KATY FREEWAY CORRIDOR FLOOD CONTROL STUDY

EXECUTIVE SUMMARY

There are a number of drainage and flood control problems in the Buffalo Bayou watershed, including problems with the Addicks and Barker reservoir systems. Of primary concern is the fact that the reservoirs do not function as originally intended which translates into increased risk of flooding upstream of the reservoirs and less protection downstream. As development continues behind the reservoirs, there is the potential to expose as many as 25,000 homes and businesses in the reservoir fringe areas to flooding.

Buffalo Bayou has its own problems in that the reservoirs do not completely protect downstream development along the bayou from flooding. Due to the unique environment of the bayou, it is not practical to increase its flood control capacity, and land for flood control storage is generally not available. In addition, many of the tributaries which drain to Buffalo Bayou from the north are generally inadequate, environmentally sensitive, and capacity cannot be increased due to potential flooding impacts on Buffalo Bayou. Land development along the tributaries also makes storm water detention storage infeasible.

There are a number of possible ways to address the reservoir system’s inadequacies, including: controls on upstream development; modifications within the reservoir; increasing reservoir outfall capacity (to Buffalo Bayou or elsewhere); living with the problem and the potential damages.

One of the more promising possibilities involves the creation of additional reservoir outfall capacity by building a closed conduit system (culverts) down the Katy Freeway corridor. The Texas Department of Transportation has purchased the adjacent railroad corridor and is currently reviewing the transportation needs of the combined corridor from the Brazos River to downtown Houston. Major reconstruction of the freeway system would provide a unique opportunity to include a flood water conveyance system that could address many if not all of the Buffalo Bayou system’s drainage and flood control problems. The box culverts along the corridor could allow increased discharge from the reservoirs, intercept increased runoff from tributaries of Buffalo Bayou, divert flood waters from Buffalo Bayou, and provide drainage and flooding impact mitigation for the highway project.

A conceptual review of the system shows that it may work and would cost several hundred million dollars ($325 to $400 million). The potential flood control problems are severe enough to consider this magnitude of project, and the major transportation construction in the Katy Freeway corridor presents a unique, once-in-a-lifetime opportunity to consider this type of flood control option. To determine if a conduit system under the freeway is justified, it needs to be evaluated against other options.
INTRODUCTION

The Harris County Flood Control District (HCFCD) has completed a preliminary investigation to assess the technical merits of constructing a large flood control bypass conduit within the Katy Freeway right-of-way from the Addicks and Barker Reservoirs to a discharge point near downtown Houston. The primary reason for constructing a bypass conduit is to increase reservoir outlet capacity and drain the reservoirs more efficiently. Secondary reasons include providing flood relief to those areas located north of the Katy Freeway in the Buffalo Bayou watershed, reducing flood flows on Buffalo Bayou, and protecting Buffalo Bayou from environmentally damaging reservoir discharges.

Over the past several years, the concept of constructing a flood control bypass conduit within the Katy Freeway/railroad right-of-way has been discussed. The concept recently surfaced again during a series of public information meetings for the Texas Department of Transportation’s (TxDOT) Major Investment Study (MIS) of the Katy Freeway corridor. TxDOT is currently conducting a MIS to assess future transportation needs for a 40-mile section of IH-10 from the Brazos River to downtown Houston. Alternative transportation plans are being developed and screened considering transportation needs to the Year 2020. The MIS will culminate with selection and recommendation of a transportation plan for implementation. TxDOT’s current schedule is to begin major construction of the new IH-10 transportation facilities in Year 2001.

Problem Statement

The primary flood threat facing the citizens of west Harris County and west Houston comes from the inability to drain the Addicks and Barker reservoirs in an efficient manner. The maximum flood pool levels of the Addicks and Barker reservoirs extend far beyond the limits of the government owned land. There are currently 6,000 structures and more than 8,000 acres within the reservoir "fringe" areas between the limits of the government owned land and the extent of the Addicks and Barker maximum flood pools. While 6,000 is a large number, projected growth rates for west Harris County could easily increase the number of structures in the fringe to 25,000 or more. Delineations of the Addicks Reservoir and Barker Reservoir fringe areas are shown in Appendix A.

The addition of gates to the reservoirs' original uncontrolled outlet design, and the necessarily restrictive gate operations criteria used by the Corps of Engineers has limited the ability to empty the reservoirs in an efficient manner. Under the original design of the reservoirs with free outflow conditions, it would have taken a storm of unusually large magnitude to threaten properties not acquired by the federal government. However, under current conditions with the addition of gates and the restrictive operations criteria, it no longer takes an extreme storm. Just a wet period, consisting of a series of "normal" frequent storms (like the rainy period between November 1991 and June 1992) is enough to "ratchet" reservoir levels upward and severely flood private properties.
Flooding problems also exist downstream of the reservoirs. Buffalo Bayou has an extensive flood plain due to limited flood carrying capacity. Flood control alternatives to address flooding along Buffalo Bayou are limited due to the desire to preserve the bayou's unique environmental characteristics, and the scarcity of available land for siting traditional detention basins. Flood carrying capacities of the tributaries located to the north of Buffalo Bayou are also inadequate. Like Buffalo Bayou, there are not many feasible flood control alternatives to solve tributary flooding because of limited available land for detention, environmental concerns, and the inability to increase tributary capacities without transferring the flood problems downstream to Buffalo Bayou.

**Flood Control Alternatives**

Several alternatives (and combinations thereof) in addition to the Katy Freeway Corridor bypass conduit can be imagined to address the flood problems associated with the reservoirs. Some of these include:

- Buying out all reservoir fringe area properties;
- Redefining regulatory levels to require elevation of new structures above the reservoir maximum pool;
- Excavating more storage within the reservoir government owned land;
- Increasing flood releases from the reservoirs by changing the gate operations and providing for increased outflows to Buffalo Bayou;
- Providing additional reservoir outlet capacity by draining Barker Reservoir to Brays Bayou, and Addicks Reservoir to White Oak Bayou;
- Inter-connecting Addicks and Barker reservoirs to optimize available storage;
- Adopting a flood warning and evacuation plan for reservoir fringe properties;
- Do nothing and accept risk of flooding.

While all of these are potentially feasible ideas, providing additional reservoir outlet capacity by way of a Katy Freeway corridor bypass conduit is really the only alternative that addresses the secondary flood problems existing in the Buffalo Bayou watershed. Constructing the Katy Freeway corridor conduit would provide opportunities to be environmentally sensitive, while addressing inadequate reservoir outlet capacity, problems along Buffalo Bayou, and the inadequacies of the northern tributary drainage system.
Is the Katy Freeway corridor bypass conduit the “right plan?” Does it make sense to build urban transportation and flood control infrastructure within one corridor? The answers to these questions will come from a full scale feasibility level study. A feasibility level study is needed to screen all of the alternatives, and develop the best flood control plan for implementation. A unique opportunity currently exist to coordinate construction of a flood control conduit with construction of the Katy Freeway transportation facilities, but the aforementioned questions need to be answered. The time to conduct a feasibility study is now, while coordination with TxDOT is still possible.

Study Area

Figure 1 illustrates the study area for this investigation which includes: the Addicks Reservoir watershed (136 square mile drainage area), the Barker Reservoir watershed (130 square miles), and the Buffalo Bayou watershed (101 square miles). The study area is located generally in west Harris County, however, portions of the Addicks Reservoir watershed extend into adjacent Waller County, and portions of the Barker Reservoir watershed extend into Waller and Fort Bend counties.

The Buffalo Bayou watershed is heavily developed (approximately 80%) and encompasses primarily incorporated jurisdictions including the Memorial Villages, and portions of the City of Houston. In contrast, the Addicks and Barker watersheds are considerably less developed (approximately 30%) and are primarily unincorporated.
ADDICKS AND BARKER RESERVOIRS

The Corps of Engineers was given Congressional authorization to construct the Addicks and Barker reservoirs as part of the Buffalo Bayou and Tributaries, Texas Project by the Rivers and Harbors Act of June 20, 1938. The authorization was prompted by the devastating flood events of 1929 and 1935. The intent of the authorization was to construct a project to protect the City of Houston and the Houston Ship Channel. Part of the authorization provided for construction of the Addicks and Barker dam facilities, a channel project to enlarge and straighten Buffalo Bayou downstream of the reservoirs to a point where a diversion canal would convey flood waters to Galveston Bay, and a levee along Cypress Creek to block overflows into the Addicks Reservoir watershed. The detailed plan was approved in 1940. Construction of Barker Reservoir was completed in 1945. Addicks Reservoir and the 7.4 miles of outlet channel were completed in 1948. The diversion canal and the levee along Cypress Creek were never constructed.

Each reservoir was intended to have five outlet conduits (four ungated and one gated) with a total combined uncontrolled design flood discharge of 15,700 cubic feet per second (cfs). The reservoirs were originally designed to remain dry most of the time, and not store water for prolonged periods.

The federal government acquired property for the reservoir projects at an elevation three feet above the pools that would have been produced had the 1935 storm event been centered over each of the reservoir watersheds. This resulted in land acquisitions 5.9 feet below the maximum flood control pool of Addicks Reservoir, and 8.7 feet below the maximum pool of Barker Reservoir.

The purchase of land in this manner created a zone of land or "fringe" area upstream and adjacent to the reservoirs that was not purchased by the federal government but, could indeed flood given the height of the dams relative to these upstream areas. At the time, potential inundation of the fringe areas caused little concern and was viewed as an acceptable low risk for the government to incur. Since the fringe areas were primarily either agricultural land or undisturbed prairie land, the government presumed that damages resulting from inundation would be minimal.

Existing Conditions

Today, conditions are quite different. To begin with, the Corps of Engineers have added gates to all of the outlet conduits at both Addicks and Barker Dams to regulate reservoir discharges into Buffalo Bayou. The Corps developed and currently use a gate operations criteria to determine how much and when to open the gates. The criteria takes into account reservoir conditions (quantity of inflows to the reservoirs and the rate at which the reservoir pools rise), flooding conditions downstream along Buffalo Bayou, and predicted conditions from weather forecasts. During dry weather conditions, the Corps will release a maximum flow of 2,000 cfs measured at Piney Point Road. During wet weather conditions, when rain is forecasted to occur, the gates are closed. The
gates remain closed until flow conditions in Buffalo Bayou and weather forecast permit reservoir releases.

The addition of gates and the restrictive operation criteria to limit reservoir discharges causes water to be stored in the reservoirs for longer durations than the original designers ever intended. There is now cause for concern about the prolonged ponding time in the reservoirs and with the fact that the maximum pool levels of both reservoirs extend far beyond the limits of the government owned land. There are 3,600 acres of land and approximately 6,000 structures within the fringe areas of Addicks and Barker reservoirs. The fringe area adjacent to Addicks Reservoir encompasses 4,000 acres of land with approximately 5,000 structures, while the fringe area adjacent to Barker Reservoir encompasses 4,600 acres of land with approximately 1,000 structures.

Flooding of fringe area structures and properties from high reservoir pool levels would be different than the type of riverine flooding typically experienced in this region. Flood levels would not recede over the course of several hours like typically experienced with flooding from channels, in fact, fringe area properties could be inundated for an extended period because of the restrictive gate operations criteria. The types of problems encountered due to the inability to draw the reservoir pools down would be much more severe than those that occurred when the reservoirs reached record levels in March 1992. Not only would public park and transportation facilities be severely impacted from prolonged storage of water, but structures, including homes would also be impacted. As it was, the closure of State Highway 6 during a 10-day period in early March 1992 affected 37,000 vehicles per day.

Considering the original design of the reservoir and outfall facilities and the project's remote rural location; the land acquired by the government was probably an adequate amount, and potential flooding of the fringe areas was probably an acceptable low risk. However, some 50 years later, with the addition of gates and the restrictive operations criteria to limit reservoir discharges and the substantial amount of urban developments now occurring in both the fringe areas and throughout both of the watersheds, the project's original design parameters and assumptions are severely outdated and invalid.

Reservoir Levels and Storage

Table 1 is a summary of physical data for Addicks and Barker reservoirs. Among other pertinent data, Table 1 shows the limits of the government owned land in terms of surface area. The federal government owns 12,460 acres at the Addicks Reservoir site and 12,060 acres at the Barker Reservoir site. However, the limits of the maximum pool for Addicks and Barker reservoirs are 16,423 acres and 16,739 acres, respectively. Figure 2 is a graphic illustration of critical reservoir levels.
TABLE 1
Addicks and Barker Reservoir Data

<table>
<thead>
<tr>
<th></th>
<th>Reservoirs</th>
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<tbody>
<tr>
<td></td>
<td>Addicks</td>
<td>Barker</td>
<td></td>
</tr>
<tr>
<td>Drainage Area Above Dams</td>
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<td></td>
<td></td>
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<tr>
<td>(sq. miles)</td>
<td>136</td>
<td>130</td>
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<td>Elevation (NGVD, 1973 Adj.)</td>
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<tr>
<td>100-Year Flood</td>
<td>104.1</td>
<td>97.8</td>
<td></td>
</tr>
<tr>
<td>Limit of Government Owned Land</td>
<td>106.1</td>
<td>97.3</td>
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</tr>
<tr>
<td>Maximum Storage Capacity</td>
<td>112.0</td>
<td>106.0</td>
<td></td>
</tr>
<tr>
<td>Flood of Record (3/9/92 Addicks, 3/6/92 Barker)</td>
<td>100.6</td>
<td>95.9</td>
<td></td>
</tr>
<tr>
<td>Reservoir Surface Area (acres)</td>
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<tr>
<td>100-Year Flood</td>
<td>11,213</td>
<td>12,293</td>
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<tr>
<td>Limit of Government Owned Land</td>
<td>12,460</td>
<td>12,060</td>
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<tr>
<td>Maximum Storage Capacity</td>
<td>16,423</td>
<td>16,739</td>
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<td>Flood of Record (3/9/92 Addicks, 3/6/92 Barker)</td>
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<tr>
<td>Storage Capacity (acre-feet)</td>
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<td>100-Year Flood</td>
<td>92,572</td>
<td>89,498</td>
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<td>Limit of Government Owned Land</td>
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<td>Maximum Storage Capacity</td>
<td>200,800</td>
<td>209,000</td>
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<td>57,956</td>
<td>66,910</td>
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<tr>
<td>Storage Capacity (inches of runoff)</td>
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<td></td>
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<tr>
<td>100-Year Flood</td>
<td>12.8</td>
<td>12.9</td>
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<tr>
<td>Limit of Government Owned Land</td>
<td>16.0</td>
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<tr>
<td>Maximum Storage Capacity</td>
<td>27.7</td>
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<td>8.0</td>
<td>9.7</td>
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</table>

1. Source: U.S. Army Corps of Engineers
Figures 3 and 4 show the relative amount of storage volumes (converted to inches of runoff from the watershed) for some of the critical reservoir levels. For example, approximately 12 inches of runoff from the Barker watershed are required to reach the limits of the government owned land, and 30 inches of runoff are needed to reach the maximum pool level. The record level for Barker occurred from a net accumulation of 10 inches of runoff over a three month period. Similarly, Figure 4 demonstrates relative amounts of storage volumes for Addicks Reservoir.

**Reservoir Analysis**

An analysis was conducted to illustrate how storage levels in the reservoirs fluctuated over the period from December 1, 1991 through June 30, 1992. Figures 5 and 6 demonstrate the reservoirs' storage volume fluctuations in terms of inches of runoff. The amount of water stored in the reservoirs reached record levels in early March 1992 (March 6 for Barker and March 9 for Addicks). The figures illustrate that over a two-week time frame beginning in mid-December, runoff resulting from a number of small rainfall events filled Barker to a storage volume equivalent to about six inches of runoff, and Addicks to a storage volume of about eight inches of runoff. Once the reservoirs were filled to this capacity, subsequent “normal” and frequent rain storms coupled with the restrictive gate operations criteria "ratcheted" the amount of water in the reservoirs upward until record capacities and pool levels were reached in early March.

It is conceivable and not hard to imagine that a single storm event could have a catastrophic impact to several thousand people in the reservoirs and the fringe areas. But, it's just as important to realize that a rainy season consisting of several “normal” rain storms (like the period from December 1991-March 1992) could be just as catastrophic because of the ratcheting effect. When the reservoirs store water for extended periods, fringe area properties are at greater risk from additional normal rains or a moderate single event pushing reservoir pools upward to damaging levels.

To illustrate this, an analysis was conducted to demonstrate and compare flood conditions that would have occurred in the reservoirs from, first, a period of multiple normal rain storms over the Addicks and Barker watersheds, and second, from centering a large single event storm system over the watersheds. The December 1991 to mid-March 1992 storm period (including the event of March 4, 1992, which was actually centered 10-miles to the east of Addicks and Barker reservoirs) was analyzed to simulate the effects on the reservoirs from multiple storms. The October 15-18, 1994 storm event, which was actually centered 20-miles to the north of Addicks and Barker reservoirs, was used to simulate the effects of a large, single event storm system.

Assumptions were made regarding overflows from the Cypress Creek watershed to the Addicks Reservoir watershed and the available reservoir storage capacities at the start of each storm. The analysis assumed that no overflows occurred from Cypress Creek to Addicks Reservoir, and that the reservoirs were empty at the onset of the October 1994 storm. For the multiple event storm
analysis, simulating the December 1991 to mid-March 1992 storm period, actual reservoir pool levels were used.

Results of the analysis indicate that either storm system centered over the Addicks and Barker watersheds would have caused pool levels to surpass record flood levels and severely impact several thousand people and several public facilities in both the reservoirs and the fringe areas. The results of the analysis are shown in terms of reservoir pool levels on Figure 2 (labeled “shifted storm”), and shown in terms of resulting storage volumes on Figures 3 and 4. Tables 2 and 3 provide a comparison between the levels that resulted from the actual storm events and the levels that would have occurred had the storms been centered over the Addicks and Barker watersheds.

For the multiple storm scenario analysis using the December 1991 to mid-March 1992 rainy period and centering the March 4, 1992 storm event 10-miles to the west of where it actually occurred, Addicks Reservoir would have reached a pool level 3.8 feet higher (Elevation 104.4) than its record level (Elevation 100.6) and Barker Reservoir would have reached a pool level 2.3 feet higher (Elevation 98.2) than its record level (Elevation 95.9).

For the single event storm scenario analysis centering the October 1994 storm system over the Addicks and Barker watersheds (20-miles to the south of where it actually occurred), Addicks Reservoir would have reached a pool level 10.7 feet higher (Elevation 111.3) than its record level and Barker Reservoir would have reached a pool level 8.4 feet higher (Elevation 104.3) than its record level.

The analysis indicates that storm events typical of the Gulf Coast region, coupled with the inability to empty the reservoirs in a timely manner because of restrictive gate operations, can cause reservoir pool levels to:

- rise over the course of several days from a large single storm event; and
- be ratcheted upward over several months from a series of “normal” frequent rain events.
### TABLE 2
ANALYSIS OF MARCH 4, 1992 STORM
(MULTIPLE EVENT STORM SCENARIO)

<table>
<thead>
<tr>
<th>Conditions Prior to Storm</th>
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<tr>
<td>Pool Elevation</td>
<td>98.1</td>
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<tr>
<td>Volume (acre-feet)</td>
<td>39,330</td>
<td>42,260</td>
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<table>
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<th>Results of Actual Storm (Flood of Record)</th>
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<tr>
<td>Maximum Pool Elevation</td>
<td>100.6</td>
<td>95.9</td>
</tr>
<tr>
<td>Corresponding Volume (acre-feet)</td>
<td>57,956</td>
<td>66,910</td>
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<td>Corresponding Pool Area (acres)</td>
<td>8,442</td>
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<th>Results of Hypothetical Storm (Shifted 10 miles West)</th>
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<th>Barker</th>
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<tbody>
<tr>
<td>Maximum Pool Elevation</td>
<td>104.4</td>
<td>98.2</td>
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<tr>
<td>Corresponding Volume (acre-feet)</td>
<td>95,540</td>
<td>94,293</td>
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<tr>
<td>Corresponding Pool Area (acres)</td>
<td>11,378</td>
<td>12,523</td>
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Note: All elevations referenced to NGVD, 1973 Adj.

### TABLE 3
ANALYSIS OF OCTOBER 15-18, 1994 STORM
(SINGLE EVENT STORM SCENARIO)

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<tr>
<td>Pool Elevation</td>
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<td>Volume (acre-feet)</td>
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<table>
<thead>
<tr>
<th>Results of Actual Storm</th>
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<th>Barker</th>
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</thead>
<tbody>
<tr>
<td>Maximum Pool Elevation</td>
<td>98.8</td>
<td>92.8</td>
</tr>
<tr>
<td>Corresponding Volume (acre-feet)</td>
<td>43,670</td>
<td>32,571</td>
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<tr>
<td>Corresponding Pool Area (acres)</td>
<td>7,196</td>
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<th>Results of Hypothetical Storm (Shifted 20 miles South)</th>
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<tr>
<td>Maximum Pool Elevation</td>
<td>111.3</td>
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<tr>
<td>Corresponding Volume (acre-feet)</td>
<td>188,587</td>
<td>180,310</td>
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<tr>
<td>Corresponding Pool Area (acres)</td>
<td>15,877</td>
<td>15,755</td>
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Note: All elevations referenced to NGVD, 1973 Adj.
BUFFALO BAYOU WATERSHED

Existing Conditions

There are several constraining factors related to flood control and drainage in the Buffalo Bayou Watershed downstream of the reservoirs. To begin with, Buffalo Bayou is subject to flooding even without the influence of reservoir discharges. The large drainage area combined with limited channel capacity, results in a 100-year flood plain covering approximately 3,000 acres and affecting about 3,000 structures.

The watershed is divided by the Katy Freeway corridor transportation facilities. Historically, storm runoff from the northern sections of the watershed drained relatively unimpeded to Buffalo Bayou by way of several major tributaries including Turkey Creek, Rummel Creek, Soldiers Creek, and Spring Branch. As the watershed developed and the Katy Freeway corridor transportation facilities (freeway lanes, frontage roads and railroad) were built, culverts and drainage structures were constructed to bridge the tributaries. Today, stream capacities and drainage structures do not meet current desired levels of service and storm water drainage from north of the transportation corridor to Buffalo Bayou has become restricted.

The area located to the north of the Katy Freeway and railroad right-of-way has a number of flooding and drainage problems. The flood control options for this area are limited. Detention basins are used throughout Harris County to store flood waters in areas without adequate channel capacity. In the case of Spring Branch and adjacent communities north of the Katy Freeway, detention basins are not practical alternatives due to the scarcity of available vacant land. Channelization is also a typical flood control measure used to efficiently convey storm water away from areas that flood. However, in this case, channelization of the northern tributaries without mitigating detention would merely transfer the flooding problems downstream toward and/or to Buffalo Bayou.

Environmental Aspects

"Traditional" channelization to increase the flood carrying capacity of Buffalo Bayou is an old and unpopular idea that has met much opposition due to the bayou’s unique environmental characteristics. Buffalo Bayou extends approximately 26 miles from the Ship Channel turning basin to the Addicks and Barker reservoirs. The reach of the bayou between Shepherd Drive and Rummel Creek (approximately 19 miles) remains in its natural condition meandering through lush and dense vegetation through the Memorial and River Oaks sections of Houston. Because of its perennial flow characteristics, the bayou offers a unique habitat for diverse plant and animal species to thrive. Buffalo Bayou and its tributaries are unique in that they pass through three primary ecosystems converging in the Houston area. The three ecosystems include: the East Texas Piney Woods, the Fayette Prairie, and the coastal marsh.
Many natural processes take place along the riparian corridor of Buffalo Bayou. The fluvial geomorphological process or the bayou's desire to equalize water flow and sediment transport is no exception. There are numerous bank failures along Buffalo Bayou due to the fluvial process. Erosion of material at the toe of the side slopes and the transport of stream bed material cause bank failures to occur in several different modes.

One theory faults sustained reservoir discharges for some of the bank failures. Water levels in Buffalo Bayou due to reservoir releases are typically much higher than normal base flow levels. The sustained higher water levels tend to kill vegetation making the banks of the bayou more susceptible to erosion. Bank saturation at higher than normal water levels and the drawdown effect as reservoir releases are lowered, have the potential to weaken the structural integrity of the channel banks causing failures to occur. While reservoir discharges are not the only factor influencing the erosion process, the ability to consistently maintain the bayou's normal base flow level would sustain vegetation growth resulting in more stable slope conditions.
BUFFALO BAYOU BYPASS CONDUIT

The conceptual plan derived during this preliminary investigation is illustrated on Figure 7. The plan consists of a conduit structure extending approximately 12 miles from the reservoirs to an outfall or discharge point near downtown Houston. Figure 7 shows the conduit outfall point at White Oak Bayou, but other alternative outfall points, like at the Ship Channel, may be feasible. The structural configuration consists of multiple box structures buried underneath the Katy Freeway transportation facilities. Two alternative structures were sized for discussion purposes, and it was found that either 8-12-foot by 12-foot boxes or 6-14-foot by 14-foot boxes would be adequate to convey reservoir discharges of about 8,000 cfs (approximately one-half of the Corps' original outfall design capacity for the ungated reservoir outlets). An optimization analysis would need to be part of a full feasibility study to determine the conduit size that would be appropriate.

Operation of the reservoir-conduit flood control system would likely be required and is a factor that needs to be considered. Reservoir releases would be made after the threat of downstream flooding has passed. That is, after the tributaries north of Buffalo Bayou have drained, and after the downstream outfall channel has receded. Between periods of reservoir releases, the conduits would be used to provide volume (approximately 200 acre-feet for each 12-foot by 12-foot box structure) for storm water storage.

Additionally, several other factors need to be considered, such as:

- specific system operation criteria and controls;
- an inlet design for the conduit to provide a safe means to capture reservoir discharges;
- a way to intercept some of the lateral drainage channels and re-route others to provide drainage and flood control outfall to the areas north of the Katy Freeway transportation facilities;
- accommodating utility and transportation crossings within TxDOT's right-of-way;
- avoiding adverse impacts to the receiving channel and areas downstream; and
- disposal of the excess material left over from the excavation operation.

Potential Costs and Benefits

Preliminary estimates suggest a construction cost for the bypass conduit on the order of $325 million. The cost estimate takes into account labor and materials for construction of the bypass structure, excavation, subgrade and foundation preparation, backfill, and 10% for
The estimate does not specifically account for utility relocations; transportation facility relocations; lateral channel modifications; or inlet, outlet, and receiving channel features. Additionally, the estimate does not specifically account for the cost savings of constructing the bypass conduit in conjunction with construction of the transportation facilities. A detailed cost estimate is needed for consideration of all these factors and should be part of a full scale feasibility level study.

An economic analysis is also needed to quantify all the flood damage reduction benefits, but it is conceivable that under existing conditions in the reservoir fringe areas, on the average of $10,000 of damage per structure and per flood occurrence (or $60 million total per flood occurrence) could be prevented by constructing the bypass conduit. Future damage reduction benefits would increase as the fringe area develops and could easily reach the $250 million to $300 million total level per flood occurrence assuming 25,000 structures ultimately occupy the fringe area. Other benefits to consider include preventing closures of transportation facilities (mainly State Highway 6, but also Eldridge Parkway, Clay Road, Barker Cypress Road, and Westheimer Parkway), and flood damage reduction in the Buffalo Bayou watershed.
CONCLUSION AND RECOMMENDATION

The Addicks and Barker reservoirs-Buffalo Bayou flood control system has never been constructed to completion, and because of this, Buffalo Bayou lacks adequate outfall capacity to convey unregulated reservoir discharges. The addition of gates to the outlet conduits and the restrictive operations criteria cause prolonged storage of water, thus, increasing the risk of flooding to reservoir fringe area properties. Buffalo Bayou has an extensive 100-year flood plain, and there are several flooding and drainage problems throughout the Buffalo Bayou watershed, including those areas located north of the Katy corridor transportation facilities.

This investigation concludes that construction of a bypass conduit offers an opportunity to:

- drain the reservoirs faster, reducing extended risk to fringe area properties;
- address the drainage and flooding problems in the areas of the Buffalo Bayou watershed located north of the Katy Freeway corridor transportation facilities;
- protect Buffalo Bayou from environmentally damaging reservoir discharges;
- reduce flooding on Buffalo Bayou because the tributaries draining from the north could be intercepted; and
- eliminate and/or reduce the need to structurally modify Buffalo Bayou to increase conveyance capacity.

Because major reconstruction of the Katy Freeway corridor transportation facilities presents an opportunity to address the inadequacies of the reservoirs as well as many of the flooding problems throughout the Buffalo Bayou watershed, it is recommended that a full scale feasibility study be conducted now to evaluate all the options and select the best flood control alternative for implementation, while coordination with TxDOT’s construction schedule is still possible.
KATY FREEWAY CORRIDOR FLOOD CONTROL STUDY
HARRIS COUNTY FLOOD CONTROL DISTRICT PLANNING DEPARTMENT
ADDICKS RESERVOIR VOLUME TOTALS
(Inches of Runoff)

FIGURE 4
APPENDIX A

RESERVOIR FRINGE AREA MAP
Content Overview

The information below elaborates on what you heard and saw in the video portion of this lesson.

Hazard Mitigation

As stated earlier, hazard mitigation can be defined as any action of a long-term, permanent nature that reduces the actual or potential risk of loss of life or property from a hazardous event.

Examples of mitigation measures include:

- elevating a structure.
- strengthening existing foundations, floors, and walls to withstand stress.
- making utilities, structural components, and contents resistant to damage.

FEMA has two primary hazard mitigation programs: Public Assistance hazard mitigation (known as Section 406 mitigation) and the Hazard Mitigation Grant Program (also known as Section 404 mitigation.) The numbers refer to the relevant sections of the Stafford Act. The objective of both programs is to prevent future loss of property and lives.

It is helpful to understand the similarities and differences between the two types of mitigation. There will be times when you will need to work closely with mitigation personnel or be asked by applicants to explain these similarities and differences.

Public Assistance Hazard Mitigation Activities (406 Mitigation)

One intent of the PA Program is to promote hazard mitigation measures in the repair of damaged facilities and infrastructure. Under this program, all repairs must be made in accordance with applicable codes and standards. Mitigation measures can be included in the repair of damaged facilities if the measures are at an eligible site, are technically feasible, are cost-effective, and comply with all other federal laws and regulations. FEMA may prescribe codes and standards where they are lacking. Public Assistance staff duties include:

- reviewing project worksheets for mitigation opportunities.
- making recommendations for hazard mitigation measures based on project worksheet reviews.
- ensuring that the solution is physically part of the damaged facility.

Examples of Section 406 mitigation include (but are not limited to):

- Relocation of facilities in hazardous locations
- Roads and bridges
- Utilities
- Buildings
- Riprap
- Cribbing or retaining walls
- Soil-retention blankets
- Flattening of slopes
Seeding

Floodproofing buildings
- Construction of low-level rigid dikes
- Abandonment
- Use of flood-resistant materials
- Use of shields, flood barriers, or sealants at doors and windows
- Installation of hurricane shutters
- Elevation of mechanical equipment and utilities
- Elevation of the building
- Installation of anti-backflow devices on floor drains

Floodproofing of utilities
- Placement of utilities on bridges instead of channel bottoms
- Encasing utilities or constructing low head dams for protection
- Installation of flap gates on storm sewer outlets
- Elevation of controls and motors at lift stations
- Use of submersible pumps
- Use of shields or sealants

Floodproofing of bridges and culverts
- Clear spans instead of multispans
- Low water crossings instead of bridges
- Installation of cut-off walls or headwalls on culverts
- Increasing hydraulic capacity
- Flared end sections
- Use of disaster-resistant materials
- Abandonment or consolidation
- Lower abutment footings
- Use of tie-downs on bridge decks
- Installation of jump spans instead of replacement of embankments
Hazard Mitigation Grant Program (404 Mitigation)

PURPOSE AND OBJECTIVES

The purpose of the Hazard Mitigation Grant Program is to:

- Reduce the risk of future damage, hardship, loss, or suffering as a result of major disasters by providing substantial financial support to implement cost-effective, post-disaster state and local hazard mitigation measures.
- Provide funding for mitigation measures identified through the post-disaster hazard mitigation plan required of state and local governments as a condition of receiving federal assistance.

The objectives of the program are to encourage state and local governments to:

- Identify and implement cost-effective mitigation measures that will reduce future disaster losses.
- Coordinate mitigation needs with existing state and federal efforts.
- Capitalize on previous mitigation planning efforts to maximize the financial opportunities available.

PROGRAM GUIDELINES

The Hazard Mitigation Grant Program is available following a disaster declaration. The program is managed by the state. Applicants, primarily local governments and non-profits, put together projects and submit them to the state. The state prioritizes the projects based on its Hazard Mitigation Plan, ranks them, and recommends them to FEMA for funding, if so desired. FEMA does a final eligibility determination, an environmental review, and a benefit-cost analysis to ensure cost-effectiveness.

The amount of funding is based on the federal expenditures during the disaster response and recovery. The federal share of the grants cannot exceed 15 percent of the total federal expenditures.

FEMA may contribute up to 75 percent of the costs approved for funding. The state and/or local cost share, which must be not less than 25 percent, may be met with cash or in-kind contributions.

Projects funded under this program must:

- conform to the state Hazard Mitigation Plan.
- provide a beneficial impact on the disaster area.
- conform to all federal laws and regulations.
- solve a problem independently or constitute a functional part of the solution.
- be cost effective.
ELIGIBLE PROJECTS

Types of projects that are eligible include:

- property acquisition, relocation of structures, and conversion of land to open space.
- retrofitting or seismic rehabilitation of facilities.
- implementation of state or local mitigation standards.
- initial implementation of vegetation management programs to reduce wildfire hazards to high-risk structures.

Key Differences Between 404 and 406 Mitigation

The differences between the programs are summarized below.

<table>
<thead>
<tr>
<th>404 Mitigation</th>
<th>406 Mitigation</th>
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</thead>
<tbody>
<tr>
<td>The state administers the program and prioritizes projects. The applicants are usually local communities.</td>
<td>Administered by FEMA’s PA Program.</td>
</tr>
<tr>
<td>Covers structural measures and non-structural measures.</td>
<td>Covers structural measures.</td>
</tr>
<tr>
<td>Can be anywhere in the state and not directly related to disaster damage.</td>
<td>Covers disaster-related damage only.</td>
</tr>
<tr>
<td>Program funds capped at 15 percent of total disaster funds spent in the state. The Hazard Mitigation Grant Program can allocate up to 75 percent per project for the federal share.</td>
<td>No program-wide cap on funds. The federal cost share is not less than 75 percent.</td>
</tr>
</tbody>
</table>