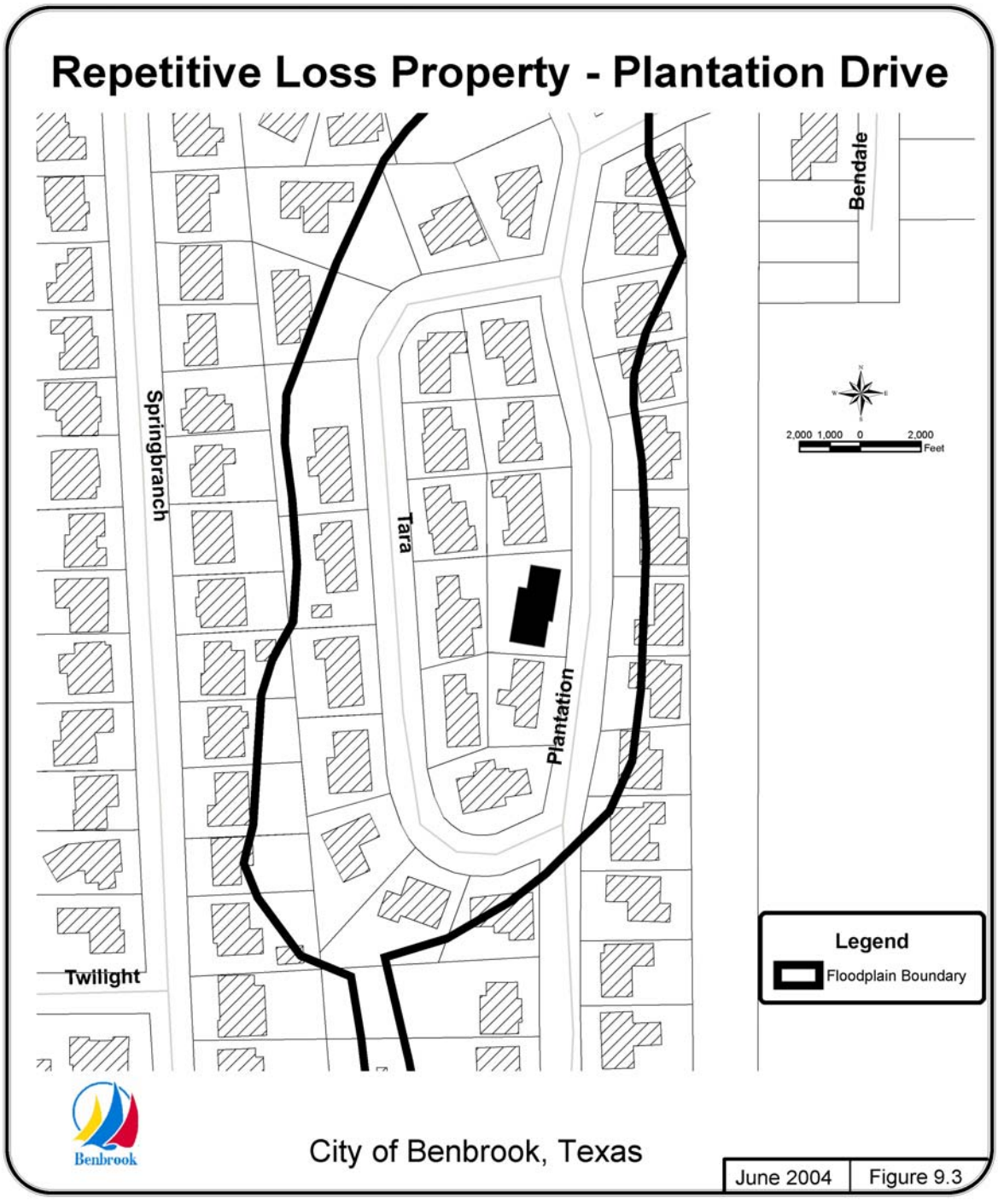


Figure 9.4 Repetitive Loss Property on Dry Branch

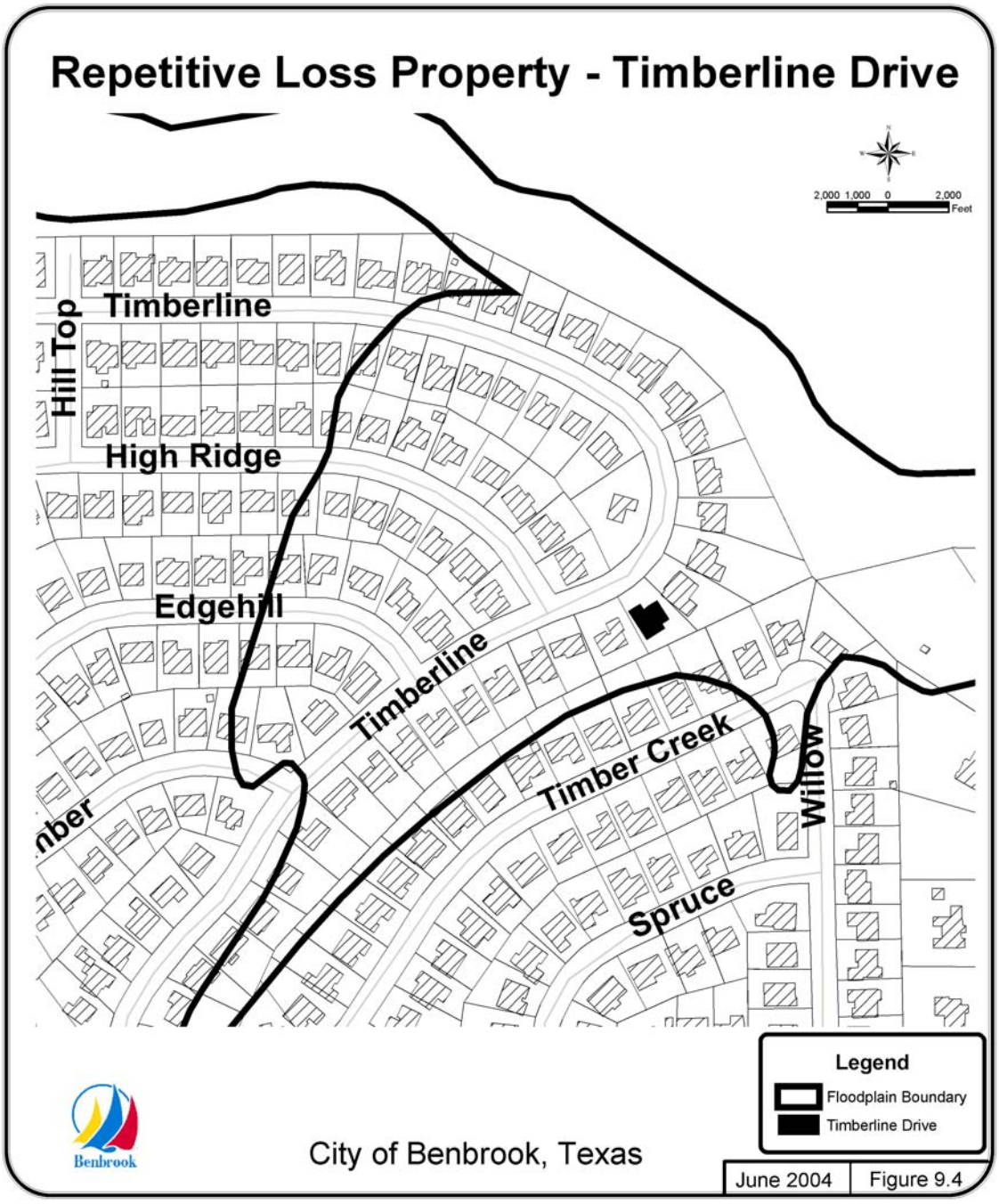
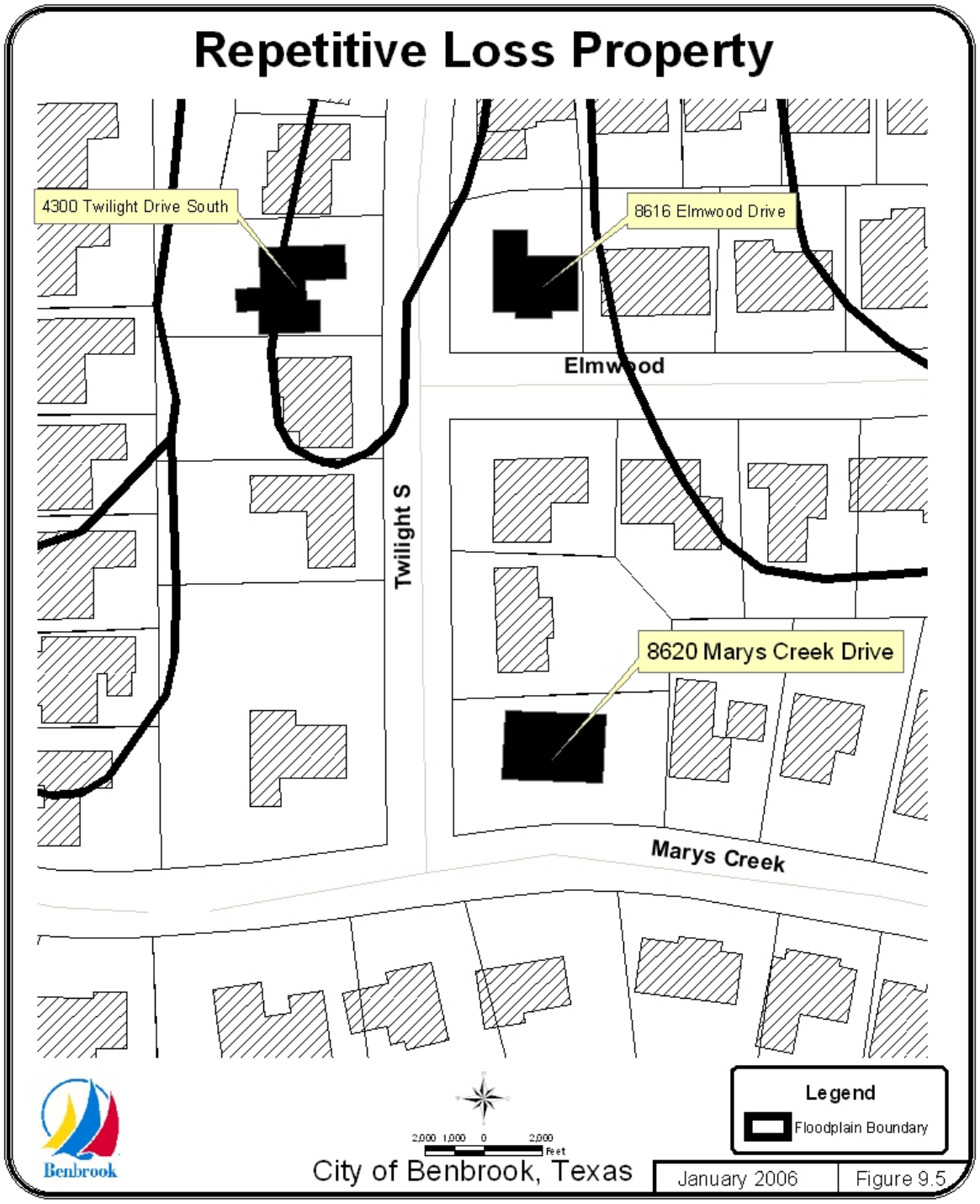


Figure 9.5. Repetitive Loss Properties along Plantation West Creek



9.4 SITE-SPECIFIC DRAINAGE PLANS

During Fiscal Year 1990-1991, the Engineer evaluated certain base line information and prepared an analysis of various drainage options for Mary's Creek-Main Channel, Plantation West Creek, Plantation East Creek and Mont Del Creek. During 1991-1992, plans were developed for portions of the Timber Creek watershed. Plans for the Dutch Branch and adjacent watersheds were prepared during 1992-1993. Plans for South Benbrook and Walnut Creek were prepared during 1993-1994. Plans for the remainder of the City were prepared during Fiscal Year 1994-1995.

In cases where more than one channel or culvert design could be employed, the City Engineer and staff prepared evaluations of costs, benefits, and effects of each alternate. These were presented to the Planning and Zoning Commission for review during a public hearing for final recommendation of the selected alternative. For example, most open channel sections included review of no-action, improved earthen channel, concrete-lined channel, vertical wall channel, and, in some cases, underground box culverts. The evaluation included the capital cost, operation and maintenance cost, estimated flood damages, estimated flood insurance premiums, and the number of houses that would need to be relocated.

In 2004, the City Engineer prepared revised plans for the Timber Creek watershed, Plantation East Creek watershed, Plantation West Creek watershed, and the Willow Bend Creek watershed. The revised plans reflect the changed attitude of the U.S. Army Corps of Engineers against concrete-lined channels in favor of gabion-lined channels with natural bottoms. The City Engineer also updated all of the previously-prepared cost estimates.

A description of each of the recommended drainage improvements is presented in the paragraphs below. A summary table of the proposed improvements is presented in Table 9.5. These are also presented graphically in the Plates at the back of this Drainage element. Each of the recommended projects will be included in the Capital Improvements Program as it is updated annually.

9.4.1 Mary's Creek Watershed (Drainage Area A)

Mary's Creek drains a total of 56.04 square miles in Tarrant and Parker County. Table 9.6 presents the calculated flood volumes at various locations along Mary's Creek.

A. Mary's Creek Main Channel: Mary's Creek is a major stream within the City with a normal channel width of approximately 100-feet and normal channel depth of 15 to 20 feet. The 100-year floodplain extends from 1000 to 1,500 feet in width in North Benbrook (Planning Area A) and from 1,500 feet to 2,000 feet in width in Ridglea Country Club Estates (Planning Area B).

The U.S. Army Corps of Engineers evaluated proposed channel improvements in January 1993 for two sections of Mary's Creek between its confluence with the Clear Fork Trinity River and U.S. 80. In particular, the Corps studied a reach extending from the confluence to the Texas and Pacific Railroad crossing (through Ridglea Country Club Estates) and a reach from U.S. 377 to IH Loop 820 (North Benbrook.) This evaluation was part of a larger flood control sturdy of the entire upper Trinity River watershed. The existing 30-foot bottom channel of Mary's Creek would be widened and straightened to provide a gabion-lined channel with a 50-foot wide bottom, 3-to-1 side slopes, and an upper width of 150 to 225 feet in width. A channel of this size would contain the 25-year flood. Although a channel

Table 9.5. Summary of Proposed Drainage Improvements

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
Mary's Creek	A	Loop 820 to Owendale	Earthen channel	$4,436,744
Stream MSC-1	A1a	Loop 820 to Mary's Creek	Concrete channel	$271,000
Stream MSC-1	A1b	Chapin Road to Mary's Creek	Concrete channel	$549,000
Stream MSC-1	A1c	Van Deman Drive	Curb inlets & storm drain	$92,000
Stream MSC-1	A1d	Carman & Mahan Drives	Curb inlets & storm drain	$111,000
Stream MSC-1	A1f	Burkett Drive	Curb inlets & storm drain	$176,000
Stream MSC-1	A1h	Burkett Drive to Mary's Creek	Storm drain	$9,000
Plantation West Creek	A2a	Chapin Road	Box culvert	$194,000
Plantation West Creek	A2b	Chapin Road to Dawn Drive	Concrete channel	$506,000
Plantation West Creek	A2c	Sundown/Twilight Drive	Curb inlets & storm drain	$184,000
Plantation West Creek	A2d	Mary's Creek Drive	Curb inlets & storm drain	$13,767
Plantation West Creek	A2e	Dawn Drive to Mary's Creek Drive	Concrete channel	$187,183
Plantation West Creek	A2k	Mary's Creek Drive	Curb inlets & storm drain	$23,000
Plantation East Creek	A3a	Chapin Road	Box culvert	$244,000
Plantation East Creek	A3c	Springbranch Drive	Curb inlets & storm drain	$57,000
Plantation East Creek	A3e	Chapin Road to Plantation Drive	Concrete channel	$325,000
Plantation East Creek	A3h	Plantation Drive	Curb inlets & storm drain	$138,000
Plantation East Creek	A3k	Mary's Creek Dr. to Mary's Creek	Concrete channel	$57,000

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
Plantation East Creek	A3l	Springbranch to Mary's Creek Dr.	Concrete channel	$334,000
Plantation East Creek	A3m	Elmwood Drive	Curb inlets & storm drain	$13,000
Mary's Creek	A4b	Team Ranch	Storm drain	$128,000
Mary's Creek	A4c	Team Ranch	Storm drain	$33,000
Mary's Creek	A4d	Team Ranch	Storm drain	$137,000
Mary's Creek	A4e	Reata/Team Ranch	Storm drain	$164,000
Mary's Creek	A4g	La Cantera/Team Ranch	Storm drain	$212,000
Mary's Creek	A4j	Idledell Drive	Curb inlets & storm drain	$60,000
Mary's Creek	A4l	Owendale Drive	Curb inlets & storm drain	$281,000
Willow Bend Creek	A5c	Westerly/Beechwood Roads	Curb inlets & storm drain	$144,000
Willow Bend Creek	A5f	Sutherland's parking lot	Grate inlets & storm drain	$179,000
Willow Bend Creek	A5n	Willow Bend Road	Curb inlets & storm drain	$96,000
Willow Bend Creek	A5v	Williams Road	Curb inlets & storm drain	$107,000
Willow Bend Creek	A5y	Palomino	Concrete channel	$287,000
Willow Bend Creek	A5ab	Llano Avenue	Curb inlets & storm drain	$41,000
Willow Bend Creek	A5ac	Queens Court Channel	Concrete channel	$184,000
Mary's Creek	A6a	La Vista/Team Ranch	Storm drain	$500,000
Mary's Creek	A8a	Vickery Loop West	Curb inlets & storm drain	$29,000
Mary's Creek	A9c	Benbrook Parkway	Storm drain	$263,000
Mary's Creek	A9d	Benbrook Industrial Park	Storm drain	$634,000
Mary's Creek	A9e	Horseshoe Club South	Storm drain	$663,000

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
Mary's Creek	A9j	Ridglea Country Club Golf Course	Storm drain	$98,000
Walnut Creek	B1	Whitestone Crest	Storm drain	$19,000
Walnut Creek	B2	Tabernacle of Praise parking lot	Storm drain	$67,000
Walnut Creek	B4	Neely Drive outfall	Storm drain	$75,000
Walnut Creek	B5	Woodglen/Wandering Way	Curb inlets & storm drain	$102,000
Walnut Creek	B6	Sexton	Storm drain	$38,000
Walnut Creek	B7	Creekside Trails, Phase 1	Storm drain	$73,000
Walnut Creek	B8	Creekside Trails, Phase 1	Storm drain	$161,000
Walnut Creek	B9	Benbrook Towne Crossing	Storm drain	$46,000
Clear Fork/Spillway	C1a	Mildred Lane	Curb inlets & storm drain	$242,000
Clear Fork/Dry Branch	C2a	Lampasas Drive	Curb inlets	$14,000
Clear Fork/Dry Branch	C2d	Trinity Estates Phase 3&4	Curb inlets & storm drain	$374,135
Clear Fork/Dry Branch	C2h	Briar Run	Curb inlets & storm drain	$309,000
Clear Fork/Dry Branch	C2p	Timber Creek Road	Curb inlets & storm drain	$19,000
Clear Fork/Dry Branch	C2q	Edgehill Road	Curb inlets & storm drain	$7,000
Clear Fork/Dry Branch	C2r	High Ridge Road	Curb inlets & storm drain	$29,000
Clear Fork/Dry Branch	C2s	Timberline Drive	Curb inlets & storm drain	$15,000
Clear Fork/Dry Branch	C2t	Willow Way	Curb inlets & storm drain	$25,000
Timber Creek	C3a	Beall's Channel	Concrete channel & storm drain	$196,616

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
Timber Creek	C3b	U.S. 377	Curb inlets & storm drain	$306,000
Timber Creek	C3c	U.S. 377	Curb inlets & storm drain	$419,000
Timber Creek	C3d	U.S. 377/Mercedes/Cozby North	Curb inlets & storm drain	$311,000
Timber Creek	C3f	Cozby East Street	Curb inlets & storm drain	$285,000
Timber Creek	C3g	Winscott Road	Curb inlets & storm drain	$381,000
Timber Creek	C3i	Kerry Street	Curb inlets & storm drain	$273,000
Timber Creek	C3l	Cottonwood Trail	Curb inlet & storm drain	$4,000
Timber Creek	C3q	Town Center	Storm drain	$717,000
Timber Creek	C3s	Cassco Land	Storm drain	$203,000
Timber Creek	C3v	Mildred/Vernon Castle	Curb inlets & storm drain	$1,329,000
Timber Creek	C3w	McKinley Street	Curb inlets & storm drain	$274,000
Timber Creek	C3x	Bryant Street	Curb inlets & storm drain	$83,000
Timber Creek	C3y	Bryant/Usher	Curb inlets & storm drain	$135,000
Timber Creek	C3aa	Park Center Street	Curb inlets & storm drain	$316,000
Timber Creek	C3aq	John Reagan Street	Box culvert	$41,791
Timber Creek	C3as	Keller Avenue	Curb inlets & storm drain	$27,000
Clear Fork	C4a	Timber Creek Land 77-acre tract	Storm drain	$233,000
Clear Fork	C4d	Edward's tract	Storm drain	$151,000
Clear Fork	C6a	Crosslands/Legend	Curb inlets & storm drain	$137,000

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
Clear Fork	C6c	Crosslands/Lago Vista	Storm drain	$30,000
Clear Fork	C6g	Crosslands	Curb inlets & storm drain	$152,000
Clear Fork	C6h	Southwest Boulevard	Driveway culverts	$57,000
Clear Fork	C6m	Crosslands Blvd.	Curb inlets & storm drain	$141,000
Mont Del Creek	C7c	Crosslands Road	Box culvert	$457,000
Mont Del Creek	C7e	Bounty Road West	Curb inlets & storm drain	$41,341
Mont Del Creek	C7f	Mont Del Road	Curb inlets & storm drain	$351,811
Mont Del Creek	C7g	Crosslands Rd. to Park Drive	Curb inlets & storm drain	$75,612
Mont Del Creek	C7g	Park Drive	Box culvert	$144,000
Mont Del Creek	C7g	Crosslands Road to Park Drive	Channel stabilization	$1,600,000
Mont Del Creek	C7j	Legend Road to frontage road	Concrete channel	$86,000
Mont Del Creek	C7j	Southwest Boulevard	Box culvert	$476,000
Mont Del Creek	C7k	Frontage road to Stream CF-5	Gabion-lined channel	$1,900,000
Mont Del Creek	C7l	Legend Road	Curb inlets & storm drain	$7,922
Mont Del Creek	C7m	Frontage Road	Curb inlets & storm drain	$129,565
Stream CF-5	C8	Bryant-Irvin Rd. to Bellaire Drive	Concrete pilot channel	$211,497
Dutch Branch	D3a	Whitestone Crest	Storm drain	$513,000
Dutch Branch	D4	U.S. 377	Box culvert	$1,125,000
Dutch Branch	D6a1	Trinity Ranch	Storm drain	$110,000
Dutch Branch	D6a2	Trinity Ranch/U.S. 377	Box culvert	$65,000
Dutch Branch	D6d2	Trinity Ranch/U.S. 377	Storm drain	$13,000
Dutch Branch	D7c	R.M. 2871	Storm drain & curb	$411,000

Drainage Basin	Watershed Number	Location	Project Description	2004 Capital Cost
			inlets	
Dutch Branch	D7e	Park Road No. 3	Road culvert	$10,000
Dutch Branch	D7f	Park Road No. 3	Road culvert	$7,000
Dutch Branch	D8	Stephens Road	Culvert & storm drain	$60,000
Dutch Branch	D9a	Stephens Road	Road culvert & storm drain	$23,000
Dutch Branch	D9b	Stephens Road	Road culvert & storm drain	$170,000
Dutch Branch	D9d1	Lakeview Drive	Road culvert	$7,000
Dutch Branch	D10	Lakeview Drive	Road culvert	$9,000
Benbrook Lake	E1a	Haywood Drive	Storm drain & culvert	$126,000
Benbrook Lake	E1b	Kenshire Drive	Curb inlets	$22,000
Benbrook Lake	E1c	Overcrest/U.S. 377	Storm drains & curb inlets	$129,000
Benbrook Lake	E1e	Covington Dr./U.S. 377	Curb inlets	$17,000
Benbrook Lake	E1f	Park Road No. 3	Road culvert	$51,000
Benbrook Lake	E2a	U.S. 377, Amory to Lochness	Storm drain & curb inlets	$122,000
Benbrook Lake	E2b	Park Road No. 1	Road culvert	$20,000
Benbrook Lake	E2c	Park Road No. 3	Road culvert	$22,000
Benbrook Lake	F1a	Stephens Road area	Storm drain	$482,000
Benbrook Lake	F1b	Stephens Road	Storm drain & curb inlets	$132,000
Benbrook Lake	F2a	Jakmar Road	Storm drain & curb inlets	$25,000
Benbrook Lake	F2b	Rogers Road	Storm drain & curb inlets	$26,000
Benbrook Lake	F2d	Lakeview Drive	Road culvert	$17,000
Benbrook Lake	F3a	Lakeview Drive	Road culvert	$10,000
Total Planned Improvements				$29,190,528

Table 9.6

SUMMARY OF FLOOD DISCHARGES
MARY'S CREEK WATERSHED

Location	Drainage Area (square miles)	Return Frequency			
		10 year	50 year	100 year	500 year
At confluence with Clear Fork	56.04	25,600	36,600	42,800	55,000
Approx. 1,800 feet downstream of Old Benbrook Rd.	54.03	25,700	36,900	43,400	56,300
Approx. 1,100 feet upstream of Old Benbrook Rd.	43.31	22,300	32,200	37,500	47,900
Approx. 0.95 miles downstream of Loop 820	41.98	22,900	33,000	38,100	42,200
Approx. 0.76 miles downstream of Loop 820	40.83	22,900	32,900	37,900	47,900

could be situated to avoid the taking of existing residences, at least four fairways at the Ridglea Country Club golf course would be displaced and many of the trees along the creek would be removed.

The Corps of Engineers estimates the capital cost (including engineering, land acquisition and construction) for this channel would be approximately $5.5 million for the lower reach and $4.3 million for the upper reach. Using federal guidelines for evaluating project feasibility, the Corps of Engineers determined that the annual benefits would exceed annualized costs for both reaches. Therefore, the Corps of Engineers considers this project as cost-effective, but the neither project was pursued for further investigation because of lack of local matching funds..

In lieu of the expensive gabion or concrete-lined channel option, the City has also evaluated the feasibility of an earthen channel between U.S. 377 and Loop I-820. To contain the 100-year flood would require a 200-foot wide bottom with 4 to 1 side slopes with a channel depth of 16 to 18 feet. A 350-foot wide easement would be required to accommodate a channel of this size, all of which would be expected to be obtained from the south side of the channel. The total estimated cost for these improvements would be $1.96 million.

B. Watershed A1: Watershed A1 includes the drainage from Stream MSC-1, that drains approximately 645 acres northwest of the intersection of Chapin Road and Loop 820, and a smaller adjacent unnamed stream that drains approximately 194 acres. The drainage plan calls for concrete lining both of these channels.

Watershed A1 also includes the Pecan Valley subdivision and the drainage plan calls for the installation of additional curb inlets and storm drains, to drain portions of Van Deman Drive, Carman Drive and Mahan Drive. The drainage plan also calls for additional curb inlets and storm drain on Burkett Drive, with the underground storm drain extending to

Mary's Creek.

C. Watershed A2 - Plantation West Creek: Plantation West Creek originates in Fort Worth and drains approximately 1 square mile. At its confluence, the following storm flows have been calculated:

Table 9.7
SUMMARY OF DISCHARGES
PLANTATION WEST CREEK
(in cubic feet per second)

Return Period	Peak Discharge
10 year	1,790
50 year	2,370
100 year	2,630
500 year	3,200

Source: FEMA, 2000 Flood Insurance Study

Approximately 518 acres of the watershed are located north of Chapin Road in the Fort Worth city limits. The existing culvert under Chapin Road consists of a three barrel 9' by 6' multibox culvert with an estimated capacity of 1,380 cfs. This is less than the 100-year storm flow of 2,700 cfs, so it is proposed that this culvert be replaced with a 4-barrel 9' by 8' multibox culvert. It is also proposed that an additional 10-foot curb inlet be provided on Chapin Road.

The existing channel between Chapin Road and Dawn Drive is earthen and unimproved. A makeshift levee was constructed on the east side of this channel to protect a home prior to regulation of such development by the City. After evaluating the costs and benefits of various alternatives for this segment, it is proposed that this segment remain an earthen channel with a 30-foot bottom width and 3 to 1 side slopes.

The culvert at Dawn Drive was reconstructed in 1990 and has adequate capacity for the 100-year flood. However, it is planned to extend a storm drain to the intersection of Dawn Drive and Mary's Creek Drive with two 10-foot inlets, at an estimated cost of $22,350.

The channel between Dawn Drive and Mary's Creek Drive is currently earthen and unimproved. It is planned to construct a gabion-lined channel with a 30-foot bottom width along this segment. In addition to the channel, it is also planned that additional curb inlets be added on both Mary's Creek Drive to the east and Dawn Drive to the west.

The existing box culvert at Mary's Creek Drive consists of a 2-barrel, 4' by 3.5' multibox culvert with a capacity of 150 cfs, considerably less than the 2,700 cfs 100-year flood. This culvert is planned to be replaced with a 4 barrel, 10' by 6' multibox culvert.

Between Mary's Creek Drive and the existing vertical wall channel is a section of unimproved channel that flows, in part, through Valley West Park. It is planned to construct a gabion-lined channel from Mary's Creek Drive all the way to the confluence with Mary's Creek. This project is planned for early 2006, pending acquisition of necessary drainage easements. It is recommended that a storm drain be extended along Sundown Drive with

inlets at Sundown, Sunnyvale, and Twilight Drives.

The road crossing at the south end of Mary's Creek Drive was never completed. It is planned that a 4-barrel 10'-by-6' multibox culvert be constructed in the future. Additional curb inlets are planned along Mary's Creek Drive.

D. Watershed A3 - Plantation East Creek: Plantation East Creek originates in western Fort Worth and drains approximately 1.2 square miles. At a location approximately 500 feet north of the confluence, the storm flows have been calculated and are presented in Table 9.8

Table 9.8
SUMMARY OF DISCHARGES
PLANTATION EAST CREEK
(in cubic feet per second)

Return Period	Peak Discharge
10 year	2,200
50 year	2,900
100 year	3,300
500 year	4,200

Approximately 652 acres of the watershed are located north of Chapin Road in the City of Fort Worth. The existing culvert under Chapin Road consists of a 25-foot bridge section with an estimated capacity of 1150 cfs, well below the 3,300 cfs 100-year flood flow. It is recommended that this structure be replaced with a 4-barrel, 9' by 9' multibox culvert. The City of Fort Worth is currently preparing plans which would include replacement of this structure. In addition, it is recommended that additional curb inlets be added to Chapin Road.

Between Chapin Road and Plantation Drive, Plantation East Creek flows through an unimproved channel along the Texas Electric Service Company power line easement. It is recommended that this segment be lowered as a earthen channel.

The existing 3-barrel 9' by 5' multi box culvert at Plantation Drive is adequate to convey the portion of the 100-year food flow which is not diverted through the underground box culvert under Tara Drive.

The City constructed a major storm sewer project between Plantation Drive and Springbranch Drive in 1992. This $1.7 million project consists of twin 9' by 8' underground box culverts under Tara Drive, discharging into a 22-foot wide vertical wall channel. While the vertical wall channel has the capacity for the full 3,300 cfs, the underground box culvert only has capacity for 2,050 cfs because of space limitations. It is planned that the existing stream channel behind Tara Drive will be improved to handle the remaining 1,250 cfs by constructing a gabion-lined channel. This project is scheduled for early 2006 pending acquisition of necessary drainage easements.

To reduce some of the flow in Springbranch Drive, it is recommended that two sets of curb inlets be added to divert flow into the channel. Additional curb inlets are proposed along Plantation Drive.

The existing box culvert at Springbranch Drive is a 3-barrel, 9' by 7.5 ' multibox culvert with an estimated capacity of 1,695 cfs. To convey the 100-year flood of 3,300 cfs, it is recommended that the existing culvert be replaced with a 4-barrel, 10' by 9' multibox culvert.

The channel downstream of Springbranch Drive is currently unimproved. It was originally intended that this would be improved prior to the upstream section, but in 1988, the adjacent landowners opposed any improvements. To bring this section up to the 100-year flood capacity, it is projected that it be concrete-lined, with a 10-foot bottom width, 2 to 1 side slopes and a top width of 42 feet. It is recommended that additional curb inlets be installed along Elmwood Drive, at a cost of approximately $10,435.

The 2-barrel, 9' by 11' multibox culvert at Mary's Creek Drive has a capacity of 2,200 cfs, less than the required 3,300 cfs associated with the 100-year flood. It is planned that an additional 9' by 11' box will be added to the existing structure. Additional curb inlets are also proposed. The channel downstream of the Mary's Creek culvert is recommended to be constructed as a concrete-lined channel.

E. Watersheds A4: Watershed A4 drains a portion of the south side of Mary's Creek in an area known as Team Ranch. The drainage plan shows the need for several storm drain systems, all of which will be installed by private development.

F. Watershed A5: Watershed A5 is drained by Willow Bend Creek. Willow Bend Creek was channelized from Williams Road to Llano Avenue in the early 1980s. Using more current hydrology and hydraulic data, the following changes need to be made to the existing concrete-lined channel: enlarge culvert at Northbrook Drive and enlarge upstream channel, replace culvert at Ferndale and enlarge upstream channel, replace culverts at Pinewood and enlarge upstream channel, enlarge culverts at Herndon and enlarge upstream channel, and enlarge culvert at Llano and enlarge upstream channel. The remainder of the channel downstream is proposed to be concrete-lined.

Table 9.9
WILLOW BEND CREEK
SUMMARY OF DISCHARGES (CFS)

Location	Drainage Area (mi^2)	10-year	50-year	100-year	500-year
At confluence with Mary's Creek	0.8	1,755	2,315	2,535	3,050
At Meadowside Drive	0.68	1,575	2,055	2,250	2,720
At Pinewood Drive	0.36	1,035	1,340	1,470	1,785
At Ferndale Drive	0.27	855	1,095	1,205	1,465
At Chapin Road	0.19	635	815	890	1,080

Willow Bend Creek has a tributary to the west, which is also known as the Queen's Court channel. The portion of this earthen channel adjacent to the Palomino development was partially-improved by the developer. The remainder of the channel between Chapin Road and the Palomino improvements need to be improved as a earthen channel. Downstream

of Llano Avenue, the Queen's Court channel is proposed to be concrete-lined.

Drainage plans for this watershed also include additional curb inlets and storm drain along Willow Bend Road, along Westerly and Beechwood Drive, and along Williams Road.

G. Watershed A6: Watershed A6 drains a portion of the area along the south side of Mary's Creek in the development known as Team Ranch. The drainage plan shows the need for additional storm drainage in this area, all of which is to be built by private developers.

H. Watershed A7: With the exception of two lots on the south side of Chapin Road east of Williams Road, all of Watershed A7 is within the City of Fort Worth. No drainage improvements are planned in the portion of Watershed A7 within the City of Benbrook.

I. Watershed A8: Watershed A8 drains the industrial area north of Mary's Creek and south of Vickery Boulevard. The only improvements proposed for this area is the need for curb inlets and storm drain at the southwest corner of Vickery Loop West and Vickery Loop.

J. Watershed A9: Watershed A9 drains the area south of Mary's Creek and east of Winscott Road. The drainage plan shows the need for three major storm drains to serve the industrial park and developing area along I-20. It is expected that these improvements will be made private development.

K. Watershed A10: Watershed A10 drains a small industrial area at the east end of the area between Vickery Boulevard and the Union Pacific Railroad. No drainage improvements are planned for this area.

9.4.2 Walnut Creek (Drainage Area B)

Walnut Creek drains approximately 10.1 square miles west of its confluence with Mary's Creek. Most of the watershed lies within the unincorporated area of Tarrant County and within Fort Worth's extraterritorial jurisdiction. Table 9.10 presents the calculated flood volumes at two locations along Walnut Creek.

Table 9.10
SUMMARY OF FLOOD DISCHARGES
WALNUT CREEK
(cubic feet per second)

Location	Drainage Area (Square Miles)	Return Frequency			
		10 Year	50 Year	100 Year	500 Year
500 ft upstream of confluence	10.1	7,900	11,000	12,600	16,100
1.42 miles upstream of confluence	7.0	5,700	8,000	9,100	11,700

A. Walnut Creek Main Channel: It is planned for the main channel of Walnut Creek to remain in its natural condition.

B. Watershed B1 - Trinity Ranch: A portion of Whitestone Ranch, northwest of Trail Ridge Addition, drains northward into Walnut Creek. When this area develops, a 24-inch storm

drain will be required to carry the 100-year storm flow.

C. Watershed B2 - Rolling Hills: Water draining under R.M. 2871 drains northeastward across a portion of Rolling Hills north of the Tabernacle of Praise Church. A 42-inch storm drain is proposed to carry this water under their proposed parking lot to Walnut Creek.

D. Watershed B4 – Martha Park Addition: A portion of the Martha Park Addition, west of Woodglen Drive, receives water from the outfall at Neely Drive. A 24- and 33-inch storm drain is proposed to carry this water to Walnut Creek.

E. Watershed B5 – Skyline Ranch Addition: A portion of the proposed West Ridge Addition, east of Woodglen, is proposed to have two drainage improvements. First, a set of curb inlets and storm drain is proposed at the location of the existing low water dam at the end of Woodglen Drive. Secondly, a 36-inch storm drain is proposed to carry water of Wandering Way to Walnut Creek.

F. Watershed B6 – Skyline Ranch: A portion of the proposed Skyline Ranch Addition, west of Sexton Drive, receives water from an outfall from Sexton Drive. A 24-inch storm drain is proposed to carry this water to Walnut Creek.

G. Watershed B7 – Creekside Trails Addition: A portion of the proposed Creekside Trails Addition, east of Sexton Drive, will need an additional storm drainage, to be built by the developer.

H. Watershed B8 – Creekside Trails Addition: A portion of the proposed Creekside Trails Addition drains undeveloped land into Walnut Creek. When this area develops, a series of three storm drains, ranging in size from 36- to 42-inches is proposed to be built by the developer.

I. Watershed B9 – Benbrook Towne Crossing: A portion of the proposed Benbrook Towne Crossing Addition drains an undeveloped area into Walnut Creek. When this area develops, a 42-inch storm drain is proposed to carry water to Walnut Creek to be built by the developer.

J. Watershed B11 - Team Ranch: A portion of the Team Ranch development drains into Walnut Creek and into an unnamed tributary of Walnut Creek. The property south of Cook Ranch Road has been developed and the appropriate storm drainage system has been installed. When the commercial area north of Cook Ranch Road develops, additional storm drainage facilities will be installed by the developer.

K. Watershed B13 - Old Benbrook Road: The existing culvert under Old Benbrook Road east of U.S. 377 was rebuilt as two 10’ by 10’ box culverts by the Texas Department of Transportation in 2005. The channel upstream will need to be improved when it develops.

9.4.3 Clear Fork - Trinity River (Drainage Area C)

The Clear Fork Trinity River drains at total of 64.5 square miles downstream of Benbrook dam and upstream of the confluence with Mary's Creek. Table 9.11 presents the calculated flood volumes at various locations along the Clear Fork.

A. Clear Fork Main Channel: The main channel of the Clear Fork Trinity River is intended to remain in its natural state.

Table 9.11
SUMMARY OF FLOOD DISCHARGES
CLEAR FORK TRINITY RIVER
(cubic feet per second)

Location	Drainage Area (Square Miles)	Return Frequency			
		10 Year	50 Year	100 Year	500 Year
Below confluence with Mary's Creek	63.2	11,700	20,700	25,400	46,000
At Interstate 20	8.49	6,000	8,400	13,000	46,000

B. Watershed C1 - Clear Fork/Spillway: A portion of south Benbrook, including parts of Hilltop Heights and Benbrook Lakeside Addition, drain southward into the spillway channel of Benbrook Lake. Most of the area is served by surface drainage or existing drainage improvements, but certain area needs to be upgraded to handle the 100-year storm.

A system of curb inlets and a 24- and 36-inch storm drain was constructed in 2002 as part of the reconstruction of Cozby South Street. The system connects with an existing storm drain at the intersection of Cozby South Street and Sproles Drive. Additional curb inlets and storm drain are needed for portions of Mildred Avenue and Paul Lane.

C. Watershed C2 - Clear Fork/Dry Branch: The main stem of the Clear Fork drains the area east of Winscott Road and south of Tobie Layne. The area north of Tobie Layne, but south of Timberline Drive is drained by Dry Branch, a tributary of Timber Creek. Most of the area is adequately served by surface runoff or by existing storm drain systems. However, in certain areas additional improvements are needed to protect against the 100-year storm event.

Additional curb inlets are required at the intersection of Lampasas Drive and Rio Grande Drive and at Trinity Drive at Paluxy Drive in Trinity Estates. The additional improvements in Trinity Estates Phases 3 and 4 will be constructed by the developer when the area is developed.

Briar Run in Greenbriar Addition is currently served by a 48-inch storm drain. Additional curb inlets are required at the intersection of Briar Run and Augusta Drive and a larger storm drain (54-inch) is required at the eastern end.

A new storm drain system was installed in 2005 from the intersection of Edgewood and Timberline Drives, down Edgewood, and then down Timbercreek Road until is discharges to Dry Branch. It is also recommended that an additional curb inlet be installed on Timbercreek Road east of Mulberry. A curb inlet should also be installed at Edgehill at Timberline, High Ridge at Timberline, on Timberline Drive east of High Ridge, and on Timbercreek Road at Willow Way.

D. Watershed C3 - Timber Creek: Timber Creek drains approximately 2.1 square miles of

South Benbrook. Table 9.11 presents the calculated flows at various locations along Timber Creek.

Table 9.11
SUMMARY OF FLOOD DISCHARGES
TIMBER CREEK WATERSHED
(cubic feet per second)

Location	Drainage Area (square miles)	Return Frequency			
		10 year	50 year	100 year	500 year
At confluence with Clear Fork	2.10	3,830	5,060	5,590	6,870
Upstream of confluence with Dry Branch	1.34	2,460	3,230	3,560	4,360
At Timbercreek Road	0.72	1,715	2,050	2,180	2,670
At Warden Street	0.46	1,110	1,420	1,540	2,020
At Bryant Street	0.14	470	590	640	900

Westpark Drive west of U.S. 377 is currently served by a storm drain ranging in size from 24 inches to 48 inches. Addition curb inlets and storm drain are needed along Benbrook Boulevard north of Westpark Drive, and the downstream channel needs to be enlarged. New storm drain inlets were installed at the corner of Mildred and Cozby West Street in 2005, but an additional storm drain is needed to serve Mildred, Bryant and Vernon Castle.

An extensive system of curb inlets and storm drain is needed to serve the west side of Benbrook Boulevard from Sproles to Interstate I-20. A system of curb inlets and storm drain is also needed along McKinley Avenue. Although Timber Creek was channelized in the early 1980s, new hydrology and hydraulics indicates that the entire system of channels and culverts needs to be enlarged from McKinley down to Winscott Road.

Winscott Road between Mercedes Street and Timber Creek is currently served by a 66-inch storm drain. To handle the additional flow from the Cozby North storm drain, an additional 33- to 36-inch storm drain should be installed. An additional curb inlet is required in the Timber Creek Square Townhomes at a cost of $3,306.

The existing Winscott Road culvert over Timber Creek consists of four 9' by 6' box culverts. To adequately handle the 100-year storm, an additional 9' by 9' culvert section will be added in early 2006.. The culverts at Timbercreek Road were enlarged and the segment of Timber Creek from Timbercreek Road to Timber Creek Park was channelized in 2004. The portion from Timber Creek Park to the confluence with the Clear Fork will be developed as an gabion-lined channel, in early 2006.

The undeveloped property north of Timbercrest Drive will ultimately be drained by a 66-inch storm drain. This system, plus an additional system to the east, will be installed by developers at the time of development.

A new storm drain system and curb inlets is proposed along Park Center Street north of

Childers Street. In addition, the box culvert at Park Center Street and the Timber Creek channel is proposed to be enlarged. The box culvert at John Reagan Street is also slated for enlargement. Additional curb inlets and storm drain are proposed along Keller Street to carry water from the street to the channel.

The existing storm drain system which carries water from the corner of Mercedes Street and Del Rio Avenue to Cozby North Street is undersized. The system within Cozby North Street was enlarged in 2003.

A new underground storm drain and curb inlets are proposed along Cozby East Street between Vernon Castle and Keller Streets. A new system is also proposed along Kerry Street and Duane Street.

An additional storm drain is also proposed along Bryant Street north of Davidson. Improvements are also proposed at the intersections of Bryant and Childers and Usher and Childers Avenue.

E. Watershed C4 - Clear Fork: This area includes I-20 and an area to south that is currently undeveloped. When it is developed, at least two storm drains will be required to be installed by the developer.

F. Watershed C5: Watershed C5 drains a portion of Country Day Estates into the Clear Fork. No improvements are planned for this watershed.

G. Watershed C6: Watershed C6 drains a portion of Country Day Estates into the Clear Fork. Additional curb inlets and storm drain is proposed from the intersection of Legend and Steppe Drive to Crosslands, and along Crosslands from Creekwood to Bellaire Drive.

H. Watershed C7 - Mont Del Creek: Mont Del Creek originates in the Cityview area of Fort Worth and drains a total watershed area of approximately 226 acres. Approximately 102.4 acres of the watershed is south of Interstate I-20 and within Fort Worth city limits. A detention pond was constructed jointly by the Cities of Benbrook and Fort Worth in CityView in 2003. The Mont Del Creek system was reevaluated in 2004 and shows the need for improvements at the upstream end under Crosslands Road, along Mont Del Road, and to the earthen channel north of State Highway 183.

The open channel between Crosslands Road and Park Drive is currently unimproved and is subject to erosion. It is planned that this channel be gabion-lined, with a 10-foot bottom width, 2 to 1 side slopes and a top width of 24 feet. These improvements also call for lowering and reshaping the duck pond at Mont Del Park.

Leaving Mont Del Park, stormwater is currently collected in a 60-inch reinforced concrete pipe. Since this is inadequate to carry the 100-year flow, it is planned that this existing storm drain be paralleled by a 6’ by 6’ box culvert.

The existing 9' by 6' box culvert under State Highway 183 has capacity for a 50-year flood. To accommodate the 100-year flood, it is planned that this culvert be paralleled by an 8' by 6' box culvert. The State Department of Highways and Public Transportation has verbally committed to making this improvement, once the downstream channel is improved, and/or the construction of the Southwest Parkway commences.

Downstream of the S.H. 183 culvert, Mont Del Creek flows through an earthen channel with inadequate capacity for the 100-year flood. To accommodate the 100-year flow, it is planned that this section will be gabion-lined.

I. Area C8 - Stream CF-5: Stream CF-5 consists of a 220-foot section of stream that passes through Benbrook before discharging into the old Clear Fork channel. With the exception of Mont Del Creek, the vast majority of the watershed is within Fort Worth. The earthen channel has a 50-foot bottom width and 120-foot top width and accommodates the 100-year flood. The banks are eroding and the bottom is overgrown with vegetation.

As an interim measure to facilitate maintenance on this channel, it is recommended that a 10-foot wide, 3-foot deep pilot channel be constructed in the center of the bottom, and that the remainder of the bottom be graded for ease in mowing.

9.4.4 Dutch Branch (Drainage Area D)

Dutch Branch, a tributary to Benbrook Lake, drains approximately 7.3 square miles to the west. A large portion of the watershed which lies within Benbrook drains the Trinity Ranch development area. Table 9.12 presents the calculated flood volumes at two locations on Dutch Branch.

Table 9.12
SUMMARY OF FLOOD DISCHARGES
DUTCH BRANCH
(cubic feet per second)

Location	Drainage Area (Square Miles)	Return Frequency			
		10 Year	50 Year	100 Year	500 Year
At Benbrook Lake	7.3	6,900	9,500	10,900	13,800
At 1.52 miles upstream of confluence	4.9	5,700	7,900	9,000	11,300

A. Dutch Branch Main Channel: The main channel of Dutch Branch traverses the Whitestone golf course, which will be preserved as open space and no improvements are proposed to the Dutch Branch channel.

B. Watershed D1: Watershed D1 (including a potion of Whitestone golf course) is drained by an unnamed tributary on the north side of Dutch Branch on the far west side of the city limits. No improvements are planned for this creek.

C. Watershed D2: Watershed D2 (including a portion of Whitestone golf course) is drained by an unnamed tributary on the south side of Dutch Branch and the western city limits. No improvements are planned for the creek. Storm drain facilities have been installed in Whitestone Heights.

D. Watershed D3: Watershed D3 is drained by an unnamed tributary on the north side of Dutch Branch west and south of Winchester Addition. A segment of the stream passes through the southwest corner of Winchester Addition.

It is proposed that the watershed upstream of Rolling Hills Drive be drained by a system of storm drains, ranging in size from 24 to 60-inches in diameter. The portion of the channel

downstream of Westpark Drive was installed by the developer as part of Whitestone Ranch Estates.

E. Watershed D4: Watershed D4 is drained by an unnamed tributary on the south side of Dutch Branch. The watershed includes a portion of U.S. 377. It is proposed that the crossing under U.S. 377 be upgraded to a 4' by 4' box culvert, at an estimated cost of $112,677. The channel downstream is proposed to remain in its natural state.

F. Watershed D5: Watershed D5 drains portions of Whitestone Ranch and the Hills of Whitestone subdivisions. The system of underground storm drains, ranging in size from 36 to 66-inches in diameter, necessary to drain this are was installed by the developer.

G. Watershed D6: Watershed D6 is drained by an unnamed tributary on the south side of Dutch Branch, including a portion of U.S. 377. It is proposed that the upstream portion of the watershed be drained by an underground 54-inch storm drain. The remainder of the channel would remain in its natural state. The culvert under U.S. 377 would be upgraded to a 6' by 4' box culvert. Also in the watershed, the capacity of the culvert under Stephens Road at the intersection of U.S. 377 would be doubled by adding a parallel 24-inch diameter storm drain.

H. Watershed D7: Watershed D7 includes the right-of-way of R.M. 2871 and the immediate contiguous land. It is proposed that the existing bar ditch system be replaced with an underground storm drain and curb inlet system, ranging in size from 30 to 36 inches in diameter. Also in the watershed, two road culverts under Park Road No. 3 would be upgraded.

I. Watershed D8: Watershed D8 is a small watershed, drained by an unnamed tributary, on the east side of U.S. 377. It is proposed that drainage be improved at the crossing of Stephens Road by adding curb inlets and extending a 30-inch storm drain upstream for a distance of approximately 500 feet.

J. Watershed D9: Watershed D9 includes the area north and west of Stephens Road, including the intersection with Lakeview Drive. Proposed improvements in this watershed include adding curb inlets and a small storm drain at a point on Stephen Road approximately 1200 feet east of U.S. 377. An additional set of curb inlets with an upstream system of storm drains is proposed for Stephens Road approximately 800 feet further to the southeast. Finally, a culvert would be added under Lakeview Drive approximately 1300 feet east of the intersection with Stephens Road.

K. Watershed D10: Watershed D10 drains the area north of Jakmar Road, including Hobie Point. The only improvement planned for this watershed is to add an additional culvert under Lakeview Drive.

9.4.5 Benbrook Lake (Drainage Areas E, F, and G)

A. Watershed E1: Watershed E1 includes most of the Westpark Addition southeast of Stoneleigh Drive and Westpark Drive to Vista Way. Most of this area has existing storm drain facilities, but some are inadequate to handle the 100-year storm using current criteria.

Drainage along the south end of Haywood Drive will be improved by adding additional storm drain and curb inlets west of the intersection with Kenshire Drive. Drainage at the

south end of Kenshire would be improved by adding additional curb inlets. The south end of Overcrest Drive and the area along U.S. 377 between Overcrest and Kenshire would be drained by a series of inlets and a 30-inch diameter storm drain, to replace the existing bar ditch. The improvements also include upgrading the box culvert under U.S. 377. Additional curb inlets would also be installed at the intersection of Covington Drive and U.S. 377.

Also in the watershed, but on the east side of U.S. 377, improvements would be made under Park Road No. 3 by replacing the existing culverts with four 6' by 4' box culverts.

B. Watershed E2: Watershed E2 includes the portion of Westpark Addition at the east end of Lakeway Drive. Drainage in this area is proposed to be improved by adding a system of curb inlets and storm drain along U.S. 377 from Amory Drive to Lochness Lane. The existing bar ditches would be removed. Also in the watershed, culverts under Park Road No.1 and park Road No. 3 would be expanded.

C. Watershed F1: Watershed F1 drains the area on the south end of Stephen Road, south of Rogers Road. It also includes the undeveloped area to the west, including an unnamed tributary the drains into Benbrook Lake. It is recommended that the area west of Stephen Road be drained by a system of storm drains, ranging in size from 48 to 66-inches in diameter. The portion of Stephens Road from Cartwright Drive to the city limits would be drained by a system curb inlets and storm drains.

D. Watershed F2: Watershed F2 includes the area east of Stephens Road including Jakmar and Rogers Road. It is recommended that a set of curb inlets and a storm drain be installed along Jakmar Road, approximately 350 feet east of the intersection with Stephens Road. A similar set of curb inlets and storm drain would be installed in Rogers Road at its 90-degree bend. Finally, the culvert under Lakeview Drive would be upgraded.

E. Watershed F3: Watershed F3 drains a small area east of Rogers Road. The only improvements proposed are to upgrade the road culvert under Lakeview Drive.

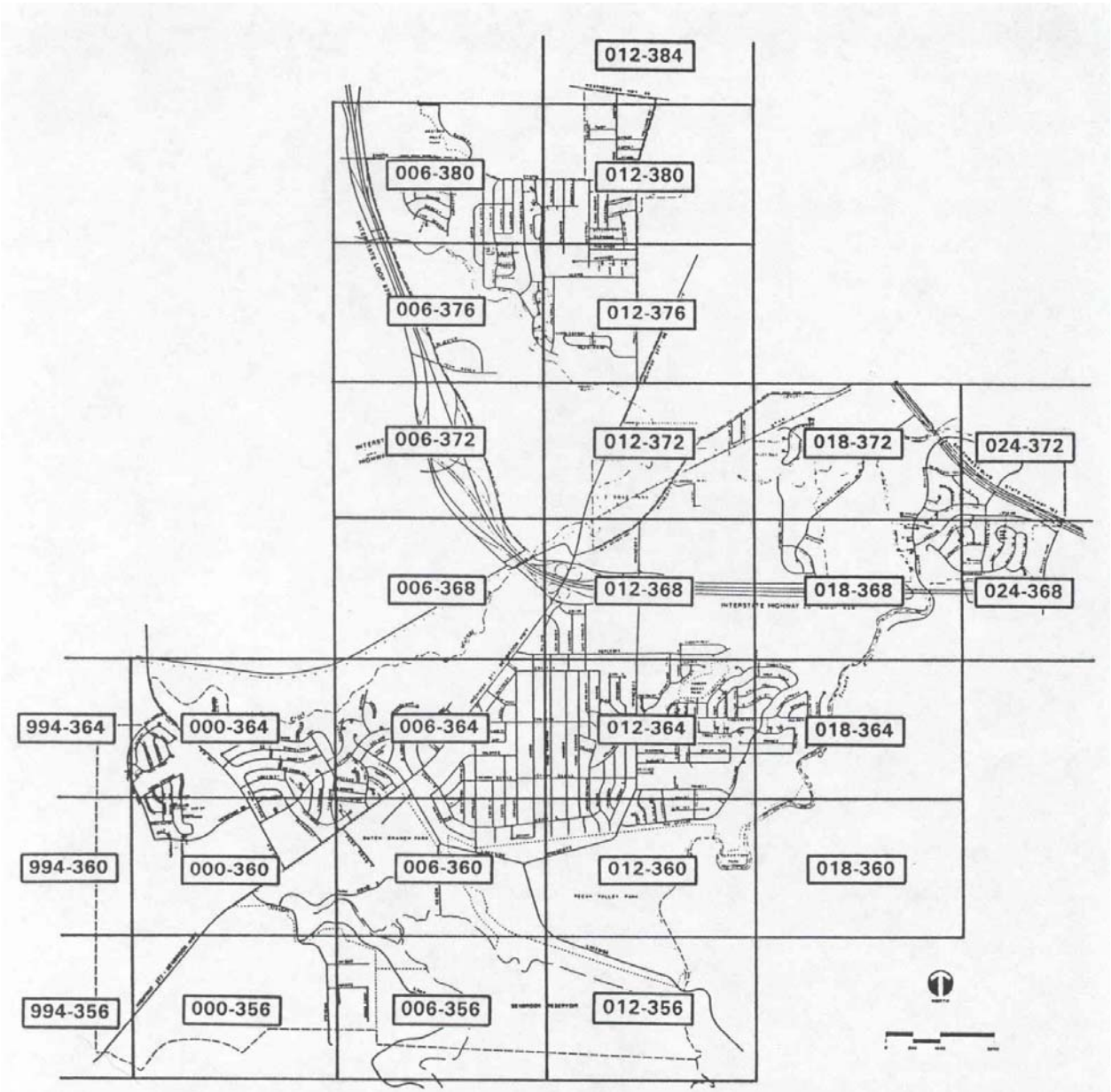

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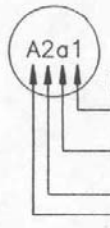
PLATE INDEX

MASTER DRAINAGE PLAN

LEGEND

DRAINAGE AREAS

- MAJOR WATERSHED DIVIDE (OR LIMITS OF STUDY AREA)
- DRAINAGE AREA DIVIDE
- DRAINAGE SUB-AREA



DRAINAGE AREA DESIGNATION
- SUB-DRAINAGE AREA WITHIN S.D. SYSTEM
- SUB-DRAINAGE AREA FOR MAJOR S.D. SYSTEMS
- DRAINAGE AREA
- MAJOR WATERSHED

- FLOW ARROWS
- A=20.2 DRAINAGE AREA SIZE (ACRES)
- C=0.5 RUNOFF COEFFICIENT
- Q5=75 DISCHARGE FOR 5 YEAR FREQUENCY STORM (C.F.S.)
- Q100=125 DISCHARGE FOR 100 YEAR FREQUENCY STORM (C.F.S.)
- A=20.2 C=0.5 Q5=75 SUMMARY OF DRAINAGE CALCULATIONS

DRAINAGE CHANNEL SYSTEMS

- EARTHEN CHANNEL SECTION
- CONCRETE LINED CHANNEL
- CONC. VERTICAL WALL CHANNEL

- 3:1 SIDE SLOPES – HORZ:VERT
- BW=6' BOTTOM WIDTH IN FEET
- n=0.035 ROUGHNESS COEFFICIENT
- S=1.2% SLOPE
- Q=250 DISCHARGE CARRIED WITHIN CHANNEL

DRAINAGE AREA INFORMATION SHOWN IN BLACK

EXISTING DRAINAGE SYSTEMS SHOWN WITH DASHED LINE IN BLUE

PROPOSED DRAINAGE SYSTEMS SHOWN WITH SOLID LINE IN RED

STORM DRAIN PIPE SYSTEMS

- STORM DRAIN PIPE
- MANHOLE
- 10' CURB INLET SIZE IN FEET
- D.I. DROP INLET
- G.I. GRATE INLET
- 54' @ 1.0% REINF. CONC. PIPE SIZE & SLOPE
- CMP CORRUGATED METAL PIPE
- 2-6'x4'MBC SINGLE AND MULTI-BOX CULVERTS
- Q=150 DISCHARGE CARRIED IN PIPE (CFS)