PHASE I GEOLOGIC FAULT ASSESSMENT
SKYSCRAPER SHADOWS LOCAL DRAINAGE PROJECT
STORM SEWER AND PAVING
WBS NO. M-000126-0070-3
HOUSTON, HARRIS COUNTY, TEXAS

PREPARED FOR:
AECOM
5444 WESTHEIMER ROAD, SUITE 200
HOUSTON, TEXAS 77056

PREPARED BY
HVJ ASSOCIATES, INC.
HOUSTON, TEXAS
FEBRUARY 17, 2015

REPORT NO. HE1510720
KEY MAP 575 P & Q

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February 17, 2015

Ms. Erin E. Williford, PE
AECOM
5444 Westheimer Road, Suite 200
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Re: Phase I Geologic Fault Assessment
Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Texas
Owner: City of Houston
HVJ Project No. HE1510720

Dear Ms. Williford:

Presented herein is our Phase I Geologic Fault Assessment draft report for the above captioned project. The study was performed in general accordance with the City of Houston Department of Public Works & Engineering Design Manual Chapter 11 and our proposal number HE1510720 dated January 16, 2015.

This report presents HVJ Associates' understanding of the project's scope, the methodology we employed in executing the work, and the conclusions we reached subject to the limitations discussed in Section 10 of this report.

It has been a pleasure to work with you on this project, and we appreciate the opportunity to be of service. Please notify us if there are questions or comments or if we may be of further assistance.

Sincerely,

HVJ ASSOCIATES, INC.
Texas Firm Registration No. F-000646

Edward F. Hawkinson, PG
Project Manager

Sharmi Vedantam, PE
Project Engineer

EH/MH/MM/SV/nl

Copies Submitted: 2 draft
The following lists the pages which complete this report:

- Main Text - 17 pages
- Plates - 8 pages
- Appendix A – 3 pages
- Appendix B – 9 pages
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EXECUTIVE SUMMARY

HVJ Associates, Inc. has completed a Phase I Geologic Fault Assessment for a project which involves the replacement of storm sewers and associated pavement along Gulick Lane from Randolph Street to Monroe Street, along Holiday Lane from Wingtip Drive to Monroe Road, at the intersection of Wetherby Lane and Monroe Road, and at the intersection of Swiftwater Lane and Monroe Road in Houston, Texas (referred to as the Subject Project Alignments in this report) in Houston, Harris County, Texas (see Plate 1- Site Vicinity Plan for the Subject Project Alignments location).

Our services included a review of available published and unpublished literature on faulting in the area and a site reconnaissance. The acreage is currently partially developed with commercial and single-family residential structures. Access to the project area was not limited. The available information for this project and the on-site reconnaissance conducted during February 2015 are summarized below:

- The subject project area appears to be in an area of south Houston with well documented fault systems with surface expressions. The project area is crossed by one down to the northwest, southwest to northeast trending geologic fault (designated Geologic Fault 25 in the literature) which may be radial to the South Houston Oil field approximately three miles northeast of the Subject Project Alignments.

- Analysis of vertical aerial photographs revealed one linear features or lineaments near the Subject Project Alignments areas. The 1944 aerial photograph showed some shading and drainage alignments which may be indicative of the documented geologic fault crossing through the Subject Project Alignments area. Development in the project area prior to 1953 makes resolution of these features in later years difficult.

- Examination of the oldest available historical topographic map for the 1915 Mykawa Quadrangle revealed topographic features and/or stream and drainage patterns that could be related to faulting.

- Cracked paving was observed at the southeast corner of the intersection of Gulick Lane and Wingtip. This may be related to the documented fault in the area. No obvious building damage indicating recent fault movement was observed.

- We conclude the potential for active surface faulting to impact the proposed Subject Project Alignments is moderate since one documented mapped fault transects the project area. We estimate that the fault extends under the Subject Project Alignments area at an angle of approximately 75° (from the horizontal). This dip is typical for faults in the Houston Metropolitan area and is a rough estimate based on invasive fault studies conducted by HVJ Associates in the general project area and from other sources.

- Geologic Fault 25 is mapped crossing Gulick Lane near the intersection of Wingtip from and at Holiday Lane between Wingtip and Randolph. The upthrown zone of fault influence for this fault is estimated to extend 100 ft. southeast of the approximate fault location. The

downthrown zone of influence for this fault is estimated to extend 100 feet northwest of the fault location.

The location of the subject faulting is fully documented in the geologic literature but not by field reconnaissance. No other faulting was observed or is documented in the literature on or near the Subject Project Alignments area. Therefore, we do not recommend additional assessment(s) to determine the extent of potential faulting in this part of the project area. We recommend installing the utilities in the normal way and provide some accommodation for future maintenance work as the actual fault location is not identified in the field. Another approach would be to take some steps at the locations where faulting might be anticipated based the historic literature review. HVJ can definitely provide such recommendations to accommodate faulting if requested even though no obvious faults are observed during our field reconnaissance.

This executive summary does not fully summarize our findings and opinions. Those findings and opinions are related through the full report only.

1. INTRODUCTION

1.1 Project Objective

HVJ Associates, Inc. was contracted by AECOM to perform a Geologic Fault Assessment along Gulick Lane from Randolph Street to Monroe Street, along Holiday Lane from Wingtip Drive to Monroe Road, at the intersection of Wetherby Lane and Monroe Road, and at the intersection of Swiftwater Lane and Monroe Road in Houston, Texas. Published geologic studies have identified one geologic fault trending through the Subject Project Alignments area. This fault may be radial to the South Houston Oil Field to the northeast. Access to the project area was not limited. The objective of this study was to identify active faulting in the study area based on available data and a site reconnaissance and to determine if faulting hazards exist that could affect planned development.

1.2 Project Scope

The scope of services for this study were performed in general accordance City of Houston, Department of Public Works & Engineering Design Manual Chapter 11 "Geotechnical and Environmental Requirements" Section 11.09 Fault Assessment. The following tasks were performed:

1. A search was conducted of available published and unpublished literature on geologic faulting to point out areas of known fault activity and assist in locating direct site-specific evidence. Literature reviewed included publications of the U.S. Geological Survey, Texas Bureau of Economic Geology, Gulf Coast Association of Geological Societies, and the Houston Geological Society.

2. A review of the results of previous fault studies, performed by HVJ Associates, in adjacent areas was conducted and relevant information from those studies was considered for this study.

3. A review of a series of black and white and color vertical historic aerial photographs (1944 through 2012) and U.S.G.S. topographic maps (1915 through 2013) was conducted to identify features that may indicate the presence of faulting.

4. A physical site and area reconnaissance was performed to identify and locate features that indicate the presence of faulting. All evidence derived from the literature, photo and map reviews was evaluated in the field.

5. This report was prepared summarizing our findings, conclusions and recommendations.

1.3 Basis of Report

Although this study has been a reasonably thorough attempt to identify faulting in the vicinity of and on the subject property, there is a possibility that existing faults may have escaped detection due to the inherent limitations of this or similar studies or the inaccuracy of published and unpublished data. If faults are present, the surface evidence may not be well developed or may be obscured by erosion, soil and vegetation cover, and/or new construction.

HVJ Associates reserves the right to alter our conclusions and recommendations based on our review of any information obtained after the date of this report. The data obtained during the course of this Assessment and this report is for the sole and exclusive use of AECOM. HVJ

Associates, Inc. will hold all project data, papers, correspondences and reports pertaining to this study confidential to the extent allowed by law.

Our professional services have been performed using that degree of care and skill ordinarily exercised, under similar conditions, by geotechnical consultants practicing in this or similar localities. No warranty, express or implied, is made as to the professional information included in this report.

1.4 Qualifications of Licensed Geologist

The primary investigator for this study is Mr. Edward Hawkinson. Mr. Hawkinson holds BS and MS degrees in geology from The Ohio State University and the University of Cincinnati respectively, and an MBA from the University of Cincinnati. Mr. Hawkinson is a registered professional geologist in Arkansas, Tennessee and Texas (License Number 45). His career encompasses a period exceeding 30 years involving both Phase I and II Geologic Fault Studies, environmental site assessments, hydrogeology, water resource evaluations, NEPA Environmental Assessments and energy exploration.

2. PROJECT DESCRIPTION

The Subject Project Alignments area is located along streets within a developed residential area of south Houston. The surface area of the Subject Project Alignments are paved with unpaved areas outside roadways within the right of way.

3. BACKGROUND

3.1 Geologic Setting

A review of the Bureau of Economic Geology 1992 Geologic Atlas of Texas, Houston Sheet indicates that the uppermost geologic formation underlying the Subject Project Alignments is the Pleistocene Beaumont Formation (map symbol Qb). This formation was deposited on land near sea level in flat river deltas and in inter-delta regions. Soil deposition occurred in fresh water streams and in flood plains (as backwater marsh and natural levees). The courses of major streams and deltaic tributaries changed frequently during the period of deposition, generating within the Beaumont clay a complex stratification of sand, silt and clay deposits. Frequently, stream courses were diverted significant distances from a given point in a backwater marsh, and the water overlying the soil would evaporate since it was cut off from a drainage path. Such water, which would be highly alkaline, would precipitate large nodules of calcium carbonate (calcareous nodules) throughout the surface of evaporation. With the coming of the Second Wisconsin Ice Age, the nearby sea withdrew, leaving the formation several hundred feet above sea level and permitting the soil to desiccate. The process of desiccation compressed the clays in the formation such that they became significantly overconsolidated to a large depth. In addition to pre-consolidating the soil, the process of desiccation, together with the later rewetting, produced a network of fissures and slickensides that are now closed but which represent potential planes of weakness in the soil. The formation weathers to a fairly flat and featureless surface except for numerous rounded shallow depressions and pimple mounds.

One down to the northwest, southwest to northeast trending geologic fault transects the Subject Project Alignments area. This fault may be radial to the South Houston Oil field approximately three miles northeast of the Subject Project Alignments. In their "Map Showing Surface Faults in the Southeast Houston Metropolitan Area, Texas" (1978) prepared in conjunction with NASA, E.R.

Verbeek and U.S. Clanton label this fault as Fault 25. This fault is part of a series of parallel faults that extend to the southwest off the South Houston Oil Field (see Plate 2 - Project Area Fault Pattern Map and Plate 3 – Project Area Fault Location Map).

3.2 Nature of Faulting

In the Gulf Coast region of Texas over 200 faults are known or suspected to be active with an aggregate length of approximately 370 miles. Many of these faults are located in the Greater Houston-Galveston area subsidence bowl. Although the existence of most of these faults have been reported in the literature, only 100, with an aggregate length of approximately 140 miles have been mapped at scales suitable for general use. These faults extend offshore several hundred miles and inland north of the Conroe area. Evidence of fault activity includes laterally persistent abrupt changes in the elevation of the ground surface (scarps) where the slope of the land on either side of the fault scarp is similar. Fault scarps can produce linear features (lineaments) on aerial photographs and topographic maps, linear patterns of vegetation that are primarily due to the ponding of water on the downthrown side of the fault, and damage to pavement and other structures. Evidence of active faulting in undeveloped areas may be obscured due to dense vegetation cover such as woods and underbrush.

Many faults are classified as growth (down-to-the-coast) faults wherein the dip angle of the fault near the ground surface is very high, averaging 75 degrees. These faults may have been active for a long period of time. As their name implies, growth faults are active during sedimentation, and consequently, subsurface features include increased thickness of geologic units on the downthrown side and increased displacement of these units with depth adjacent to the fault. Another type of fault found along the Gulf Coast is often associated with growth faults. These faults generally parallel growth faults and have a fault-plane dip that is up-to-the coast. Because of their opposite dip and close association with growth faults, these faults are known as antithetic faults. Growth faults and their antithetic faults have a strike or orientation that generally parallels the coast. Movement rates of growth and antithetic faults are slow and generally range from 0.1 in. to slightly more than 1.0 in. per year. Horizontal movements are extensional and depend upon the dip of the fault, generally being about one-fourth to one-half the vertical movement. These surface movements generally occur in a band of significant width which is likely to be different for each fault and to vary along the length of a particular fault. Band widths of 30 to 50 ft. are common, but wider or narrower bands are also found. In general, fault movement rates may be episodic for a specific fault and an extended period of time may pass between movement periods. Fault movement and fault reactivation has been attributed to fluid withdrawals from pumping of groundwater and oil and gas production, however the predominant affect of this fluid pumping has been local and regional ground subsidence. Fault movement and subsidence rates are documented in Houston where older structures or roadways can display damage.

Other types of faults found along the Gulf Coast are those associated with salt domes. Faults immediate to or overlying salt domes may have surface expressions that tend to be shorter in length and may form either an irregular radial or offset pattern around the salt dome. Away from the dome tangential faults may be present. Unlike growth faults, the orientation of dome-related faults does not follow a general orientation, that is, they can have strikes that are randomly oriented. Many faults mapped in the subsurface are inactive and do not extend to the surface.

3.3 Indications of Faulting

Evidence of faulting at the surface is not always readily identifiable and can also be falsely inferred. Topographic features such as escarpments associated with river terraces may resemble a fault scarp. However, in many cases these features cannot be traced laterally for any substantial distance, or the relative direction of movement observed might change significantly which would indicate the feature is not related to active faulting. Normal deterioration on existing buildings and other structures may produce damage that may resemble damage associated with active faulting. Other sources of linears that can erroneously suggest faulting include clearings made for seismic surveys during oil exploration, fence lines, stratigraphic contacts, or drainage patterns. In most cases, the observed linears on aerial photographs are related to changes in vegetation, while on topographic maps they are related to changes in slope and/or drainage patterns.

Though the existence of river terraces and other linear natural topographic features does not necessarily indicate the presence of a fault, there are times wherein fault scarps are coincident with and are the progenitors of these features. Additionally, there are instances where the fault may be offset from such a topographic feature yet nevertheless is the cause of its existence and the control on its orientation.

In undeveloped terrains covered by dense forest and underbrush and possessing varied topographic relief, the visual, onsite identification of fault scarps can be difficult. Lineaments that could be associated with faulting are likely to be masked by the heavy overgrowth. In such environments, several lines of boreholes across the study area may be needed to supplement the aerial photograph/topographic map analysis and field reconnaissance. Electric log data obtained from these boreholes can provide an idea of subsurface conditions and the likelihood of fault existence.

4. AERIAL PHOTOGRAPH, MAP AND LITERATURE REVIEW

4.1 Review of Aerial Photographs

HVJ Associates reviewed a series of aerial photographs from 1944 through 2012 for the Subject Project Alignments area. The 1944 aerial photograph showed some shading and drainage alignments which may be indicative of Geologic Fault 25. No other obvious fault(s) were observed due to modifications of the landscape.

In viewing aerial photographs, features that may indicate the presence of a fault, include tonal variations in vegetation, areas of standing water and lineations associated with drainage patterns. These features by themselves do not prove that a fault is present, but allow for more effective topographic map review and field reconnaissance.

4.2 Review of Topographic Maps

HVJ Associates reviewed the 1915 and later Mykawa, Pearland and Park Place quadrangle topographic maps for the project area. Because of project area terrain with relatively low relief and five-foot contour intervals, no obvious lineaments were observed on maps produced after 1915. One lineament (or linear feature) was observed on the 1915 Mykawa 1:31680 scale quadrangle map through the Subject Project Alignments area. The one-foot contour interval of this map and the relatively undeveloped nature of the area in 1915 allowed the mapping of a linear trend that coincides with a significant change in slope (a narrowing of contour spacing) roughly parallel to mapped Fault 25. Similar feature on this map may be associated with other mapped faults in the area.

4.3 Literature Review

We reviewed available literature on faults in the area which include USGS publications, university research papers and professional society publications. Although faults exist, seismic activity is not a concern based on the site's location in Seismic Zone O of the Uniform Building Code.

Many of the faults in the Texas Gulf Coast region are considered growth (down-to-the-coast) faults in which the dip angle of the fault near the ground surface averages 75 degrees. Since growth faults are active during sedimentation, subsurface features include increased thickness of geologic units on the downthrown side, and increasing displacement of these units with depth adjacent to the fault. Movement rates of these faults range from less than 0.1 to over 1.0 inches per year.

United States Geological Survey Open File Report 78-797 "Map Showing Surface Faults in the Southeast Houston Metropolitan Area, Texas" by E.R. Verbeek and U.S. Clanton (1978) shows southwest to northeast trending down to the northwest geologic Fault 25 crossing the Subject Project Alignments. Geologic Fault 25 crosses Gulick Lane near the intersection of Wingtip, extends to the southwest crossing Lanham and Holiday and ends south of the Subject Project Alignments area south of Fuqua. This fault is radial to the old South Houston Oil Field approximately three mi. northeast of the Subject Project Alignments area. A portion of the U.S.G.S. map which shows several Geologic Faults in the area is provided as Plate 3 - Project Area Fault Location Map.

5. RECONNAISSANCE

5.1 Objectives

A reconnaissance was performed in February 2015 on foot and by automobile to observe the subject areas and to observe areas identified through literature research and on topographic maps for evidence of faulting.

5.2 Field Reconnaissance

During the course of the field reconnaissance, paved roads adjacent to and within the study area were examined for road surface flexures and/or cracks that would be indicative of faulting.

Field reconnaissance was performed to physically observe the fault and to identify features. Geologic Fault 25 may cross Gulick Lane at/near the intersection of Gulick Lane and Wingtip (see Plates 3 and 4A/4B). The upthrown zone of fault influence for this fault is estimated to extend 100 ft. southeast of the approximate mapped fault location. The downthrown zone of influence for this fault is estimated to extend 100 feet northwest of the approximate mapped fault location (see Plate 5A & 5B).

We observed no vertical relief at the mapped fault locations. We observed pavement damage and cracks near the mapped fault location along Gulick Lane. We observed an area of patched paving on Holiday Lane which may be indicative of faulting. No obvious building damage indicating recent fault movement was observed (a series of site photos showing these locations is provided in Appendix A). No significant scarp development was observed on vacant land adjacent to the pavement areas.

A sag zone is a depressional feature on the downthrown side of a fault which can cause drainage problems near a fault. While sag zones are a common feature associated with active faults, no evidence of a sag zone was observed during our field reconnaissance at the Fault 25 location. The strike of Geologic Fault 25 as it crosses Gulick Lane is approximately north 45° east. Plates 2, 3 and 4A/4B show the regional trend of this fault based on our literature review. The location of this fault was not confirmed in the field with confidence.

It should be noted that a common complication in many fault studies is that much of the evidence normally used to map surface traces of faults in the Gulf Coast have been destroyed in developed areas. Only the most active and damaging faults or faults whose scarps are of substantial height are likely to be noticed during mapping of developed areas. Mapping of faults is most difficult in areas with recent development; however, in older developed areas the fault can be located quite accurately at many points where it has damaged buildings, road and other manmade structures. The fault trace is obscured by landscape modifications to the Subject Project Alignments.

6. FAULT CHARACTERIZATION

6.1 Fault Zone of Influence

The upper and lower boundaries of the main fault scarps for Geologic Fault 25 in this study was difficult to determine. The techniques for locating a fault are subject to some uncertainties, the combined effects of which can be reported as a zone of influence. Zones of influence for the upthrown and downthrown side of the fault provide a reasonable margin of safety for the project and a zone to buffer ground movements that may occur within the zone. Outside the zone of influence, there is reasonable certainty that any fault movement that does occur will not impact constructed facilities, and no special design measures are needed.

6.2 Fault Strike and Dip

While no geophysically logged borings were drilled, we estimate that the dip angle of the fault to be 75°. This is similar to the angle found during fault studies conducted by HVJ Associates in the general project area. The strike of the fault is approximately north 45° east in the vicinity of Wingtip.

6.3 Fault Movement Rates

Vertical movement rates have been measured at numerous locations in the Houston Metropolitan Area. Data presented by Elsbury, et. al. showed a movement rate of 20 mm per year (0.787 inches per year) between 1974 and 1980 on the Long Point Fault near Billings Street. At Gessner, Heuer reported a rate of 12 mm per year (0.472 inches per year) between 1971 and 1978. Mastroianni reported movement rates at three locations between June 1985 and May 1987 as follows: on Moritz, (near Bingle), Mastroianni reported a rate of 5.6 mm per year, at Cedar Post (near Campbell) a rate of 10.2 mm per year and near the West Belt a rate of 19.5 mm per year. All movement rates reported in the literature are vertical. The average vertical rate for these five observations is 12.74 mm per year or 0.502 inches per year. Movement of a fault through Ellington Field approximately 5.7 miles east of the Subject Project Alignments of approximately 0.15 in. per year has been documented by Dr. Carl Norman (personal communication).

No horizontal extension data are available from the existing surveys, or public literature. The magnitude of horizontal movement verses vertical movement is largely controlled by the dip of the

fault plane near the surface. Based on a dip angle of 75° and using the vertical design movement of 0.15 inches per year, we estimate that the total horizontal extension (i.e. lengthening parallel to the ground surface) assuming a 50 year life of the water line will be approximately two inches.

Anecdotal evidence indicates that fault movement rates have slowed markedly around the City of Houston recently. This has been attributed to progress in the City of Houston's Surface Water Transmission Program which has steadily converted water supply from well to surface water across the City. There has been a verifiable decrease in subsidence rates across the city in areas where surface water conversion is complete. Coincident with this decrease in subsidence, there seems to be a decrease in fault movement rates. Site history includes evidence of fault movement that predates any development through observation of the scarp on earliest topographic maps available for the project area. Our hypothesis is that the ground stresses induced by groundwater withdrawal that caused subsidence also accelerated the movement rate along the fault. Now that those ground stresses are relieved, the fault movement rate has decelerated. At some point, the fault will probably resume moving at its historical rate prior to development, which is unknown. How long it may take before this occurs, or even if this hypothesis is correct, is impossible to know based on existing information.

The most prudent course of action is to assume that some fault movement will occur over an extended design life. The design movements discussed above can be considered reasonable upper bound estimates of the amount of movement that might occur over an assumed 50 year design life.

7. DESIGN CRITERIA AND RECOMMENDATIONS

7.1 General

Fault 25 crossing Gulick Lane and Holiday Lane is well documented in the geologic literature and are within the project area. This fault location was not confirmed in the field with confidence. One area of cracked pavement near the southeast corner of the intersection of Gulick Lane and Wingtip may be associated with fault movement. Due to the lack of evidence of additional fault indicators (other than the distant faults shown on a regional map), other faulting is probably not present on or near this part of the project area and further assessment(s) are not recommended.

We recommend two options for this project. The first option would be to install the utilities the normal way and provide some accommodation for future maintenance work. The second option would be to take some additional steps that are discussed in this report at locations where faulting might be anticipated based the historic literature review.

We recommend that, during construction planning, consideration be given to the proximity of the fault to the project area. Construction should take into account the potential for fault movement. It should be noted that movement rates are not consistent along the fault and that the rate goes to zero at either end. We anticipate fault zones of influence on either side of the approximate fault traces shown in Plates 5A & 5B.

Pavement crossing the fault location will experience horizontal and vertical movements. These movements will cause cracking and accelerated deterioration of the pavement structure due to water infiltration. To the extent possible, the area of pavement within the zones of influence should be minimized. Where pavements must cross the fault, the pavement section recommended for heavy truck loads should be used within the zone of influence. Maintenance budgets should include

allowance for replacement of slabs within the zone near the fault much more frequently than similar pavements away from the fault. Subsurface utilities crossing the fault will experience vertical and horizontal movements. These movements will cause cracking of pipes and change the invert grades in the vicinity of the fault with time. Drainage in the vicinity of the fault will be impacted by fault movement. Over time the site grades will change near the fault to create an apparent depression that will not drain properly.

It is anticipated that the proposed storm sewers will be installed by open cut method at the fault crossing. Standard geotechnical design guidelines and recommendations are presented in our companion geotechnical report. There are three basic approaches to protective measures: avoidance, accommodation, and protection. Each is discussed below.

7.2 Avoidance

To the extent possible, subsurface utilities should avoid crossing the fault. Certainly any subsurface vault or manhole should be located outside the fault zone. Since the horizontal extension across the fault will cause the centerline to lengthen, any pipe crossing the fault zone is likely to eventually sustain damage. If feasible, this damage can be mitigated by providing service to locations north of the fault zone from the north and service to locations south of the fault zone from the south.

7.3 Accommodation

If fault crossings by lines cannot be avoided, then the need for future maintenance of pipe breaks across the fault should be anticipated. Due to the anticipated horizontal extension, pipe located within the fault zone should have flexible joints. The goal would be to make it easy for a repair crew to isolate the broken pipe from water pressure and easy to access the pipe for repair. This can be done by not locating the line underneath pavement within the fault zone and providing shutoff valves within 100 feet up and down station from the fault zone. Note that a break is most likely to occur at the first pipe joints on either side of the fault zone. It is recommended to have shorter pipes and have more joints at these locations instead of having longer pipes to accommodate fault movement. Several pipeline manufacturing companies are producing pipes that are equipped with flexible expansion joints to be considered for unstable conditions like faults.

7.4 Backfill and Bedding

Rigid backfill and bedding materials, such as cement stabilized sand, should not be used within the fault zone identified in this report. Rigid materials can cause stress concentrations leading to highly localized failure of pipes, and they also make access to the pipe for repair more difficult. Crushed rock with sand backfill is preferred.

Within the fault zone we recommend that the trench be lined with a geotextile filter installed per the manufacturer's recommendations. This lining will serve to prevent infiltration of natural soil into the backfill and will prevent sediment inflow into the pipe in the event of breakage or joint distress.

8. DESIGN REVIEW

HVJ Associates, Inc. should review the design and construction plans and specifications prior to release to make certain that the fault recommendations and design criteria presented herein have been properly interpreted.

9. SUMMARY OF FINDINGS/CONCLUSIONS

Based on our site reconnaissance and review of available information obtained for this project, our findings and conclusions are summarized below:

9.1 Findings

- One main active surface fault crosses the Subject Project Alignments at two locations. No obvious expressions of this fault (other than cracked paving at one location) were observed where the fault crosses the Subject Project Alignments.

- Geologic Fault 25 is mapped crossing Gulick Lane near the intersection of and crossing Holiday Lane between Wingtip and Randolph Street. The upthrown zone of fault influence for this fault is estimated to extend 100 ft. southeast of the approximate fault location. The downthrown zone of influence for this fault is estimated to extend 100 feet northwest of the fault location.

- No significant pavement damage, cracks and patching were observed at the mapped fault locations. No obvious building damage indicating recent fault movement was observed. No significant scarp development was observed on vacant land adjacent to the pavement areas.

- Linear features and small faults trending parallel to Geologic Fault 25 were found to be present near the project area based on literature review. These linear features and small faults do not occur within the project area and were not observed in the field.

9.2 Conclusions

Based on the information obtained in this study, the potential for surface faulting in the project area should be moderate. The mapped fault trends through the project area and probably dip below the project area at an angle of about 75° (from the horizontal). The location of this fault is fully documented in the geologic literature but not by field reconnaissance with confidence. No other faulting was observed or is documented in the literature on or near the project area. Therefore, we conclude that no additional Assessment is needed to determine the extent of potential faulting in the project area.

Faults are not always associated with definitely recognizable fault scarps and their full extent may not be identifiable by visual inspection alone. Additionally, vegetative cover and uneven topography can obscure the presence of a fault, especially if it is slow moving or currently inactive. Predicting future fault activity cannot be done with certainty due to the number of variables involved. Dormant or very slow moving faults can be, respectively, reactivated or accelerated due to a number of reasons, including groundwater withdrawals and petroleum production.

Pipe crossing the identified fault zones are likely to be impacted by fault movement. Design recommendations are provided in Section 7 including the need for restrained joints in the fault zones and shut off valves near the end of the zones. See Section 7 for a more complete discussion.

10. LIMITATIONS

The conditions and recommendations contained in this report are based on our review of available documents and field geologic mapping techniques. Shallow soil conditions, cultural activities, new construction, slow movement rates, and repair of existing fault damage may obscure fault-related features.

This report is an instrument of service of HVJ Associates, Inc. The report was prepared for and is intended for the exclusive use of AECOM. The report's contents may not be relied upon by any other party without the express written permission of HVJ Associates and AECOM.

The report's findings are based on conditions that existed on the dates of HVJ Associates site visit(s) and should not be relied upon to precisely represent conditions at any other time. All conclusions are qualified by the fact that no excavations or borings were made and no geophysical surveys or logging was conducted. Conclusions about site conditions under no circumstances comprise a warranty that conditions in all areas within the site and study area (and below existing grade) are of the same quality that HVJ Associates has inferred from observable site conditions.

HVJ Associates' findings and conclusions must be considered probabilities based on professional judgment applied to the limited data HVJ Associates was able to gather during the course of this fault study.

11. REFERENCES

The following references were used to compile this report:

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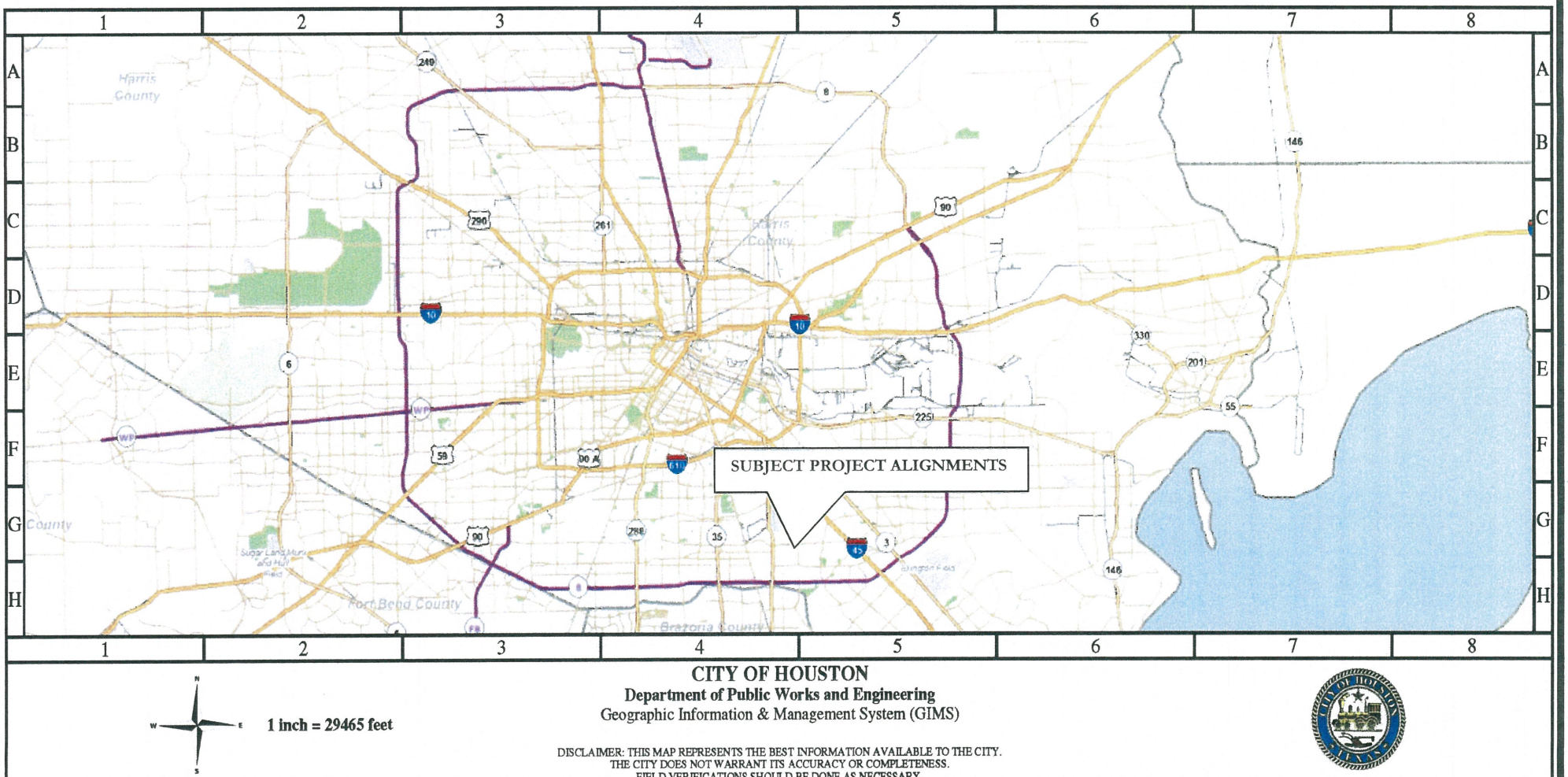
- Kreitler, C.W., 1976, Lineations and Faults in the Texas Coastal Zone, Report of Assessments No. 85, Bureau of Economic Geology, the University of Texas.

PLATES



CITY OF HOUSTON
Department of Public Works and Engineering
Geographic Information & Management System (GIMS)

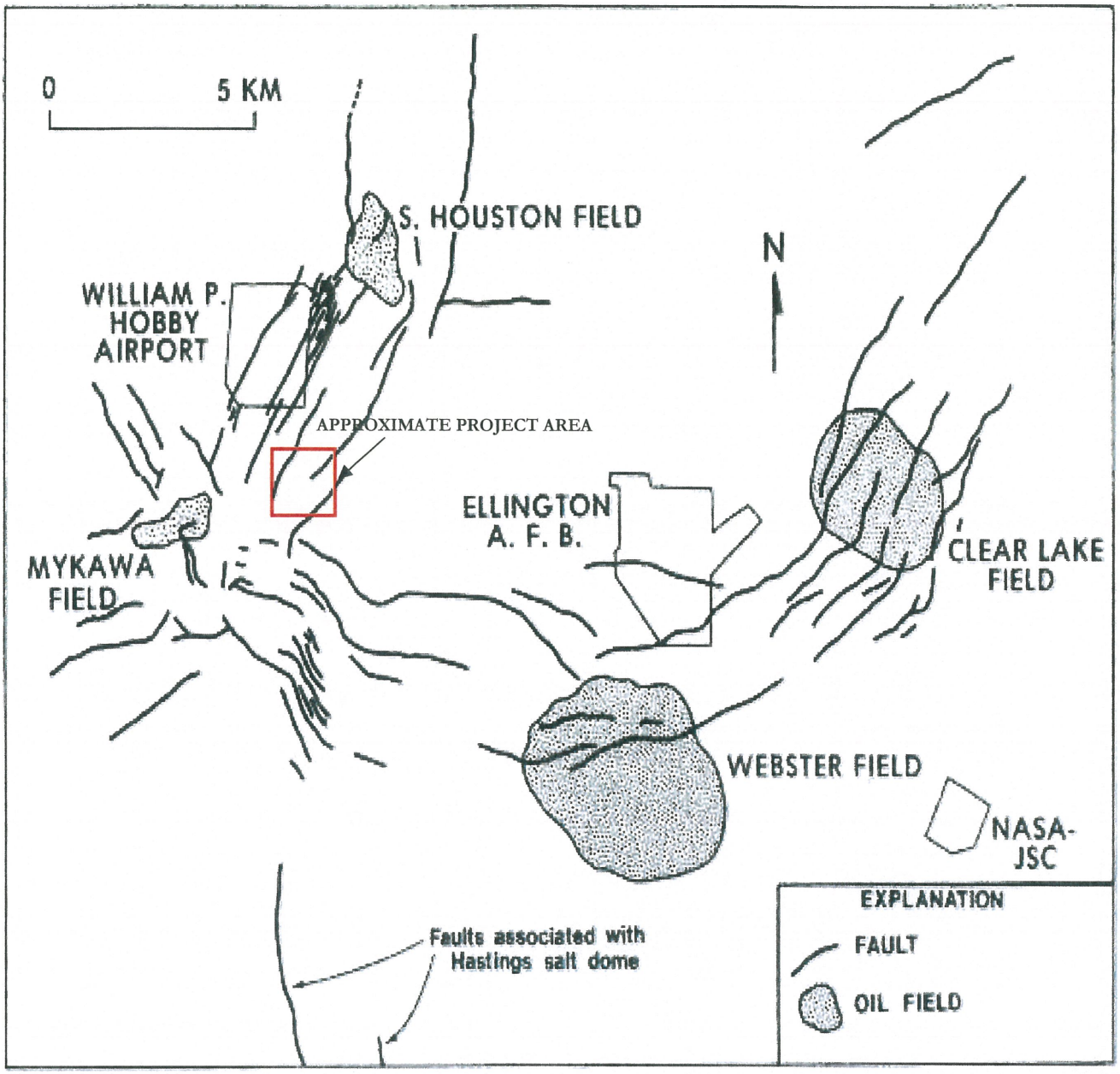
DISCLAIMER: THIS MAP REPRESENTS THE BEST INFORMATION AVAILABLE TO THE CITY.
THE CITY DOES NOT WARRANT ITS ACCURACY OR COMPLETENESS.
FIELD VERIFICATIONS SHOULD BE DONE AS NECESSARY.

HVJ ASSOCIATES
6120 S. Dairy Ashford Road
Houston, Texas 77072-1010
281.933.7388 Ph
281.933.7293 Fax

DATE: 2/9/2015	APPROVED BY: MM	PREPARED BY: EH

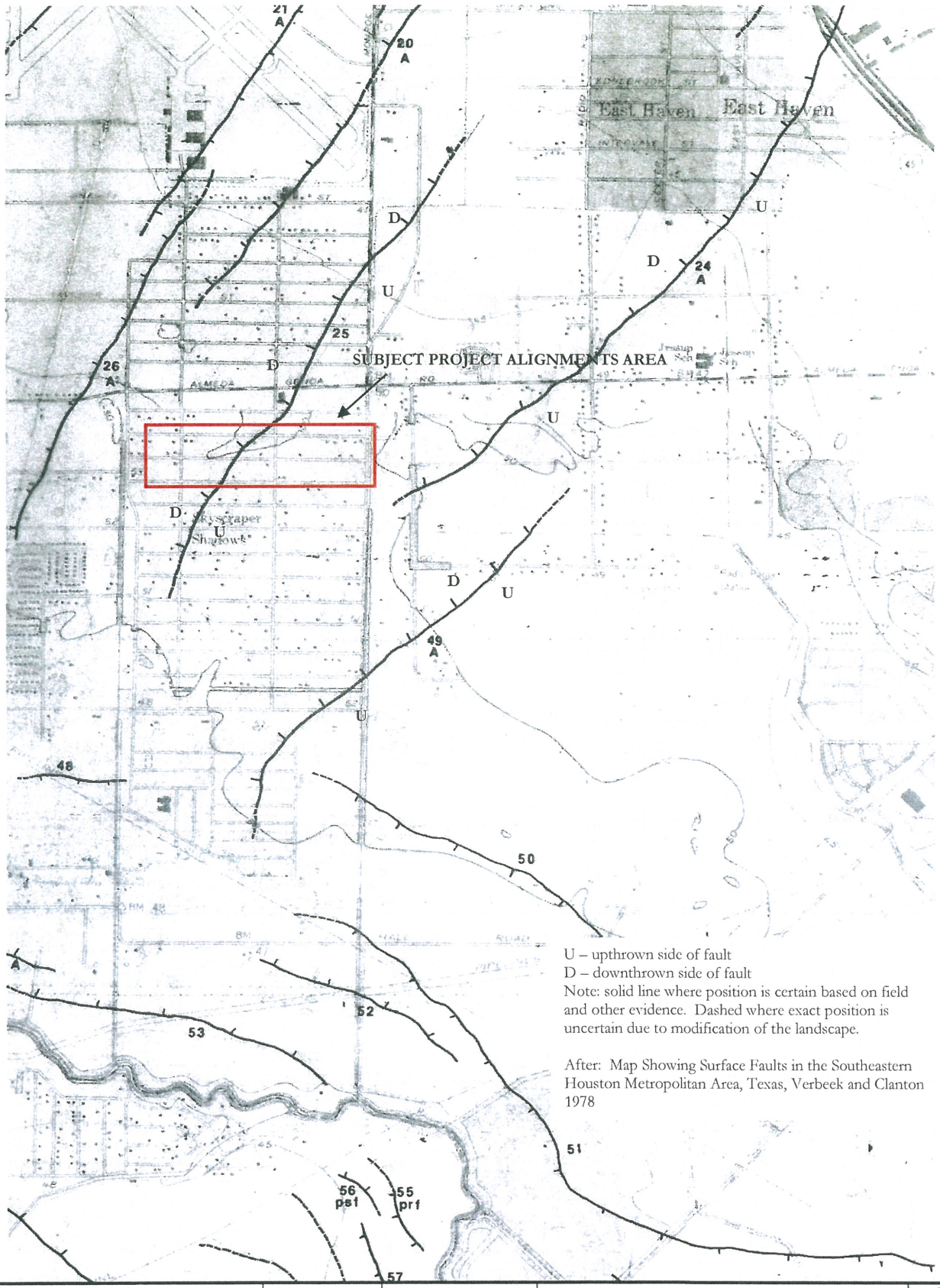
SITE VICINITY MAP
Phase I Geologic Fault Assessment
Skyscraper Project

PROJECT NO.: HE1510720	DRAWING NO.: PLATE 1



Note: Modified after Verbeek and Clanton (1978)

HVJ ASSOCIATES		Drawn:	EH	Plate 2 Project Area Fault Pattern Map Skyscraper Geologic Fault Assessment Project Houston, Harris County, Texas	N
		Checked:	MM		
		Date:	February 2015		
Report No.	HE1510720	Scale:	NTS		



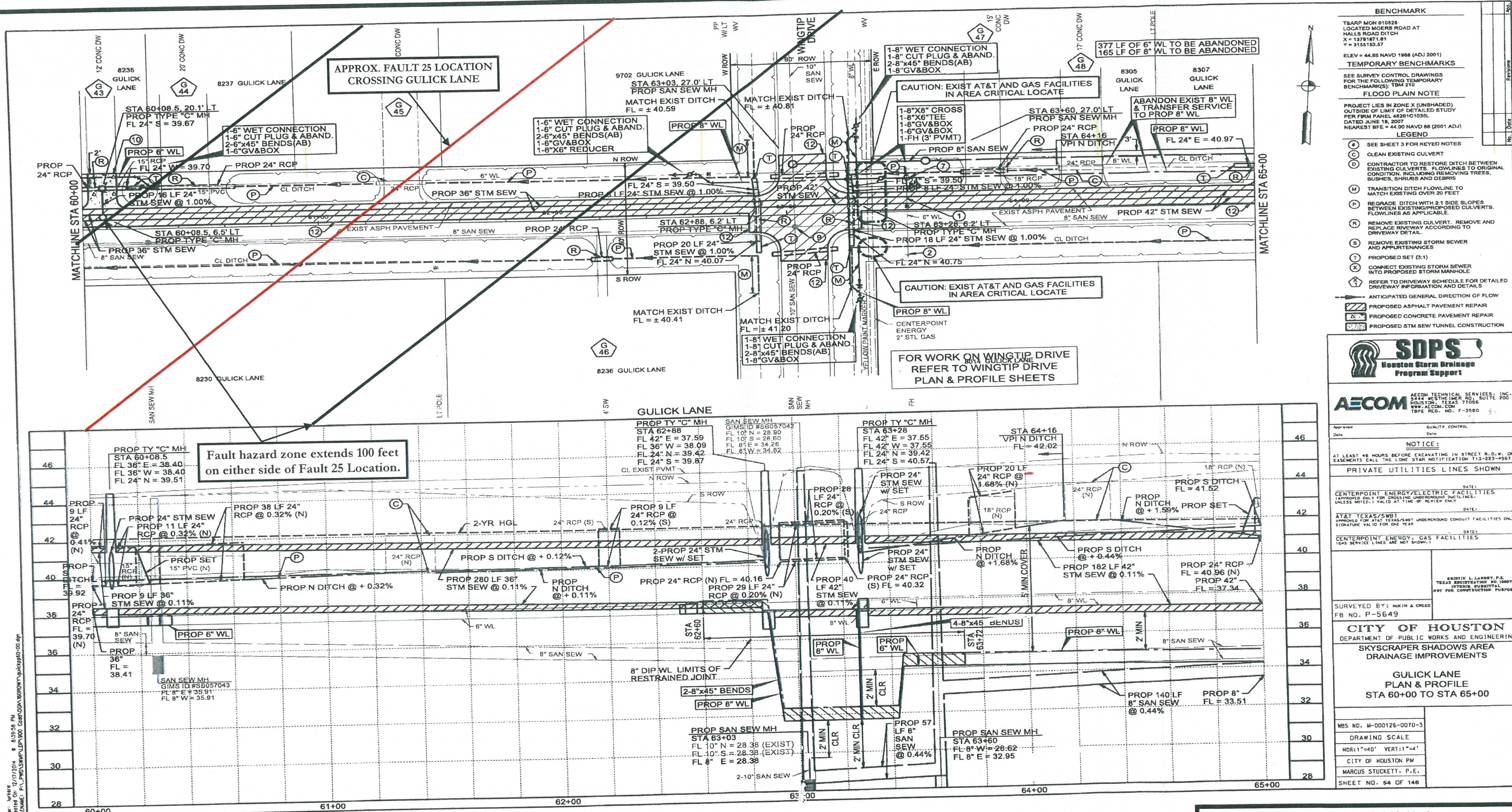
HVJ ASSOCIATES	Drawn:	EH	**Plate 3** **Project Area Fault Location Map** **Skyscraper Geologic Assessment Project** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	

HVJ ASSOCIATES	Drawn:	EH
	Checked:	MM
	Date:	February 2015
Report No. HE1510720	Scale:	NTS

Plate 4A
Approximate Mapped Fault Location Map
on Current Aerial Photograph
Skyscraper Project Area
Houston, Harris County, Texas

HVJ ASSOCIATES	Drawn:	EH
	Checked:	MM
	Date:	February 2015
Report No. HE1510720	Scale:	NTS

Plate 4B
Approximate Mapped Fault Location Map
on 1944 Aerial Photograph
Skyscraper Project Area
Houston, Harris County, Texas



HVJ ASSOCIATES

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281.933.7293 Fax

DATE: 2/12/2015	APPROVED BY: EH	PREPARED BY: NL

Skyscraper Geologic Fault Assessment
Fault 25 Location near Gulick & Wingtip

PROJECT NO.: HE1510720	DRAWING NO.: PLATE 5A

APPROX. FAULT 25 LOCATION CROSSING HOLIDAY

MATCHLINE STA 215+00

MATCHLINE STA 220+00

HOLIDAY LANE

8131 HOLIDAY LANE

8207 HOLIDAY LANE

8215 HOLIDAY LANE

8217 HOLIDAY LANE

8219 HOLIDAY LANE

8223 HOLIDAY LANE

8130 HOLIDAY LANE

8214 HOLIDAY LANE

8218 HOLIDAY LANE

8222 HOLIDAY LANE

8226 HOLIDAY LANE

8230 HOLIDAY LANE

N ROW

S ROW

60' ROW

EXIST ASPH PAVEMENT

PROP 24" RCP

8" SAN SEW

8" WL

6" WL

4" PVC

6" PVC

CL DITCH

PROP 24 LF 24" RCP @ 0.16% (N)

PROP 26 LF 24" RCP @ 0.16% (N)

PROP 20 LF 24" RCP @ 0.16% (S)

PROP N & S DITCH @ + 0.16%

PROP 13 LF 24" RCP @ 0.16% (N)

PROP 16 LF 24" RCP @ 0.16% (S)

PROP 15 LF 24" RCP @ 0.16% (N)

PROP S DITCH @ + 0.11% (S)

PROP 22 LF 24" RCP @ 0.10% (N)

PROP 21 LF 24" RCP @ 0.10% (S)

PROP S DITCH 24" RCP (N) FL = 43.33

SAN SEW MH GIMS ID #SB058046 FL 8" W = 39.73

SAN SEW MH GIMS ID #SB057074 FL 8" E = 40.72

Fault hazard zone extends 100 feet on either side of Fault 25 Location.

215+00 216+00 217+00 218+00 219+00 220+00

BENCHMARK

TSARP MON 010828
LOCATED MOERS ROAD AT HALLS ROAD DITCH
X = 13791871.81
Y = 3156153.67

ELEV = 44.85 NAVD 1988 (ADJ 2001)

TEMPORARY BENCHMARKS

SEE SURVEY CONTROL DRAWINGS FOR THE FOLLOWING TEMPORARY BENCHMARK(S):

FLOOD PLAIN NOTE

PROJECT LIES IN ZONE X (UNSHADED) OUTSIDE OF LIMIT OF DETAILED STUDY PER FIRM PANEL 48201C1035L DATED JUNE 18, 2007
NEAREST BFE = 44.00 NAVD 88 (2001 ADJ)

LEGEND

- (#) SEE SHEET 3 FOR KEYED NOTES
- (C) CLEAN EXISTING CULVERT
- (D) CONTRACTOR TO RESTORE DITCH BETWEEN EXISTING CULVERTS. FLOWLINES TO ORIGINAL CONDITION INCLUDING REMOVING TREES, BUSHES, SHRUBS AND DEBRIS
- (M) TRANSITION DITCH FLOWLINE TO MATCH EXISTING OVER 20 FEET
- (P) REGRADE DITCH WITH 2:1 SIDE SLOPES BETWEEN EXISTING/PROPOSED CULVERTS. FLOWLINES AS APPLICABLE.
- (R) REMOVE EXISTING CULVERT. REMOVE AND REPLACE RIVEWAY ACCORDING TO DRIVEWAY DETAIL.
- (S) REMOVE EXISTING STORM SEWER AND APPURTENANCES
- (T) PROPOSED SET (3:1)
- (X) CONNECT EXISTING STORM SEWER INTO PROPOSED STORM MANHOLE
- (1) REFER TO DRIVEWAY SCHEDULE FOR DETAILED DRIVEWAY INFORMATION AND DETAILS
- ANTICIPATED GENERAL DIRECTION OF FLOW
- PROPOSED ASPHALT PAVEMENT REPAIR
- PROPOSED CONCRETE PAVEMENT REPAIR
- PROPOSED STM SEW TUNNEL CONSTRUCTION

No.	Date	Revisions

SDPS
Houston Storm Drainage Program Support

AECOM
AECOM TECHNICAL SERVICES, INC.
5444 WESTHEIMER RD. SUITE 200
HOUSTON, TEXAS 77056
WWW.AECOM.COM
TBPE REG. NO. F-3580

Approved Date — QUALITY CONTROL Date

NOTICE:
AT LEAST 48 HOURS BEFORE EXCAVATING IN STREET R.O.W. OR EASEMENTS CALL THE LONE STAR NOTIFICATION 713-223-4567.

PRIVATE UTILITIES LINES SHOWN

DATE:
CENTERPOINT ENERGY/ELECTRIC FACILITIES
APPROVED ONLY FOR CROSSING UNDERGROUND DUCTLINES. UNLESS NOTED. VALID AT TIME OF REVIEW ONLY

DATE:
AT&T TEXAS/SWBT
APPROVED FOR AT&T TEXAS/SWBT UNDERGROUND CONDUIT FACILITIES ONLY. SIGNATURE VALID FOR ONE YEAR

DATE:
CENTERPOINT ENERGY: GAS FACILITIES
(GAS SERVICE LINES ARE NOT SHOWN.)

KRISTIN L. LANDRY, P.E.
TEXAS REGISTRATION NO.106074
INTERIM SUBMITTAL
NOT FOR CONSTRUCTION PURPOSES

SURVEYED BY: MCKIM & CREED
FB NO. P-5649

CITY OF HOUSTON
DEPARTMENT OF PUBLIC WORKS AND ENGINEERING

SKYSCRAPER SHADOWS AREA DRAINAGE IMPROVEMENTS

HOLIDAY LANE
PLAN & PROFILE
STA 215+00 TO STA 220+00

WBS NO. M-000126-0070-3	
DRAWING SCALE	
HOR:1"=40' VERT:1"=4'	
CITY OF HOUSTON PM	
MARCUS STUCKETT, P.E.	
SHEET NO. 70 OF 148	

NOTE:
The Fault 25 crossing at Holiday Lane is not on the proposed Subject Project Alignments.

HVJ ASSOCIATES
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281.933.7293 Fax

DATE: 2/12/2015	APPROVED BY: EH	PREPARED BY: NL

Skyscraper Geologic Fault Assessment
Fault 25 Location along Holiday

PROJECT NO.: HE1510720	DRAWING NO.: PLATE 5B

User: kphee
Created On: 12/17/2014 @ 9:14:23 PM
FILENAME: P:\...\holiday\plot25-00.dgn

APPENDIX A

SITE PHOTOGRAPHS

Photo 1. View of possible faulted area near the southeast corner of the intersection of Gulick Lane and Wingtip.

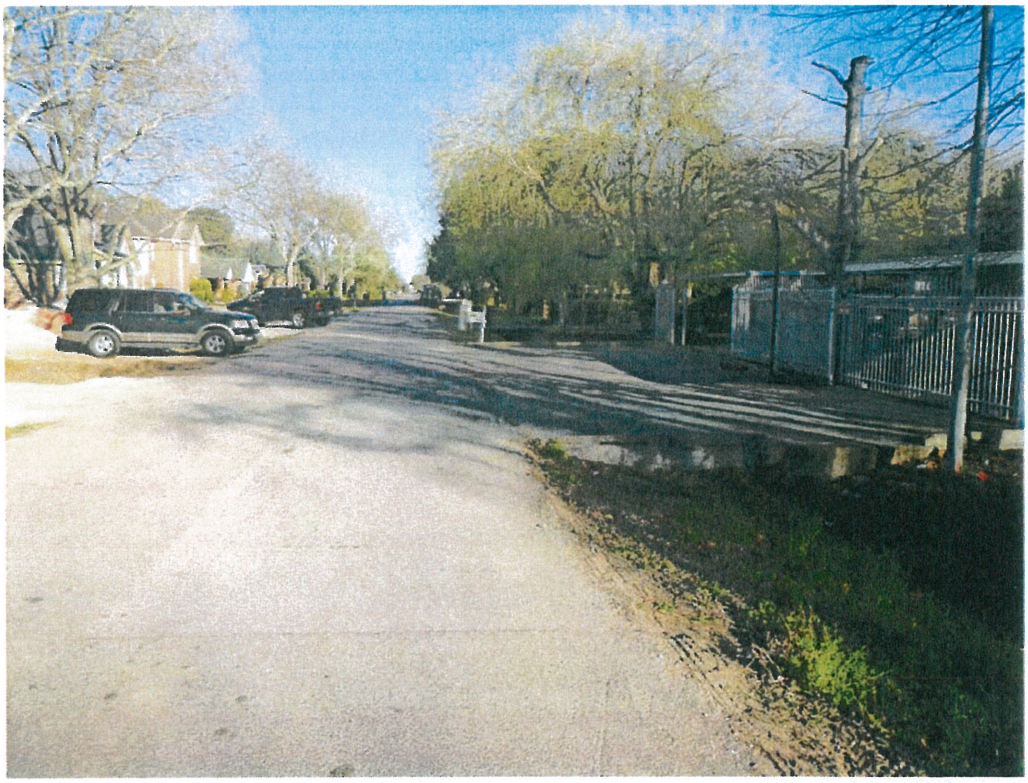


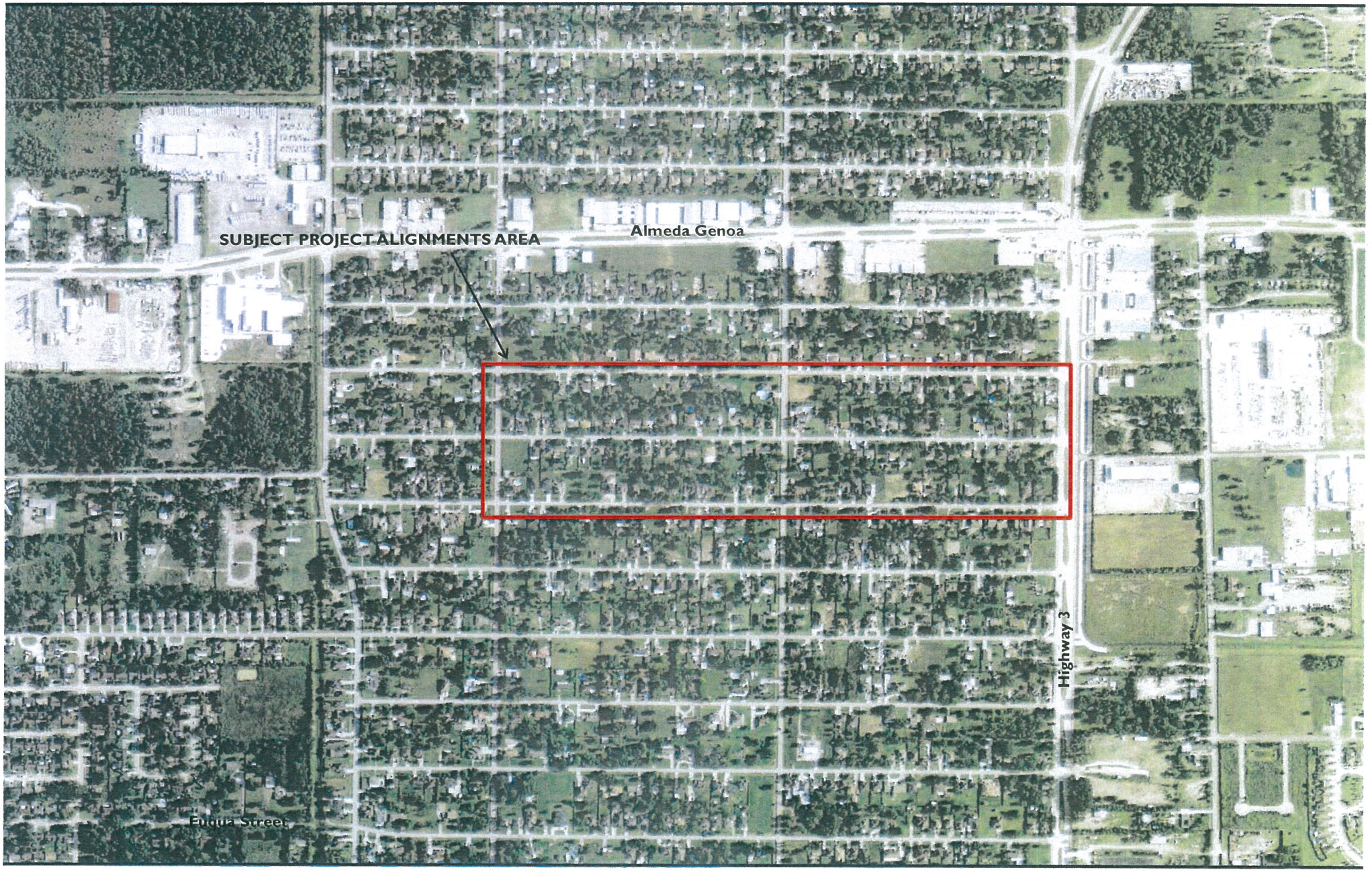
Photo 2. View looking east along Holiday Lane showing possible area of fault crossing the project alignment.

Photo 3. View of patched paving area along Holiday Lane.

Photo 4. View vacant tract along Holiday Lane near area of mapped fault crossing the project alignment.

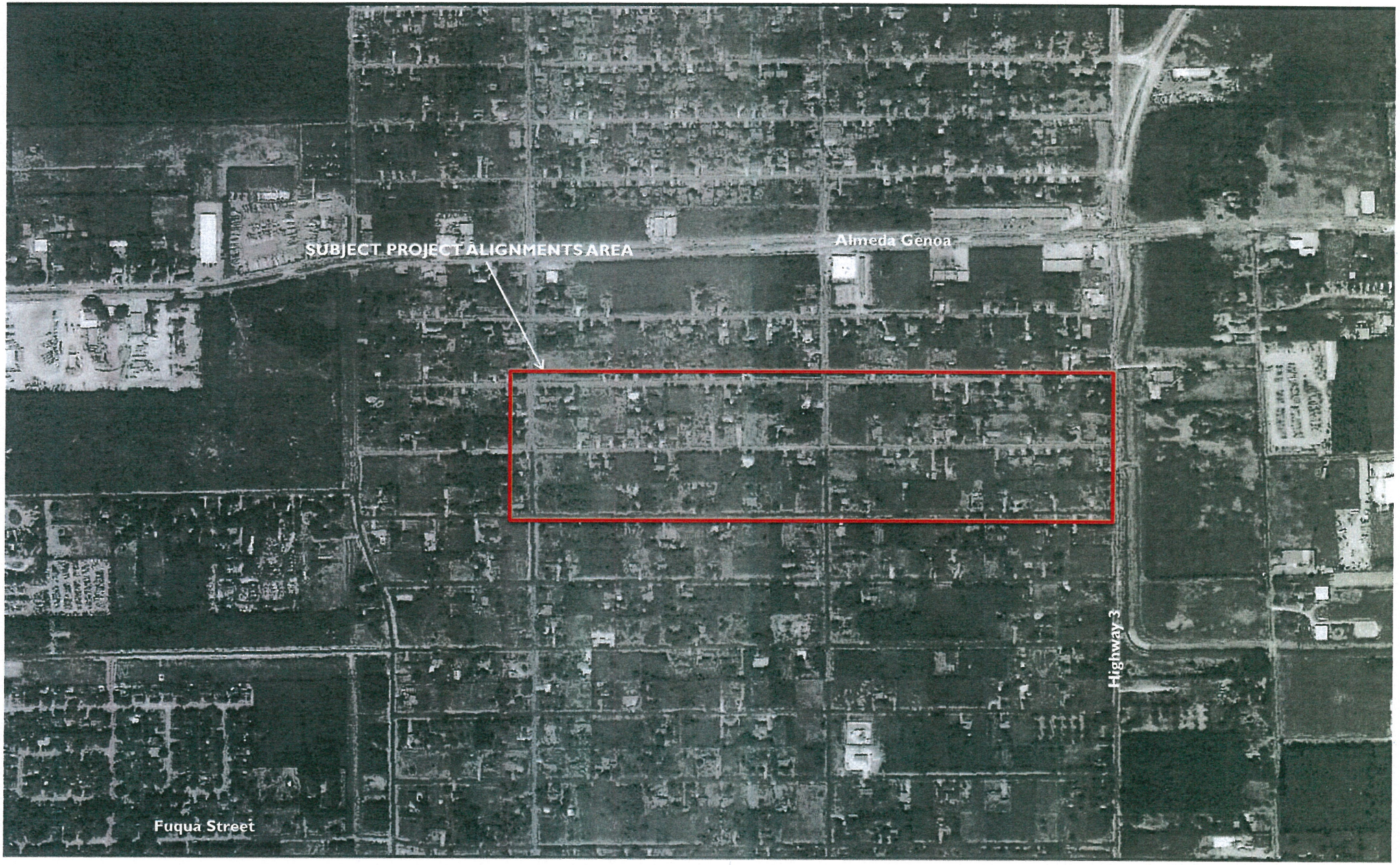
APPENDIX B

AERIAL PHOTOGRAPHS

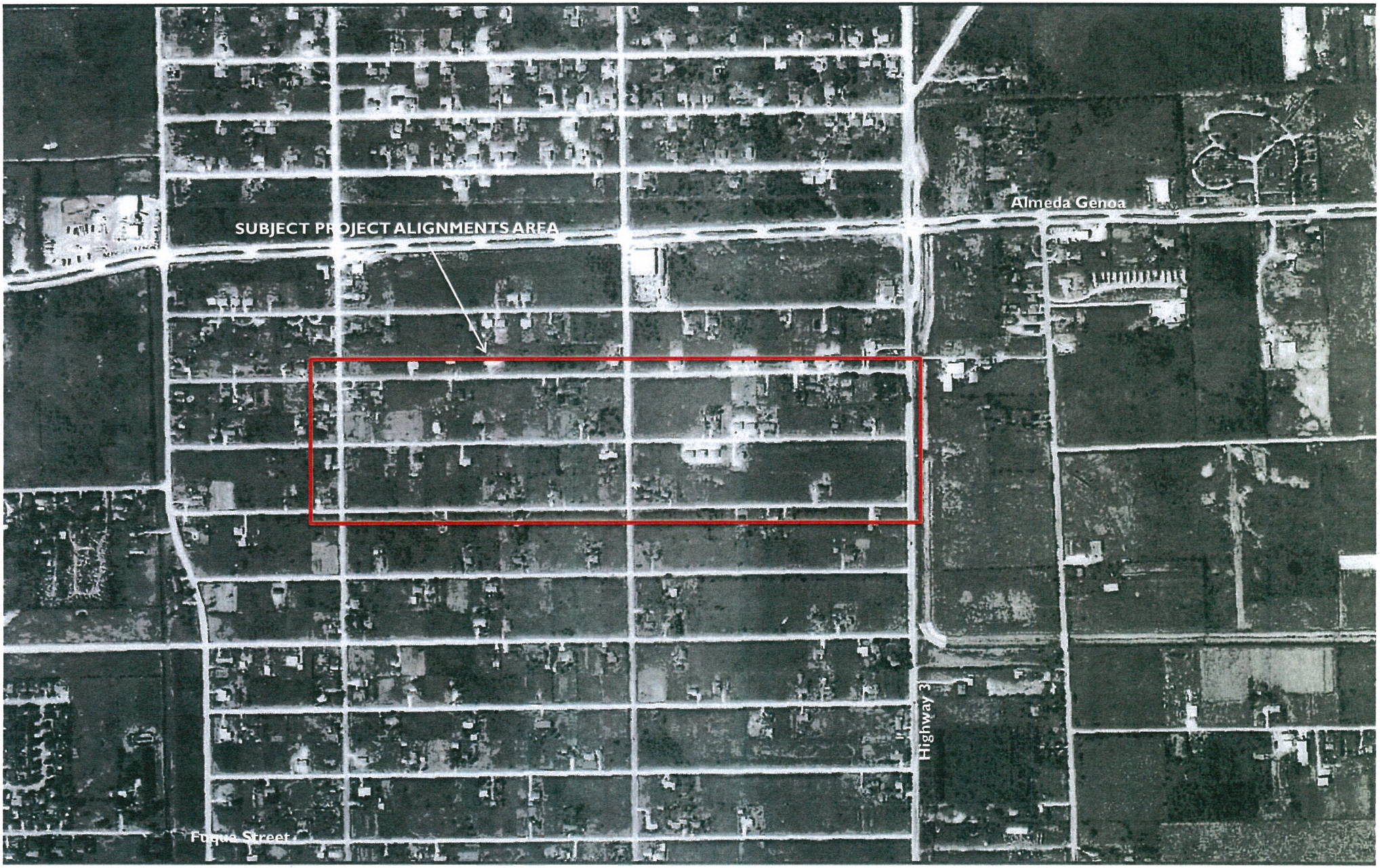


Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
2012 AERIAL PHOTO
SCALE: 1" = 700'

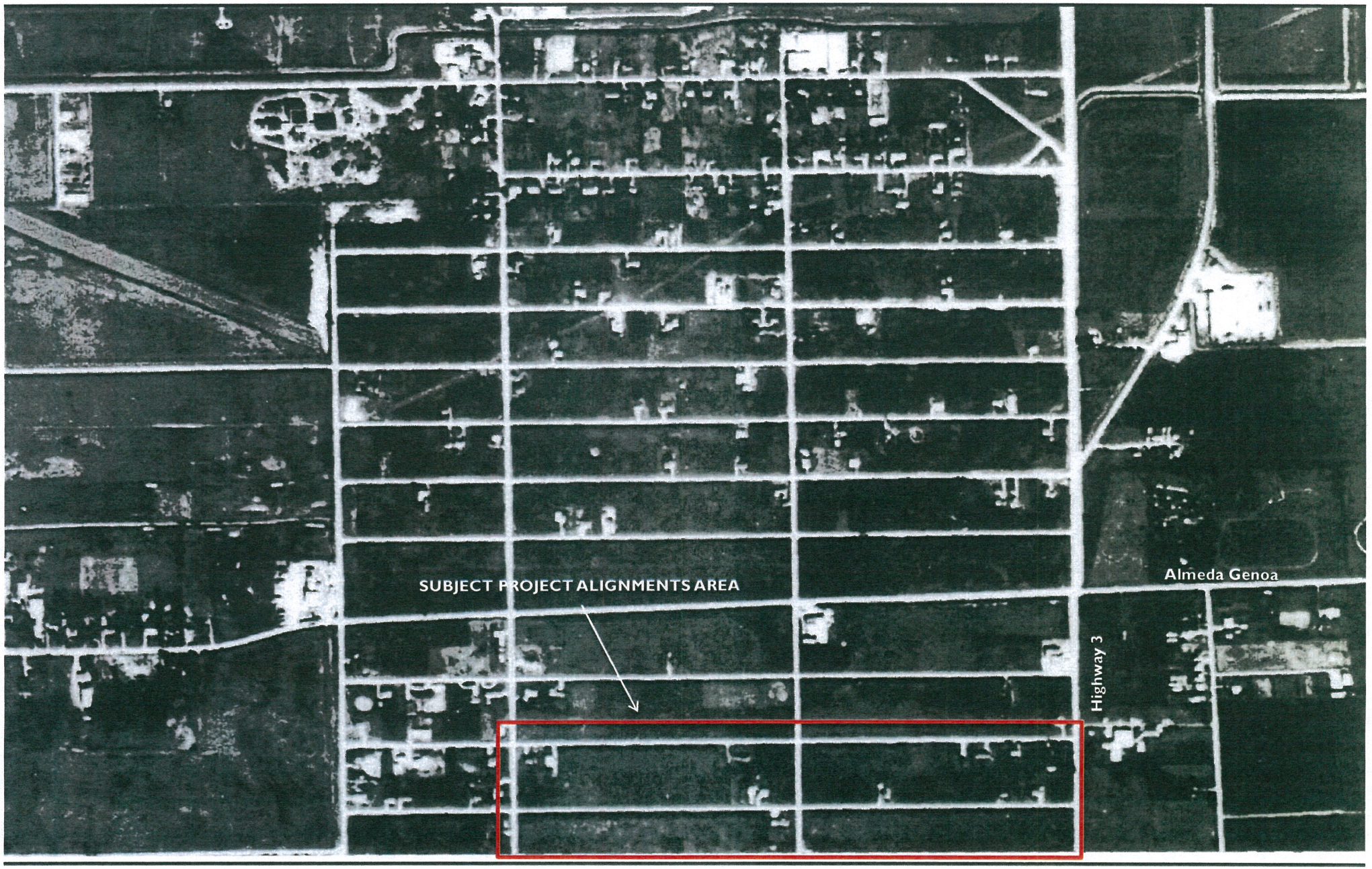
Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1996 AERIAL PHOTO
SCALE: 1" = 700'



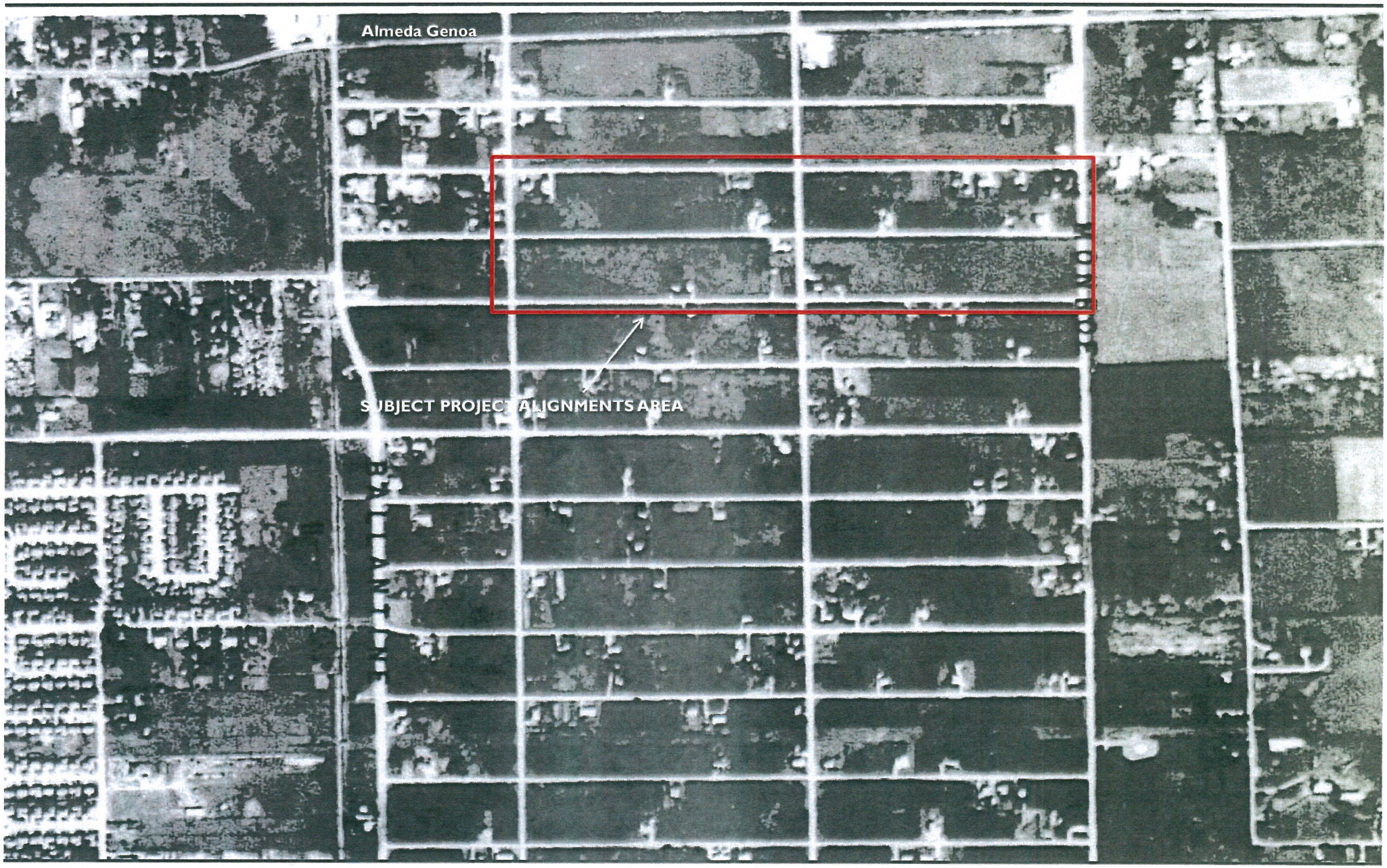
Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1989 AERIAL PHOTO
SCALE: 1" = 700'



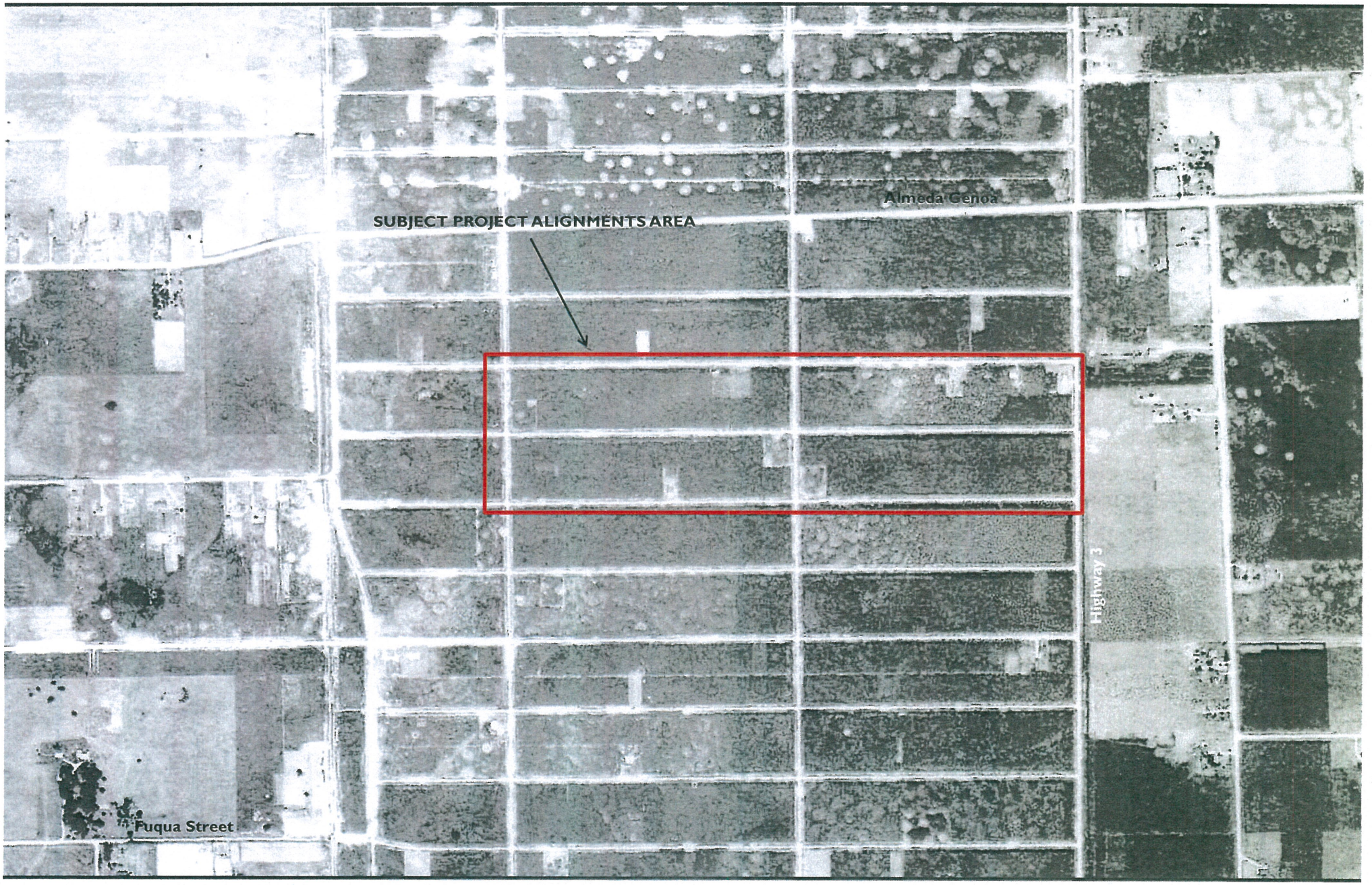
Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1979 AERIAL PHOTO
SCALE: 1" = 700'



Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1969 AERIAL PHOTO (NORTH)
SCALE: 1" = 700'



Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1969 AERIAL PHOTO (NORTH)
SCALE: 1" = 700'

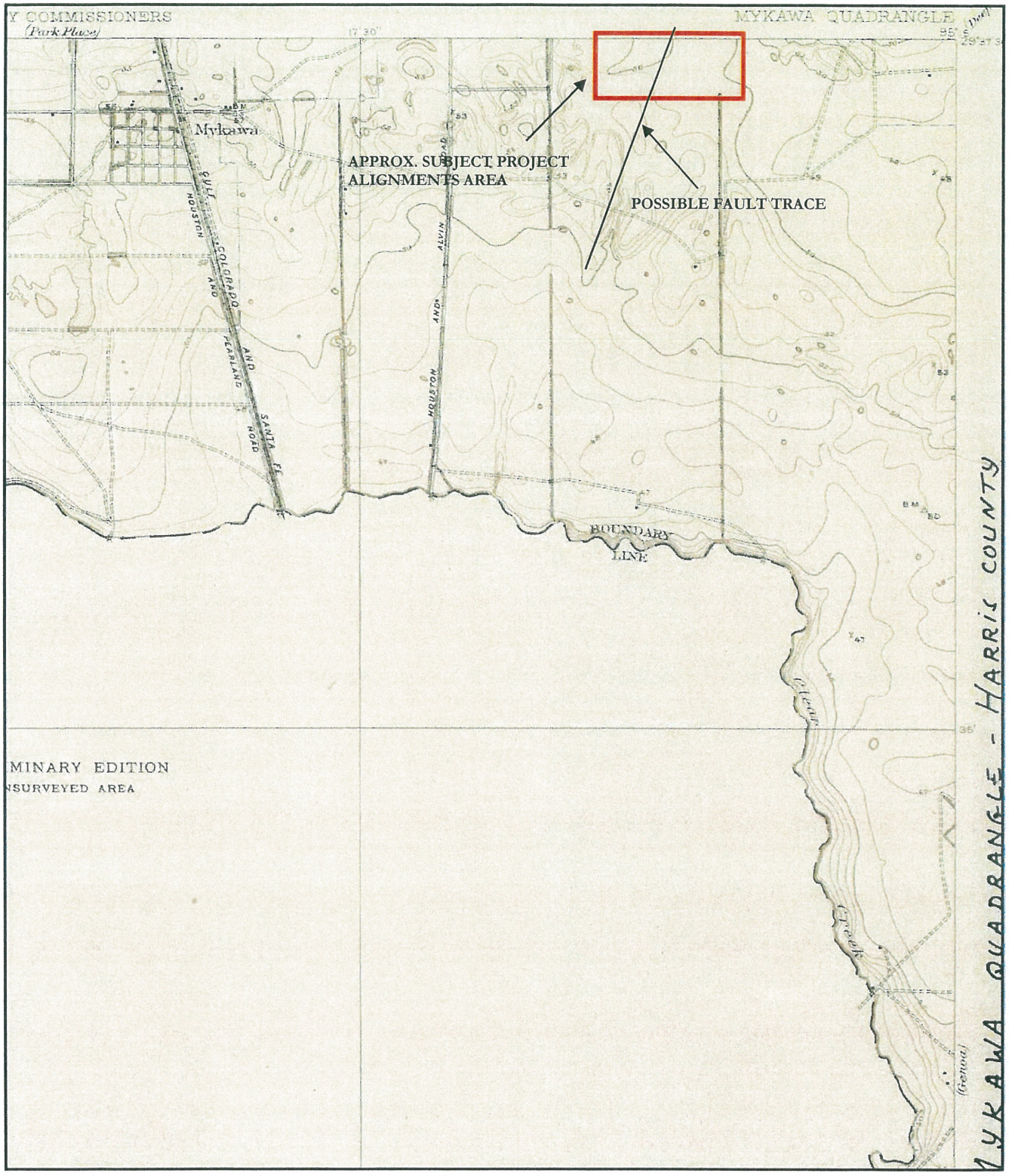


Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1953 AERIAL PHOTO
SCALE: 1" = 700'

Geologic Fault Assessment - Skyscraper Shadows Local Drainage Project - Storm Sewer and Paving
WBS No. M-000126-0070-3
Houston, Harris County, Texas
1944 AERIAL PHOTO
SCALE: 1" = 700'

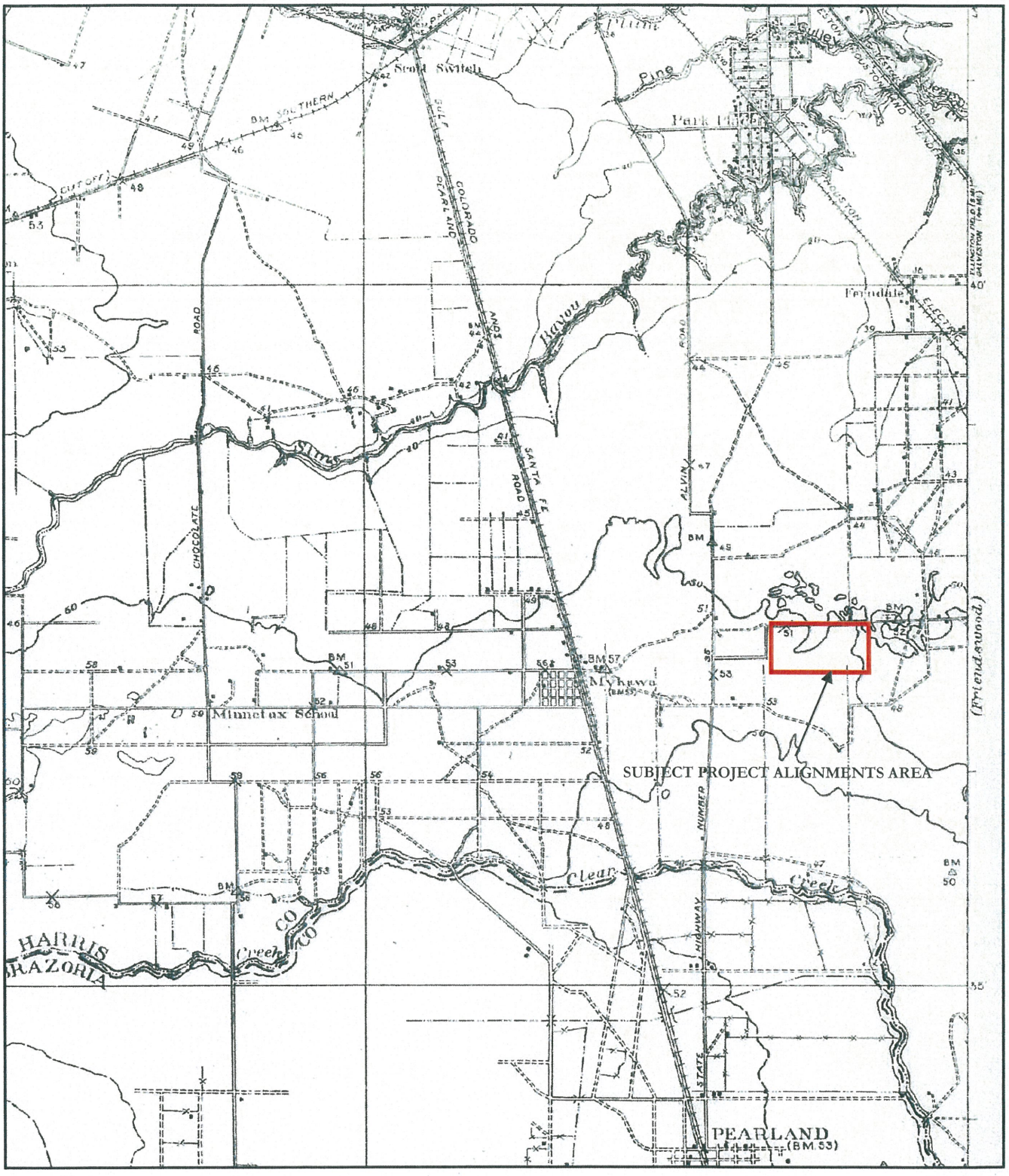
APPENDIX C

TOPOGRAPHIC MAPS



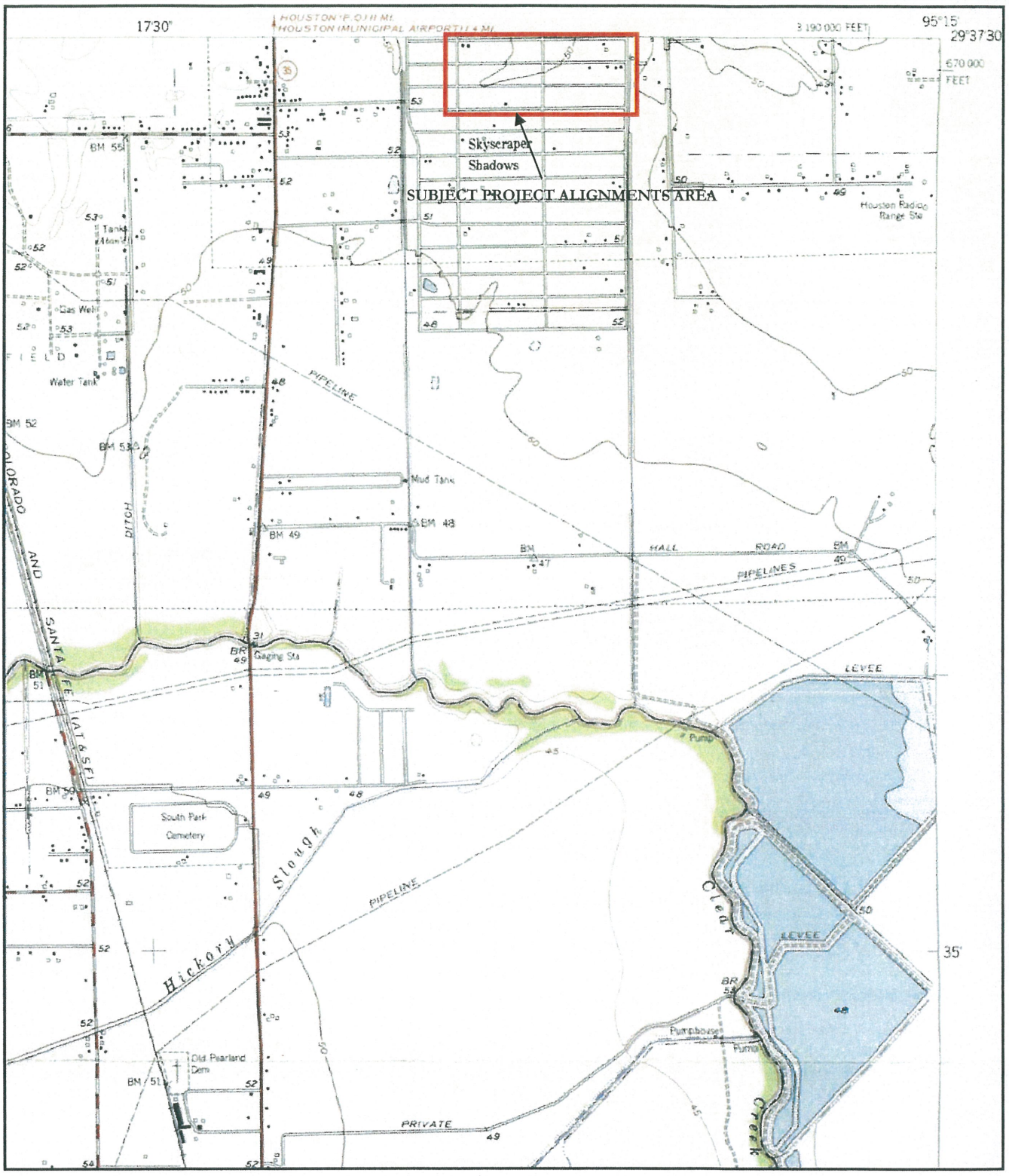
Source: U.S. Geological Survey (1915 Mykawa Quadrangle)

HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1915)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	



Source: U.S. Geological Survey (1929 Pearland Quadrangle)

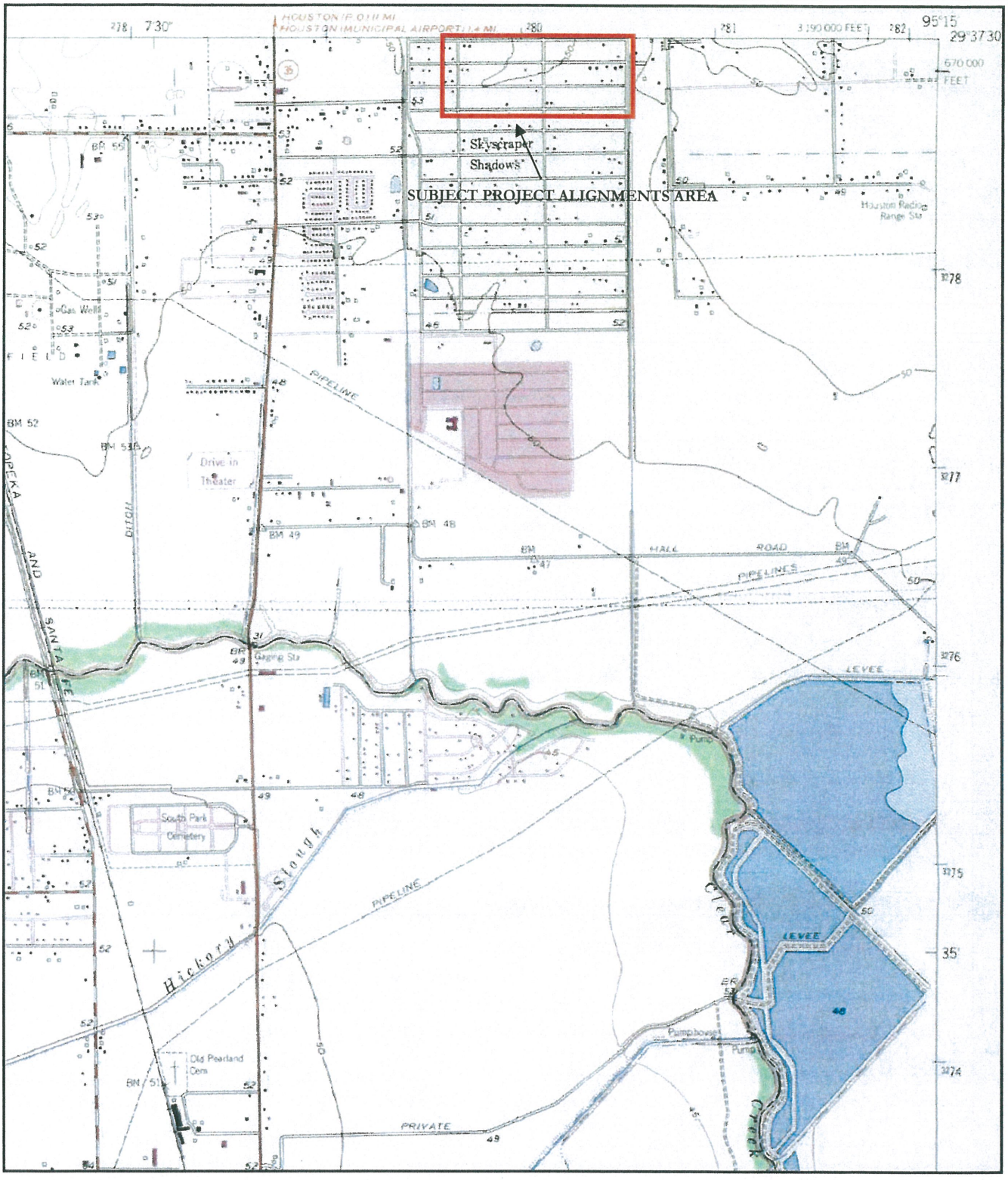
HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1929)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	



Source: U.S. Geological Survey (1955 Pearland Quadrangle)

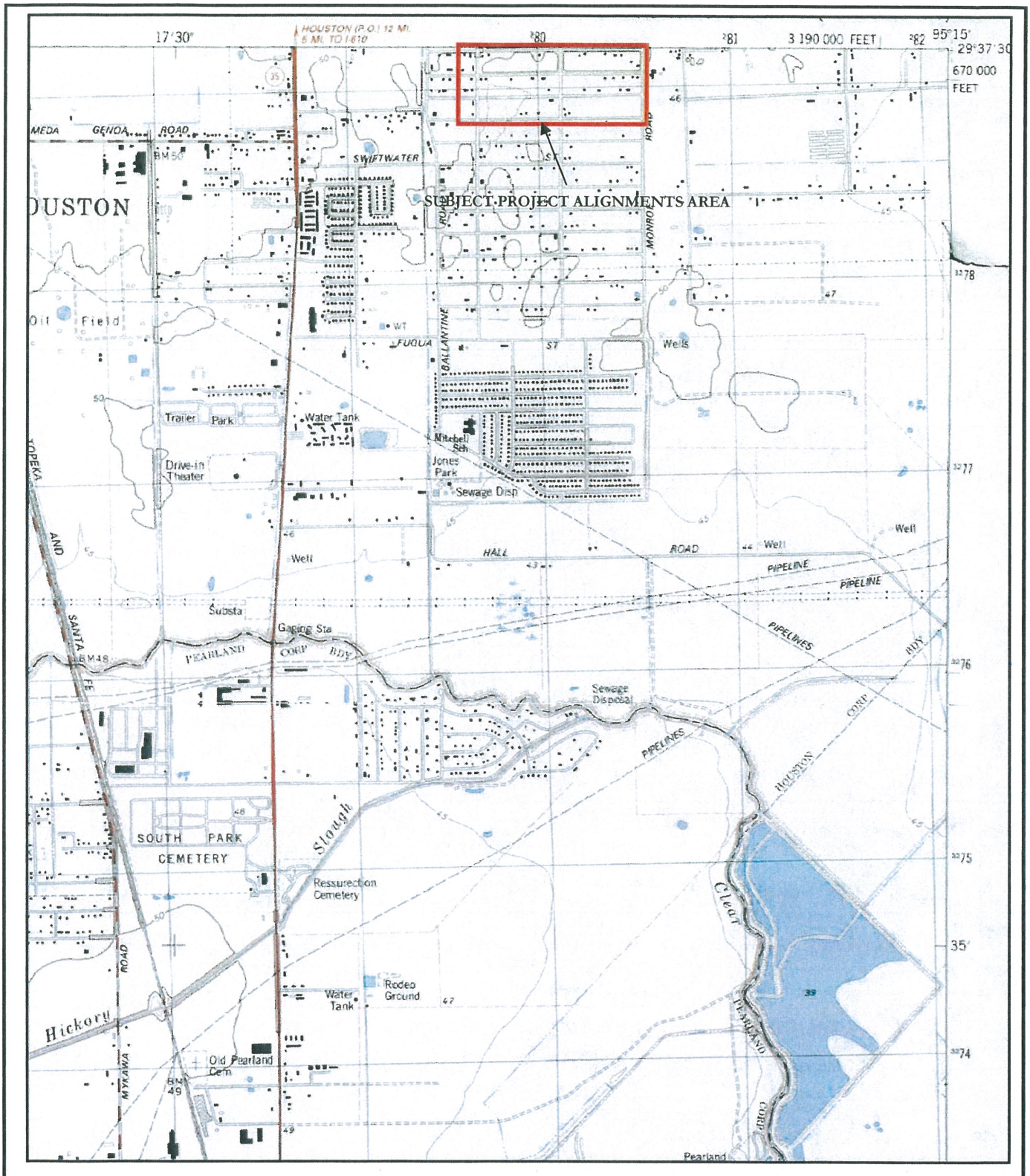
HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1955)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	

N



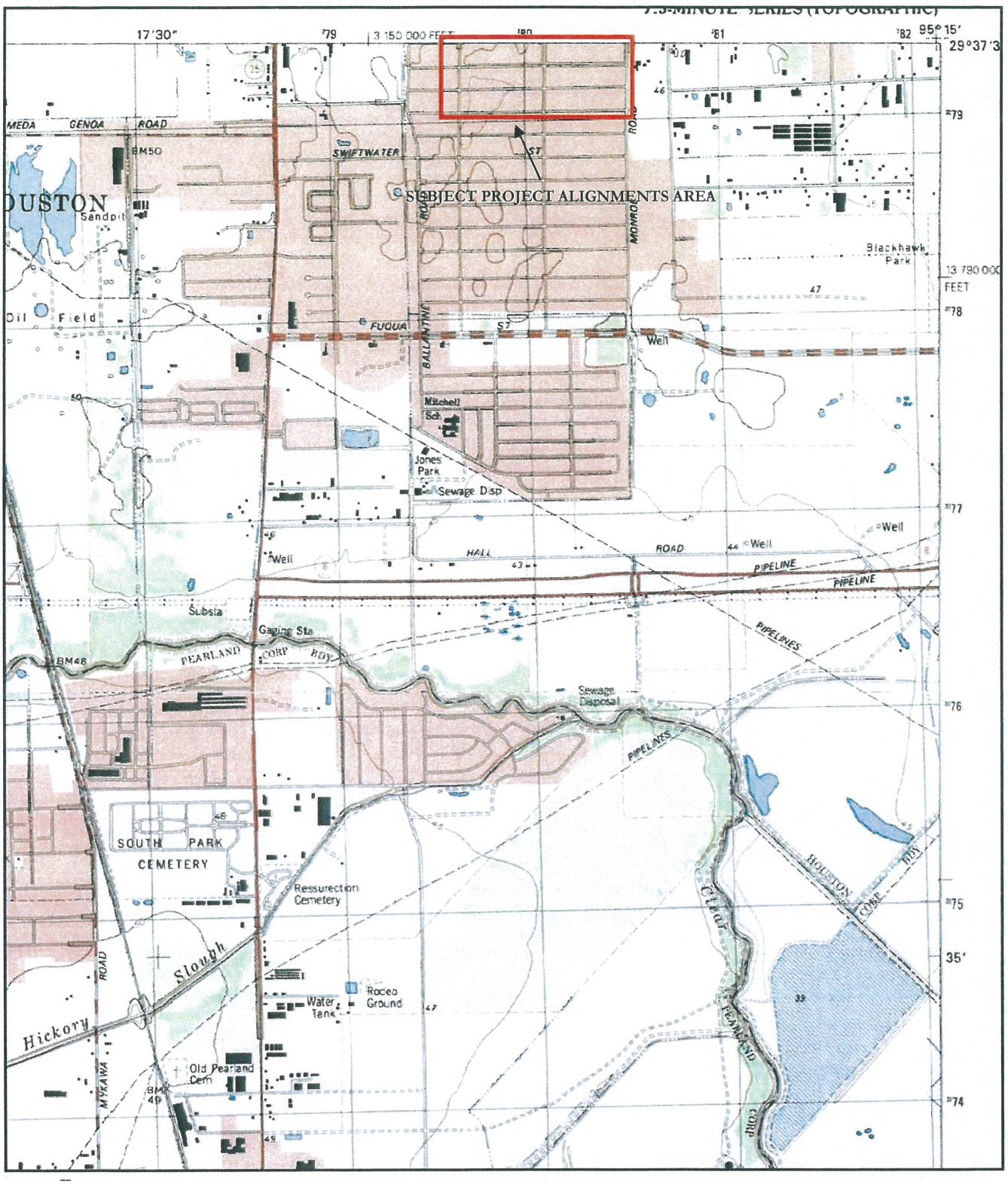
Source: U.S. Geological Survey (1969 Pearland Quadrangle)

HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1969)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	



Source: U.S. Geological Survey (1982 Pearland Quadrangle)

HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1982)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	



Source: U.S. Geological Survey (1995 Pearland Quadrangle)

HVJ ASSOCIATES	Drawn:	EH	**TOPOGRAPHIC MAP (1995)** **Phase I Geologic Fault Assessment** **Skyscraper Project Area** **Houston, Harris County, Texas**
	Checked:	MM	
	Date:	February 2015	
Report No. HE1510720	Scale:	NTS	