GROUND WATER LEVEL STUDIES AT LAGRAVE FIELD MONITORING WELLS AND THEIR SENSITIVITY TO RECHARGE FROM RAINFALL AND THE TRINITY RIVER, FORT WORTH, TEXAS

By

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Submitted to the Graduate Faculty of the
College of Science and Engineering
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in partial fulfillment of the requirements
for the degree of

Master of Science

August 2007

ACKNOWLEDGEMENTS

My deepest appreciation for this project goes to two people. First, I am very thankful to my major professor, Dr Michael Slattery who created this opportunity for me to work on this project. I am so appreciative for his unlimited and sincere assistance during all stages of my work. Secondly, I would like to thank Becky Richards for always standing by my side by providing useful information and resources for my project. With out their constructive comments and assistance, this project could have not reached to this stage. I am also grateful for those people who have been helpful to me by providing informative resource materials for my research.

I would also like to use this opportunity to express my gratitude to the Department of Geology for offering me such rewarding and unforgettable experiences of education at Texas Christian University. Finally, I appreciate Dr Ken Morgan and Dr Ranjan Muttiah who are on my research committee for their time and patience in reading my thesis work.

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INTRODUCTION

The groundwater wells studied in this thesis project are located on the eastern side of North Main Street in the Paddock Bend area of Fort Worth, Texas, which is a floodplain located in a meandering bend of Trinity River immediately north of downtown Fort Worth. As shown in Figure-1, the project site extends from LaGrave Baseball field in the Northwest to the Southeastern part of the Paddock Bend. It covers all the parking lots for LaGrave baseball field and the surroundings tracts of unused and vegetated land as well as the recreational area that encompasses the Trinity trails in between the Trinity River and its levee system (Figure-2). Southwest of the study area is the confluence point of two tributaries of the Trinity River, namely, the Clear Fork and West Fork.

Published references on the Paddock Bend area reveal that the immediate areas surrounding the project site are historically known for their aging commercial and industrial operations such as meatpacking plants, Cytec Industries (former American Cyanamid plant), Texas oil Refinery Corporation, commercial metal companies, among, others. Several reports on environmental investigations in the area reveal that the soil and groundwater is contaminated by various metals and chlorinated solvents from past activities of these industries. The study area, being a part of the Paddock Bend, has also experienced devastating flooding from the Trinity River prior to the construction of the Trinity levee system in the 1940s by the Fort Worth Floodway program. The area is still at risk and moreover, the levee system that follows the Trinity River channel is old and has been eroded slowly over the past decades. Consequently, a new project known as the

Trinity Uptown launched by the Trinity Vision Authority, has as part of its objectives to maximize the flood protection efficiency in the area through the development of a bypass channel in North Fort Worth.

The groundwater wells on which this research is based are 24 monitoring wells (table-1) that are the property of the City of Fort Worth, Cytec Industries (former American Cyanamid) and Technicoat, Inc., which is coating manufacturing facility. The wells that belong to Cytec Industries were constructed in 1995 with a hole depth that ranges from 47 to 57.5 ft, where as those for the City of Fort Worth were drilled in 2001 with a depth range of 25 to 30ft. Ten of these monitoring wells are built in the area between the Trinity River and its levee system while the remaining 14 lie on the western side of the levee that covers the parking lots and the vacant tracts of land (figure-2).

Texas Water Development Board annually measures the groundwater levels and groundwater quality in all the aquifers through out the state of Texas in order to monitor any changes in the groundwater that may occur over time. Though the scale of this aquifer is very small, the data collected and the results obtained from this research could be very helpful for researches that require the understanding of the dynamics of groundwater flow such as, for example, the transport of contaminants in the area and the appropriate remediation methods that can be taken.

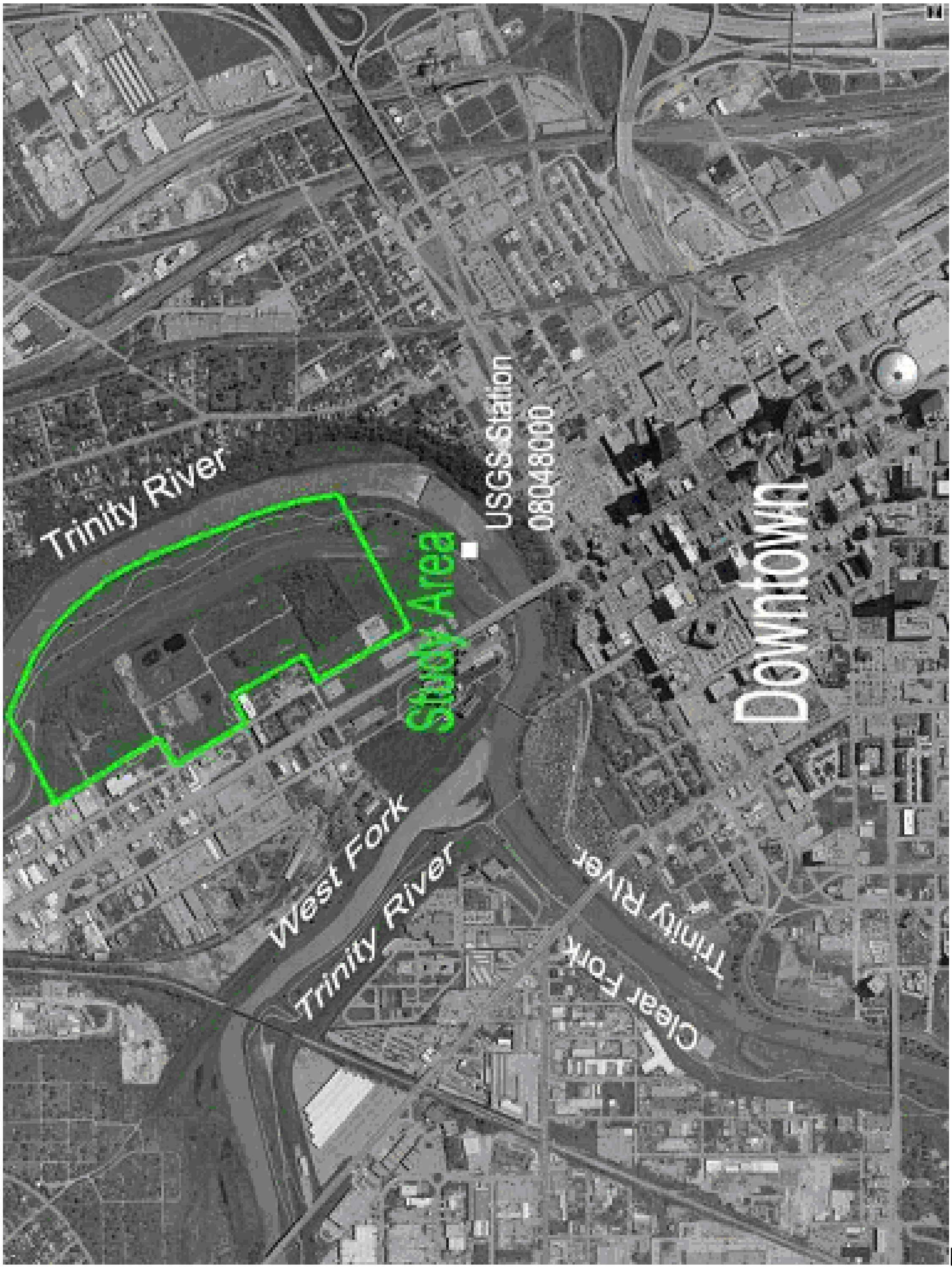

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Figure-1: Location map for the study area

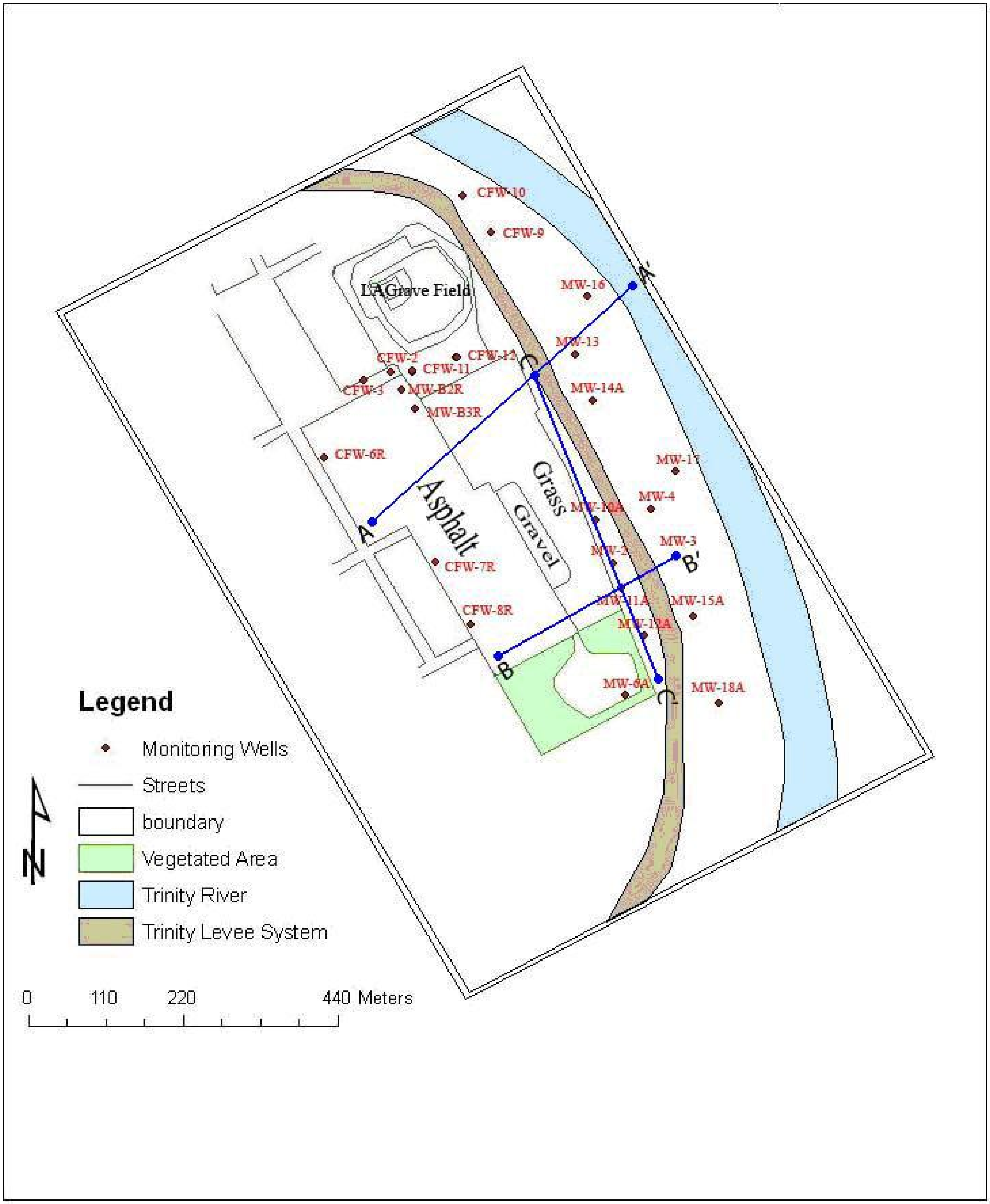


Figure-2. The study area and its monitoring wells

OBJECTIVES

The research reported here has three main objectives

1) To estimate the hydraulic properties of the aquifer – Transmissivity and Hydraulic Conductivity– by carrying out pumping tests on selected well sites.

2) To study the impact of the nearby Trinity river on the groundwater wells and thereby understand the hydraulic connection between the aquifer and the river.

3) To evaluate the effect of recharge from precipitation in the area and estimate the groundwater flow directions in the aquifer based on the water level changes during the period of research.

MATERIALS AND METHODS

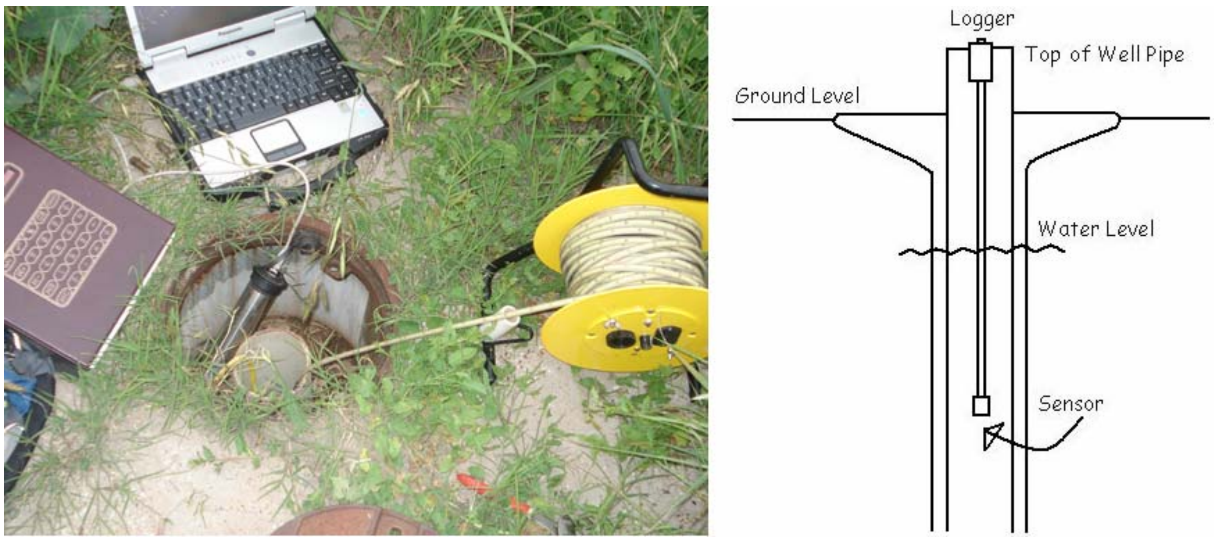
The following methodology was used in this research:

1) A literature review of previous groundwater studies carried out on the Paddock Bend Area was made in order to have a general understanding of the hydrogeology of the aquifer of interest and its monitoring wells:

2) To determine the important hydraulic characteristics of the aquifer, a constant rate pumping test was conducted in three of the wells and the data collected from this aquifer test was used to have an estimate on the storage coefficient and transmissivity of the aquifer:

3) On April 26, 2006, WL 16U water level loggers which are manufactured by Global Water Instrumentation, Inc., at Gold River, California, were inserted into 8 selected wells in the area. Four of these wells (CFW-9, MW-13, MW-16 and MW-17) are in the recreational park between the levee and the Trinity River and the remaining four (MW-10A, MW-11A, MW-B2R and CFW-7R) are on the other side of the levee that includes the parking lots for the LaGrave base ball field (See Figure-2). Selection of the wells was made based on uniform coverage of area by the water loggers, putting into consideration the proximity of some of these loggers to the Trinity River. The loggers recorded the depth from the sensor

to the water surface (figure-3) and the water levels were recorded every 30 minutes.



(a) (b)

Figure-3. (a) A water logger (b) graphical representation of the method of water level measurement by the logger.

The real-time water level records from the loggers were downloaded every week to study the weekly temporal variation of the groundwater table in the aquifer and data was collected till the end of March, 2007.

In order to study their inter-relationships with water level rise or drop in the aquifer, hourly rainfall and the water surface elevations for the Trinity River during the period of research (Apr 2006 to Feb 2007) was downloaded from the online USGS stream gauging station 08048000 at West Fork Trinity River.

PREVIOUS WORK

The Paddock Bend area, and project site in particular, has been the focus of research since early 1990s due to its impacted soil and shallow groundwater (figure-4) from the aging industrial and commercial operations in the past. Different investigators from Texas Commission of Environmental Quality (TCEQ), Environmental Trainers, Shaw Environmental and Enercon Services have been researching the project site and published numerous reports and maps on the environmental conditions of the area.

Historical soil and groundwater investigations on the site identified chemicals of concern in the soil and groundwater exceeding the applicable TCEQ Texas Risk Reduction Program (TRRP) Tier 1 Protective Concentration Levels (PCLs) for residential land use. Identified chemical of concern included chlorinated solvents in groundwater and metals such as cadmium, chromium, copper, molybdenum, and vanadium (Environmental Trainers, Inc, 2005). These soil and shallow groundwater contaminations are mainly from the historic Cytec and Technicoat operations that consisted of underground storage tank areas, hazardous waste tanks, a process area, and a surface impoundment. In compliance with the urban renewal projects by the City of Fort Worth, the Cytec site, which covers a major part of the project site, was accepted into the Texas Voluntary Cleanup Program on June 5, 2001 and various remediation operations has been undergoing since then.

Published references on groundwater monitoring events indicate that the groundwater gradient in the Paddock Bend varies over time and during periods of higher water level elevation in the aquifer system, the river gains water from discharge of the aquifer. That is to say, the western portion of the Paddock bend discharges to the west, while the eastern and southern portions discharge to the east and south respectively (Figure-5).

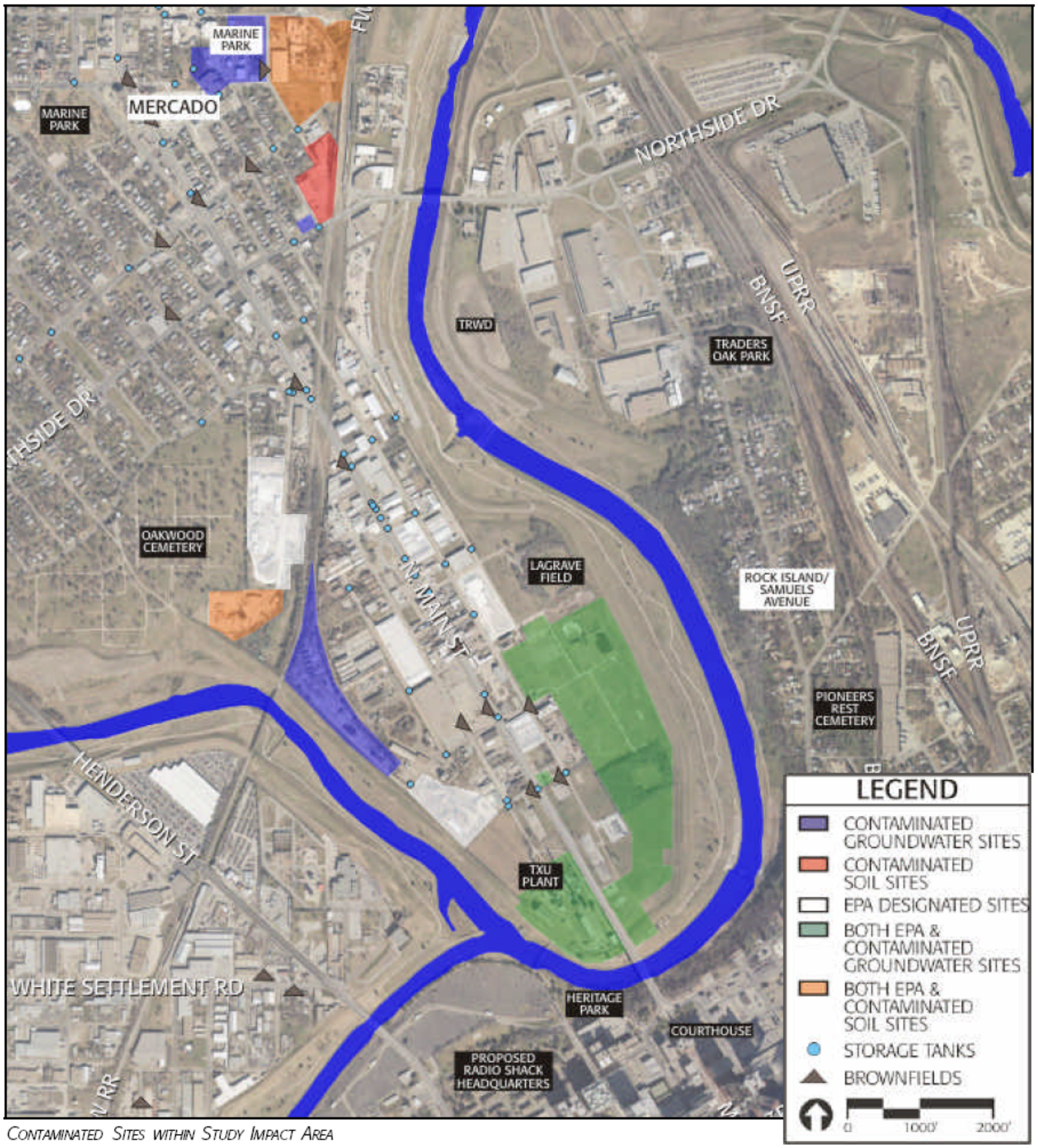


Figure-4. Impacted soil and groundwater sites for the Paddock bend Area.
(Photo taken from the April 2003 Trinity River vision report, as found online at http://trinityrivervision.com/presentations/finalreport/6_CentralCity_Segment.PDF)

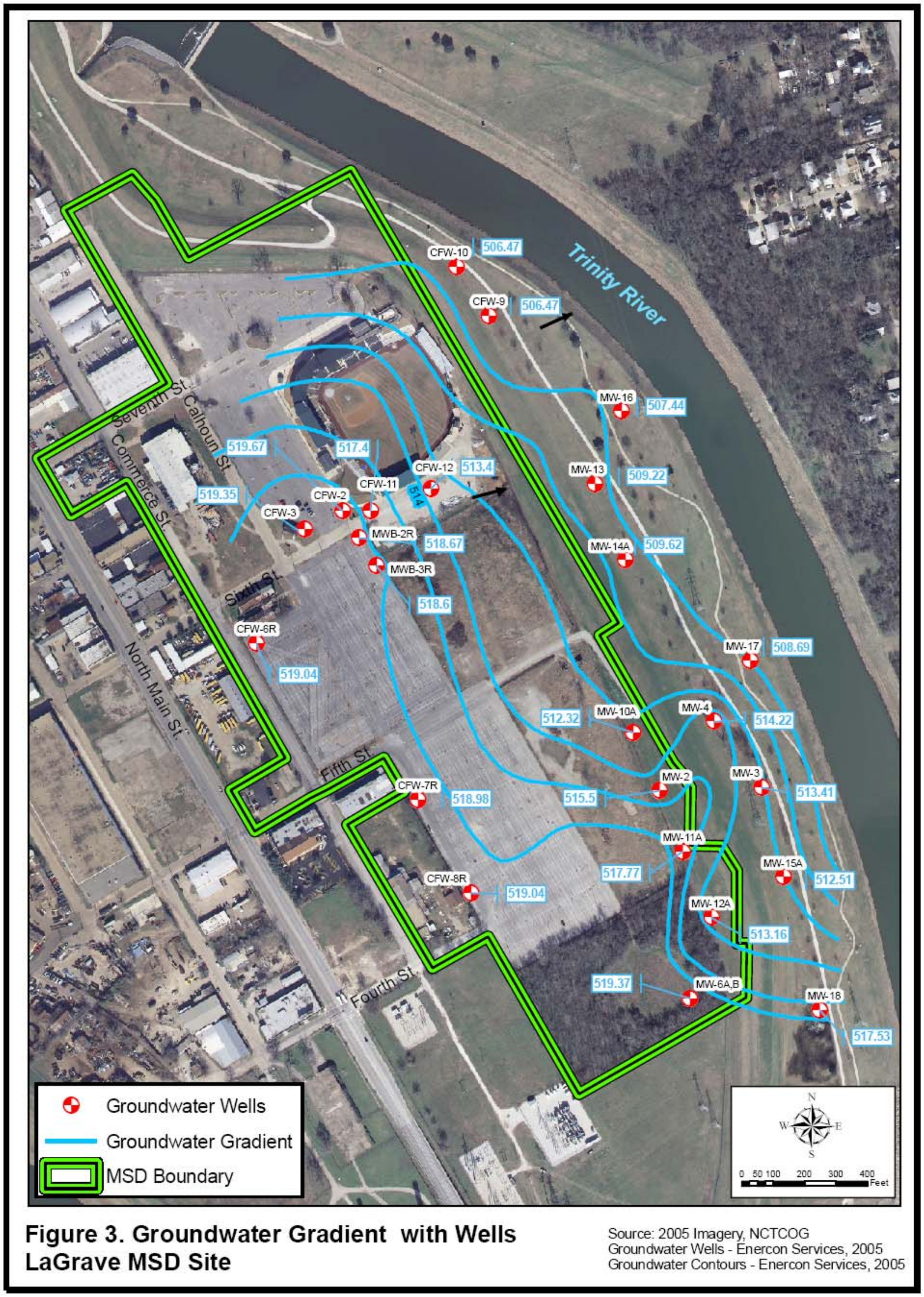


Figure-5: Groundwater contour map and its flow direction (Photo taken from Enercon Services report, 2005)

HYDROGEOLOGIC SETTING

The aquifer studied is located in the Paddock Bend area, which is a floodplain, enclosed by the Trinity River in the south, west and east. It is composed of alluvial materials that were deposited from the Trinity River during its different stages of evolution and several periods of flooding in its life history. In this research project, no soil boring or other methods were used to study the subsurface geology of this alluvial aquifer but a review and analysis of the subsurface units at the study area was made based on the data collected from well construction logs (Appendix-B) and N-S and E-W trending subsurface profiles (Appendix-B) of the wells that are owned by the City of Fort Worth.

These floodplain sediments are deposited on top of limestone bedrock which is slightly weathered and of relatively very low permeability. They are mostly overlain by a thin layer of landfill material that goes down as deep as 5 ft below the ground surface and their vertical thickness generally ranges from 20 to 45 ft with greatest thickness in the vicinity of the Trinity River. Top to Bottom, the stratigraphy of these alluvial deposits can be adequately described by five units, namely, silty clay, silt, silty and clayey sand, sand and gravel. Generally, these floodplain deposits are well sorted and well rounded due to their geologic history and therefore their porosity is high but their hydraulic conductivity varies depending on their grain size and the interconnectivity of their pores. Furthermore, as it is clearly depicted in the subsurface profiles, the vertical thickness and aerial continuity of these alluvial layers is variable. The fine-grained sediments which

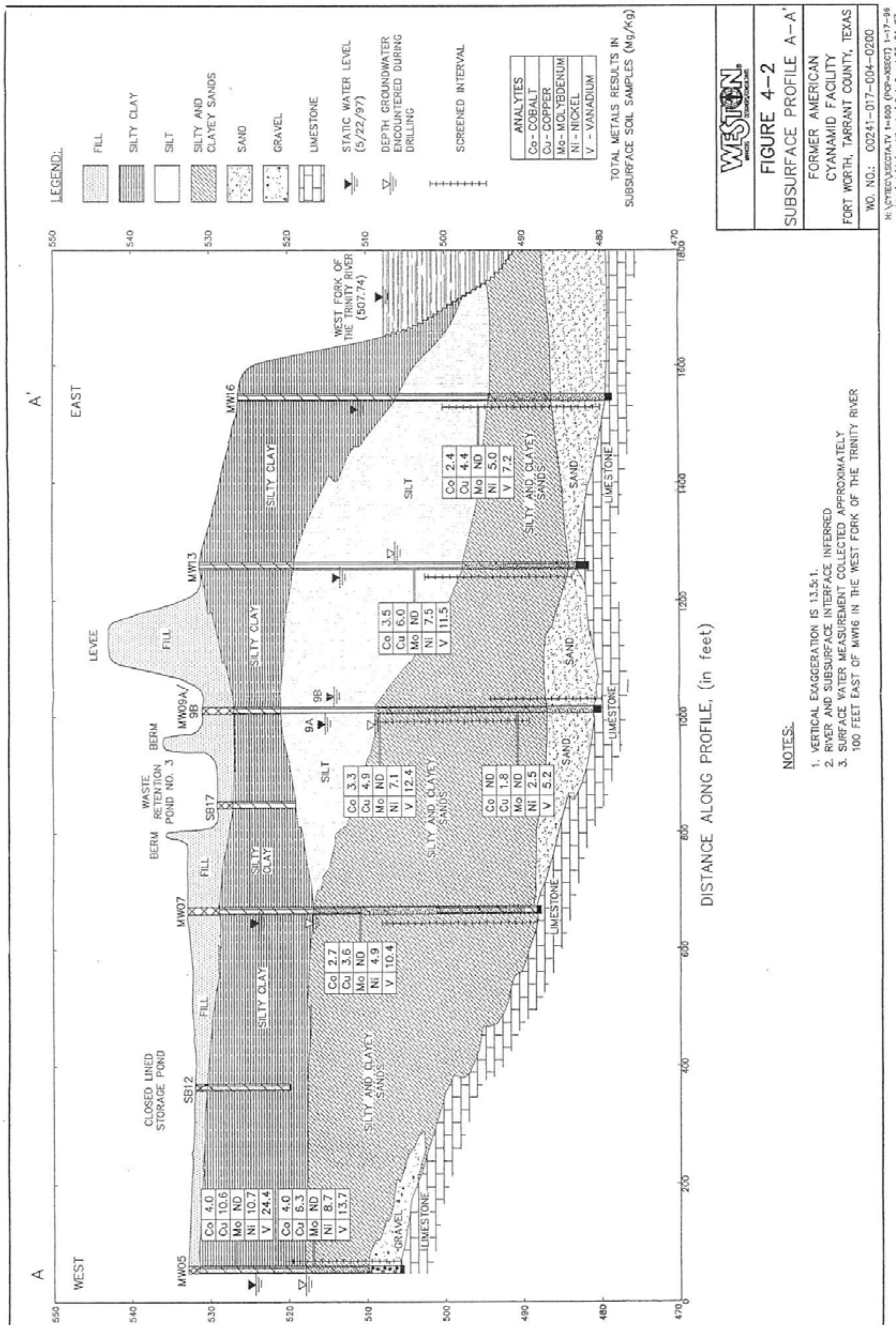


Figure-6. Subsurface profile running East to West along A-A'

have very low permeability have uniform thickness and aerial continuity and as a result, they are intercepted by all the monitoring wells in the project site. The coarse grained layers such as the gravel and sand which have very high permeability, however, have limited aerial continuity and occur as lenses of sediment on top of the limestone bed rock. The occurrence of such coarse lenses of gravel and sand
on the bedrock is probably either the result of the accumulation of coarse sediments near point bars during its meandering process or due to the deposition of bed load sediments followed by the burial of fine-grained materials as the turbidity of the flowing river gradually decreases.

All the groundwater wells are screened at the interface of the limestone which serves as a confining layer for water held by the upper alluvial units and they are all fed from the water bearing units in the area which are mainly the sand and gravel layers overlying the limestone. This water bearing zone of sand and gravel become finer upwards and change their composition to clayey and silty sand. Wells that intersect such coarse layers of sand and gravel will have higher yields than those in the finer flood plain deposits due to the higher permeability.

Groundwater in the alluvial deposits originates mostly from infiltration of precipitation in the area though, during dry seasons there may be certain degree of recharge through its most permeable alluvial layers which are in contact with the Trinity River. The study area’s zone of saturation which has a thickness of about 18 to 30 ft is due to the interception and accumulation of the downward percolating water at the relatively impervious layer of limestone bedrock. The upper surface of groundwater in the alluvial units can therefore be called a perched water table and the aquifer in the project site can be referred to as perched aquifer. This perched water table is encountered at a depth of 9 to 25 feet in the area with greatest depths in the eastern part of the project site. Based on the site's location with regard to the aquifers distribution in Texas, the regional groundwater table from the Trinity group formations that form the Trinity aquifer is very likely to be encountered at very great depths below this local zone of saturation.

Historical Water Level Record Evaluation

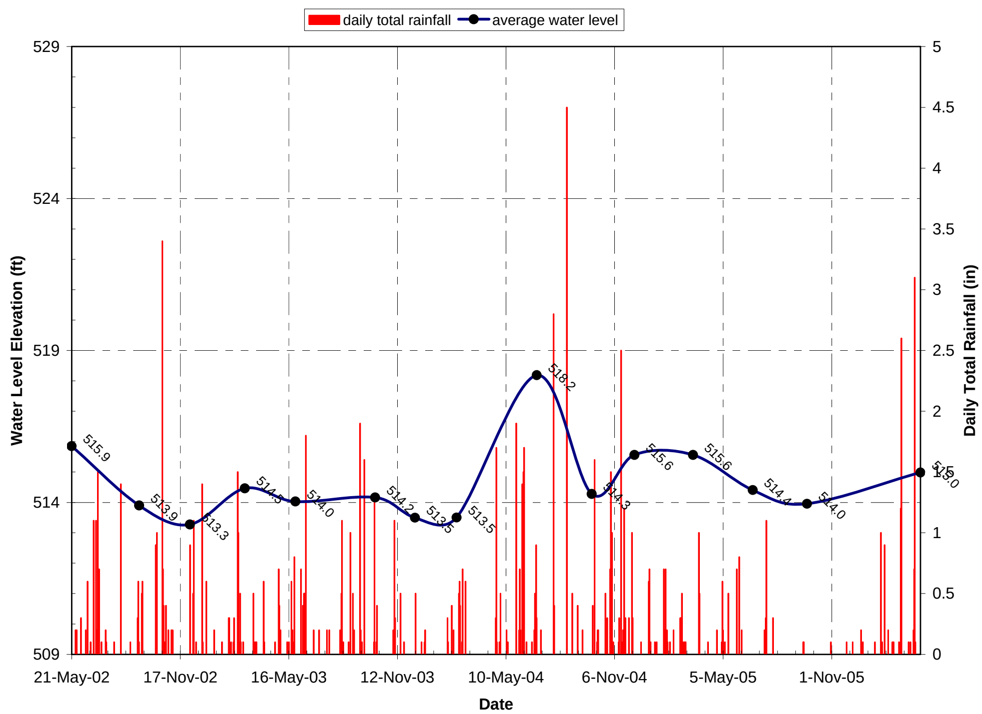
As of the day of the construction of these monitoring wells, the water levels in the study area are monitored on a quarterly to semi-annually basis in order to track the changes in the water levels and thereby have a complete understanding of long-term trends of the potentiometric surface elevations.

The water level data (Appendix-A, table-2) from this monitoring network is studied through the production of hydrographs in order relate the current water data from the monitoring event during this research project to the historic ground water levels (Sept 1995 – Mar 2006).

This historic water level record shows that the potentiometric surface for the aquifer ranged from 505 ft to 525 ft above mean sea level and generally, groundwater depths for the wells on the eastern side is much higher than those on the western side with the deepest wells on the NNE part of the project side. Therefore, from such water level measurements, it is understandable that groundwater flow is towards the Trinity River in a direction of NE to NNE.

Furthermore, this historic water level data shows that there was no severe water level decline in the area and the water level was stable over time with short-term seasonal fluctuations which is probably the result of recharge and discharge interactions of the groundwater with rainfall and nearby surface water. The changes in the groundwater level depth in most of the monitoring wells is almost the same during each of the monitoring events which may suggest the degree of homogeneity of the aquifer despite its make up of different alluvial layers. Water level hydrograph and hyetograph (figure-7 below) for the period of May 2002 to Mar 2006 was created in order to compare the changes for the average water level elevation during each monitoring event with total amount of daily rainfall. The figure shows that the average water level during each monitoring event fluctuates within a narrow range with the exception of water level peak on June 30, 2004 which is as a result of recharge from the consecutive five days of rainfall (June 26-30, 2004) prior to monitoring event.

Figure-7
Water Level Hydrograph Versus Rainfal (May 21, 2002 - Mar 28, 2006)



AQUIFER TEST

There are various methods for estimating the hydraulic properties of an aquifer. For this project, constant rate pumping tests were carried out on some of the monitoring wells in the project site in order to determine aquifer properties at or near a pumped well. Because this aquifer is contaminated by past industrial and commercial operations, selection of a pair of pumping and observation wells for the purpose of this study was mainly based on (i) the quality of the water in the well; (ii) the distance of the wells from the river in order to avoid recharge; and (iii) the proximity of the pumping and observation well from all available wells in the area.

Prior to the actual pumping test, a preliminary test was carried out for 4 hours in the selected wells in order to determine the optimum pumping rate as well as to have an estimate of the anticipated drawdown in the observation wells. The first pair of wells selected for this test was CFW6R as a pumping well and MWB2R as the observation well. The preliminary test was carried out for almost four hours with an average pumping rate of 1.75 l/min. However, the drawdown observed in the observation well was 0.01feet which is negligible and might equally be due to measurement error as opposed to any real drawdown. The same preliminary test was done on CFW9 and CFW 10 and, as with the previous test described above, there was no drawdown during the period of pumping, even though the distance between these wells is much closer than in the first preliminary test.

MW14A was ultimately selected for actual pumping test after estimating its optimum pumping rate and ensuring a continued pumping duration. Prior to pumping the water level depth in MW-14A and its observation well, MW-13, was 21.48 ft and 21.58 ft respectively. The pumping continued at a rate of 4.5 l/min for 8hours until the water level in the pumped well (drawdown) remained constant (46ft) which means a state of equilibrium in the aquifer test. The drawdowns in MW-13 and MW-14a were 25.42 ft and 0.03 ft respectively (table-3). The test was discontinued after 8 hours of pumping due to the steady water level in the pumping well as well as due to the inadequate source of the power supply for the pump. The readings of the water level data loggers in the other wells was downloaded to see if they had experienced a drawdown during the duration of the pumping but there was no change in their water level records.

The absence of appreciable drawdowns in the observation wells for all the preliminary tests during the period of pumping supports the notion that the hydraulic conductivity of the aquiver is very low in view of its subsurface composition. Ground water flow towards the pumping well was very slow compared to the pumping rate, and a result there was no significant drawdown in the observation wells despite rapid drawdown in the pumping wells. The saturated thickness of the aquifer in the three pumping wells is different and this has affected the pumping duration for the wells. The steady state of the water level at very great depth in MW-14a indicates the equivalence of the recharge rate in this well at this depth to the pumping rate and this is probably due to the occurrence of highly permeable layers of sand and gravel at this depth in the well.

Despite the absence of appreciable drawdowns in MW-13, calculations were made to estimate the minimum hydraulic conductivity (K) and transmissivity (T) using the Theim Equation by assuming steady state conditions (equilibrium) has been achieved in the wells. MW14B which is located 1foot away from MW-14a was used a second observation well during these calculations.

$$K = [Q/ (h^2_2 - h^2_1)] \ln [r_2/r_1]$$ Theim Equation

Where:

Q – Pumping rate = 228.84 ft^3/day
h_2 – Hydraulic head in MW-13 = 508.79 ft
h_1 – Hydraulic head in MW-14B = 484.95 ft
r_1 – radial distance of MW-13 = 120 ft
r_2 – radial distance of MW-14B = 1 ft
t – Average aquifer thickness = 24 ft

Using the Theim Equation and the above constants, the minimum hydraulic conductivity for this alluvial aquifer is estimated to be 2.69 ft/year and its transmissivity is 64.5 ft^2/year. This estimated value for K and T fall within the typical ranges of hydraulic conductivity values for clay and silt that are compiled by Freeze and Cherry (1979).

ANALYSIS OF THE WATER LEVEL DATA AND GROUNDWATER FLOW

As described above, the groundwater depth in the project site shows temporal variations as it is greatly influenced by variables such as rainfall, recharge/ discharge relationships with the Trinity river through its subsurface flow networks as well as other seasonal factors such evapotranspiration and infiltration properties of the soil overlying the aquifer.

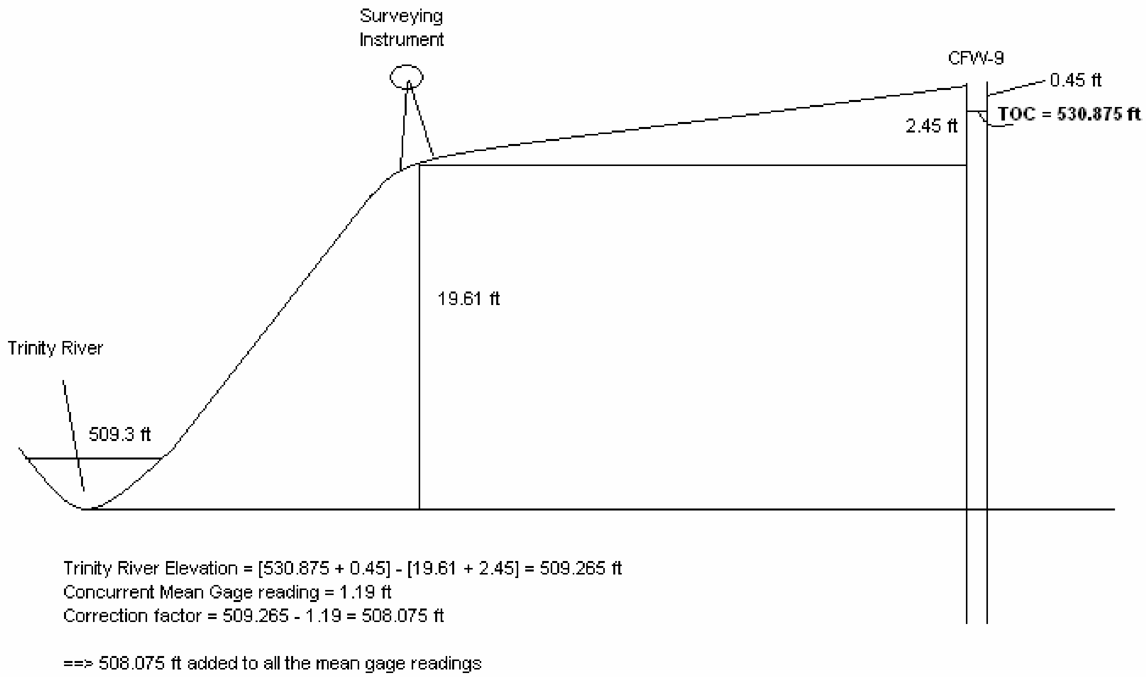
In order to have a continuous real time record of the water level for this aquifer for the period of this research, WL 16 water level loggers were installed into 8 of the monitoring wells and this automated water level loggers were set to every 30 minutes recording interval.. The water level data used in the following analysis and interpretation is for a period of about 10 months (April 2006 to Feb, 2007). Water level data from well ID MW-11A is not used due to mechanical failure of the logger for almost two months besides being flooded later several times by water in the spring. The same mechanical failure occurred in MWB2R and other wells which resulted in a discontinuity of few days to weeks of water level data.

Well hydrographs were produced for all the seven wells by plotting each hourly record (April 2006 to Feb 2007) of the water level against its corresponding real-time series (see Appendix-C). The hydrographs clearly show seasonal variations of the water level in all the wells. That is to say as summer approaches (June – August

2006), the water levels start to fall down and continue to decline gradually to its lowest levels till the early of fall as the amount of water entering the aquifer system as recharge does not exceed the amount leaving the aquifer system through evapotranspiration and possible discharge to the Trinity River. As the fall season starts, the aquifer system is replenished with water from rainfall and it continues to rise gradually through out the fall and spring as rate of evapotranspiration gradually diminishes and precipitation amount continues to increase. Hourly rainfall data for each raining day in 2006 (Appendix-A, table-4) was downloaded online from the USGS 080484000 and then added to the hydrographs in order to see if the water level variation can be attributed to infiltration from such precipitation in the project site. Such plots of real-time water levels with hourly rainfall clearly show the alignment of hourly rainfall histograms with water level rises in the wells which is an indication that recharge from rainfall was the cause for most of the appreciable water level rises.

In order to assess the horizontal and vertical hydraulic connection of the aquifer materials as the well as the wells, all the well hydrographs and hyetograph were plotted together on the same x-axis (Figure-8). All the well hydrographs follow the same concurrent pattern of water level rise and drops through time and the degree of coherence as well as magnitude of such water level patterns is also a measure of the homogeneity and isotropism of the aquifer. Both Figure-8 and the real-time water level data from the loggers show that the magnitude of the water level rise is not greater than one foot for all the wells even after the period of long rainfall. Besides, a careful study of the time difference for the start of water level rise and the start of storm events show that aquifer lags behind for about 2-3 hours after the start of water input event. Such slight changes in the water levels despite heavy rainfalls as well as the sluggishness of the aquifer to respond quickly to the rainfall event can be attributed to the infiltration properties of the soil material that make up the aquifer. As it has been explained in the first sections of this report, this aquifer is composed of fine silt-clay alluvial materials and such soil particles do not allow water to infiltrate rapidly to the subsurface as their permeability is very low though their porosity is high.

The unavailability of real time Trinity River elevations from the nearby USGS station resulted in the field measurements of the river. Consequently, on April 9, 2006, a surveying instrument was used to find the Trinity River elevation relative to CFW-9 which has a TOC (top of casing) elevation of 530.876 ft above mean sea level. The correction that has to be made for the concurrent reading of the mean gage height from the USGS station was then calculated and then added to all the reading of the mean gage height for the period of research. Despite the inaccuracy of such calculated figures, Trinity hydrograph was produced by using the mean gage height data for the gauging station in the project site so that to study the stream response to the several water inputs events as well as its relationship with the water level in the wells. Such figures show that the hydraulic head for the Trinity River remained almost stable through the period of research though the water levels declined during

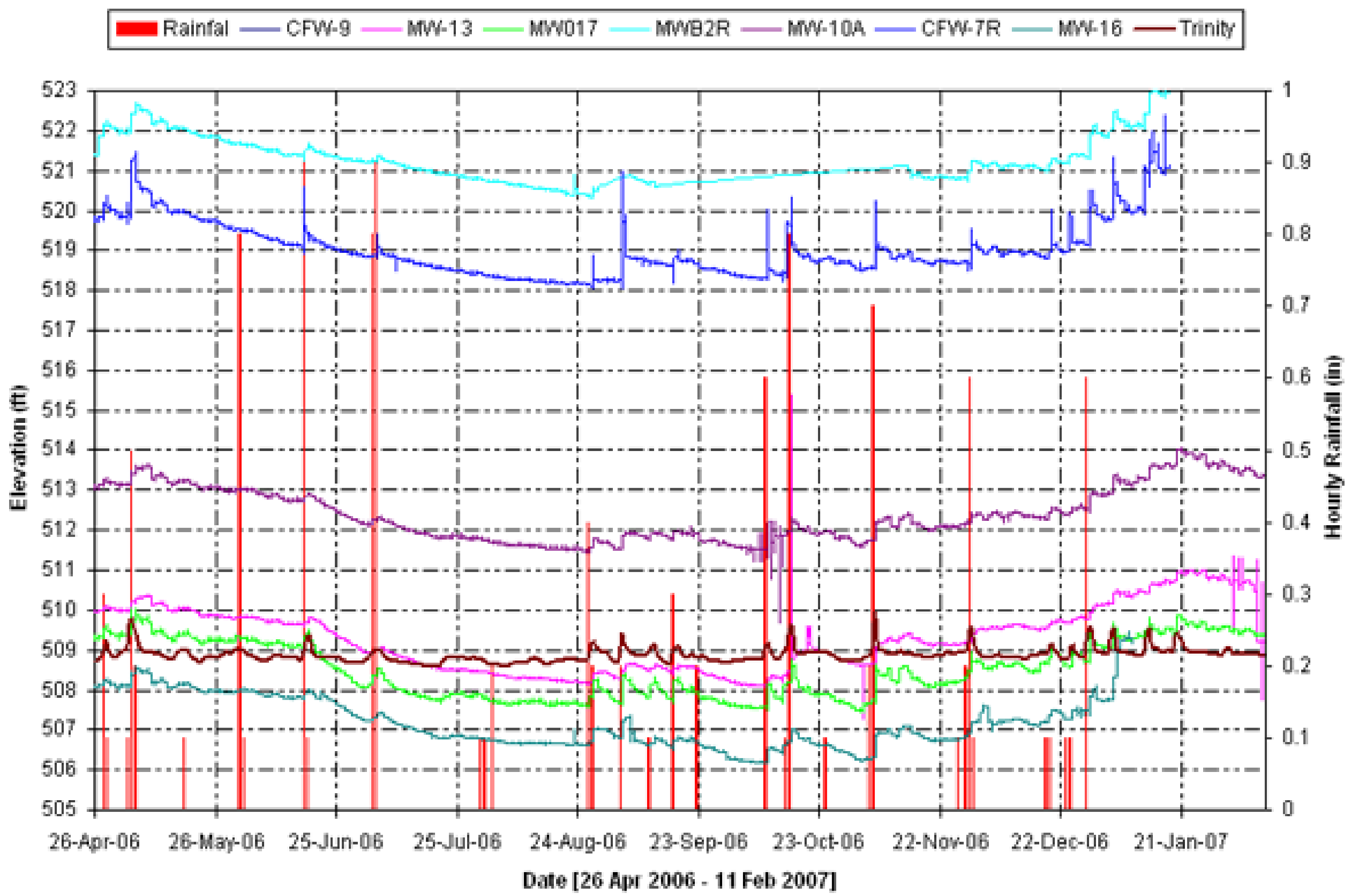


the dry seasons. This fact coupled with the low permeability of the aquifer materials which in contact with the river support the notion that they hydraulic connection between the river and the aquifer, and hence the groundwater recharge from the river, is very minimal. In general, the Trinity river elevation is lower compared to the most wells during the wet seasons and receives water discharged from aquifer. During the summer however, the Trinity River is at a higher elevation compared to the wells very close to its bank and therefore, such wells are recharged from the river only during the summer.

Figure-9 represents the predicted groundwater contour map for water measurements made manually on March 28, 2007. It was produced by first geo-referencing the base map provided for this project and then using the ordinary Kriging tool from Arc GIS software. It is evident from this figure that, groundwater level elevations are higher on the western portion of the project site and they decrease gradually towards the east in the direction of the Trinity River. The groundwater contours on the map show that groundwater gradient is gentle and almost the same through out the project site. Generally, groundwater flows towards areas of low water elevation and therefore, from the map produced it is easy to conclude that groundwater flow is generally to the river in a direction that varies from NE to NNE. During the summer, there may certain degree of groundwater flow to the areas immediate to its banks due to their water elevation difference. However, the hydrographs show there was no noticeable change in water levels during summer in regard to its higher elevations of the river and this suggest that surface water and groundwater interactions is very weak probably due to the poor interconnectivity of the aquifer materials that are in hydraulic contact with the river.

Figure-8

Combined well hydrographs, Trinity River hydrograph and rainfall hyetograph



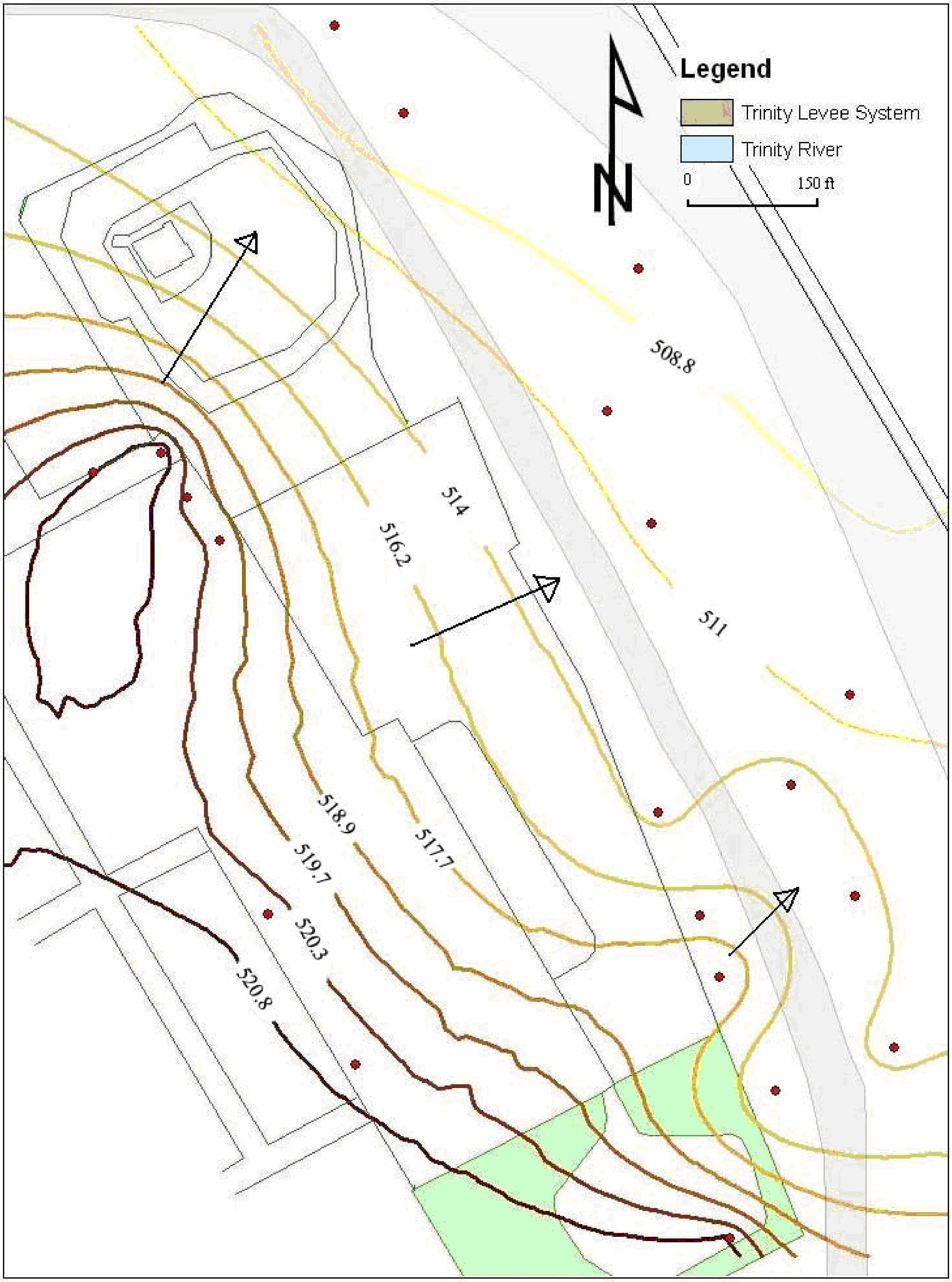


Figure-9.Grounwater contour map (Mar 28, 2007)

CONCLUSIONS

Based on the results obtained and the discussions made in the previous sections, the following conclusions can be summarized for this study:

- The aquifer studied is dominantly characterized by materials of low conductivity and therefore low transmissivity too. Consequently, the aquifer recharges slowly and only a very small percent of the water that falls as rain recharges the aquifer.

- The strong harmony of water level changes in the hydrograph to rainfall suggests that the major source of recharge for this alluvial aquifer is infiltration of rainwater.

- Likewise, the real-time water level data as well as Trinity and well hydrographs suggest that recharge from the nearby Trinity River seems to be negligible and that the hydraulic connection between the alluvial layer and the Trinity River is either very weak or indiscernible.

- There was no major water level decline in the aquifer during the past decade and this supports the notion that groundwater levels remained almost stable through time with the exception of seasonal fluctuations.

- The hydraulic gradient in the project site is very gentle and groundwater generally flows towards the Trinity River direction (NE-NNE).

APPENDIX-A

Table-1: Wells coordinates and their elevations

well ID	Date Installed	Owner	UTM Coordinate		TOC ELEV (ft)	Well Depth (ft)	Screen Interval
			Easting	Northing			
CFW-2	Jun-01	City of Fort Worth	655741	3626790	529.80	27.5	5 - 27.5'
CFW-3	Jun-01	City of Fort Worth	655708	3626775	530.32	25	5 - 25'
CFW-6R	Jun-04	City of Fort Worth	655647	3626673	531.63	30	3-26'
CFW-7R	Jun-04	City of Fort Worth	655802	3626534	531.72	30	3-28.5'
CFW-8R	Jun-04	City of Fort Worth	655868	3626425	531.45	25	5-25'
CFW-9	Jun-06	City of Fort Worth	655876	3626998	530.88	30	5-30'
CFW-10	Jun-06	City of Fort Worth	655845	3627045	531.26	30	5-30'
CFW-11	Jun-02	City of Fort Worth	655777	3626796	531.52	NM	5-30'
CFW-12	Jun-02	City of Fort Worth	655834	3626816	531.25	NM	5-30'
MW-2	Sep-95	Cytec Industries	656047	3626538	534.11	50	40-50'
MW-3	Sep-95	Cytec Industries	656140	3626545	533.28	48	38-58'
MW-4	Sep-95	Cytec Industries	656098	3626605	533.72	49	39-49'
MW-6a	Sep-95	Cytec Industries	656075	3626334	538.37	54.5	23-43'
MW-10a	Sep-95	Cytec Industries	656015	3626585	531.97	57.5	37-57'
MW-11a	Sep-95	Cytec Industries	656069	3626475	530.37	50	29.5-49.5'
MW-12a	Sep-95	Cytec Industries	656094	3626410	532.68	53.2	32.52'
MW-13	Sep-95	Cytec Industries	655992	3626820	530.34	49.5	27.5-47.5'
MW-14a	Sep-95	Cytec Industries	656016	3626769	530.59	54	33-53.5'
MW-15a	Sep-95	Cytec Industries	656175	3626444	530.03	53.3	33-53.5'
MW-16	Sep-95	Cytec Industries	656007	3626905	525.47	47	26-46'
MW-17	Sep-95	Cytec Industries	656130	3626674	527.49	47	26.5-46.5'
MW-18	Mar-03	Cytec Industries	656209	3626325	531.68	52.2	14.7-51.7'
MW-B2R	Jun-04	Technicoat Property	655758	3626770	530.39	NM	3-23'
MW-B3R	Jun-04	Technicoat Property	655757	3626768	531.21	NM	4-23'

NM = not measured

Table-2a: Historic water level elevations for former cytec and technicoat monitoring wells

	Former Cytec Property Well ID													Technicoat Well ID	
Date Gauged	MW 2	MW 3	MW 4	MW 6A	MW 10A	MW 11A	MW 12A	MW 13	MW 14A	MW 15A	MW 16	MW 17	MW 18	MW B2R	MW B3R
09/20/95	514.7	513.7	512.6	520.8	513.0	517.5	513.7	509.3	509.9	515.2	511.4	509.8			
12/21/95	513.6	512.5	511.4	519.1	511.7	515.9	512.5	508.1	508.6	511.9	506.0	507.4			
05/22/97	517.8	517.0	515.9	523.6	516.3	521.1	517.5	513.3	513.6	516.3	511.0	511.9			
11/06/00	515.4	514.0	513.1	521.1	513.6	518.1	515.1	509.9	510.3	513.6	509.9	509.5			
02/07/01	516.0	514.8	513.7	521.3	514.3	518.4	516.0	510.9	511.2	514.0	508.7	510.1			
05/21/02	517.7	516.6	515.3	523.1	516.2	522.1	517.3	512.4	513.0	515.9	510.3	511.3			
09/10/02	512.9	512.4	512.2	519.6	512.6	516.7	513.4	509.6	510.0	512.9	507.7	509.0			
12/03/02	512.7	511.6	511.1	519.2	511.6	515.1	512.2	508.5	508.8	511.8	506.5	507.6			
03/04/03	513.5	512.5	512.3	520.8	512.8	516.5	513.4	509.6	510.0	513.1	507.9	509.1	518.7		
05/27/03	514.2	513.4	514.2	519.4	512.2	515.9	512.7	509.4	509.7	512.4	507.5	508.6	517.6		
10/06/03	514.6	513.4	514.3	518.9	512.5	517.1	512.8	509.6	509.9	512.5	507.8	512.7	517.2		
12/11/03	514.3	513.1	513.8	518.7	511.8	517.0	512.3	509.1	509.5	512.1	507.3	508.4	516.9		
02/18/04	514.8	513.5	514.3	NM	512.4	517.3	512.8	509.6	510.0	512.5	511.1	509.0	517.3		
06/30/04	519.4	516.8	518.1	524.8	516.3	522.2	516.8	513.2	513.5	516.5	511.9	512.7	522.2	523.1	522.7
09/29/04	515.4	513.6	514.3	519.7	512.4	518.1	513.0	509.5	509.8	512.6	507.6	508.5	517.8	519.5	519.5
12/09/04	517.6	515.5	516.2	522.3	514.4	520.5	515.1	511.1	511.4	514.6	509.0	510.2	520.2	521.8	521.9
03/16/05	516.9	514.9	515.6	521.2	513.8	519.6	514.5	510.6	511.0	513.9	508.6	509.7	519.2	520.9	521.0
06/23/05	520.8	513.9	514.5	519.9	512.7	518.3	513.4	509.6	510.0	512.8	507.7	508.7	518.0	519.7	519.6
09/21/05	515.5	513.4	514.2	519.4	512.3	517.8	513.2	509.2	509.6	512.5	507.4	508.7	517.5	518.7	518.6
03/28/06	517.0	514.5	515.3	520.8	513.5	519.0	514.4	510.2	510.5	513.6	508.2	509.6	518.8	520.1	520.2

MW-18: installed on 03/07/03

MW-B2R and MW-B3R: installed on 06/29/04

NM = Not measured

Table-2b: Historic water Level Elevations
City of Fort Worth Wells

	Well ID								
Date Gauged	**CFW-2**	**CFW-3**	**CFW-6R**	**CFW-7R**	**CFW-8R**	**CFW-9**	**CFW-10**	**CFW-11**	**CFW-12**
6/12/2001	520.922	520.670				505.346	505.729		
5/21-26/02	NM	522.940				508.126	507.759		
6/20/2002	NM	NM				NM	NM	518.873	514.923
7/18/2002	515.442	NM				NM	NM	NM	NM
9/10/2002	515.192	520.540				506.716	506.669	517.723	513.873
12/3/2002	520.442	520.020				505.096	505.059	517.503	513.253
3/4/2003	521.432	521.110				506.146	506.709	518.393	513.963
5/27/2003	520.542	520.280				505.426	506.369	517.753	513.753
9/24/2003	519.992	NM				506.896	NM	517.313	513.663
10/6/2003	517.872	519.600				507.006	506.939	517.153	513.573
12/11/2003	519.412	NM				506.316	506.299	519.593	513.233
2/18/2004	519.502	NM				506.946	506.879	517.033	513.573
6/30/2004	524.002	523.370	523.892	524.322	524.642	510.926	510.849	520.623	517.133
9/29/2004	520.512	520.250	519.892	519.682	519.622	506.476	506.549	518.073	514.103
12/9/2004	522.812	522.410	522.382	522.272	522.302	507.756	507.719	520.113	516.103
3/16/2005	521.872	521.630	521.382	521.202	521.182	507.356	507.349	519.273	515.343
6/23/2005	520.652	NM	520.172	519.872	519.832	506.456	506.509	518.083	514.193
9/21/2005	519.672	519.350	519.042	518.982	519.042	506.466	506.469	517.403	513.403
3/28/2006	521.082	520.760	520.582	520.562	520.602	507.336	507.249	NM	NM

CFW-6R, CFW-7R and CFW-8R installed on 06/29/2004
CFW-11 and CFW-12 installed on 06/13/2002
NM = Not Measured

Table-3: Pumping test data

Pumping Test date : 16 Oct 2006 *Pumping well No* .: MW14A
pumping depth : 53ft *pumping rate* :4.5lt/min *Duration* : 8hrs
static water level : 21.48ft *well depth* : 54.0ft

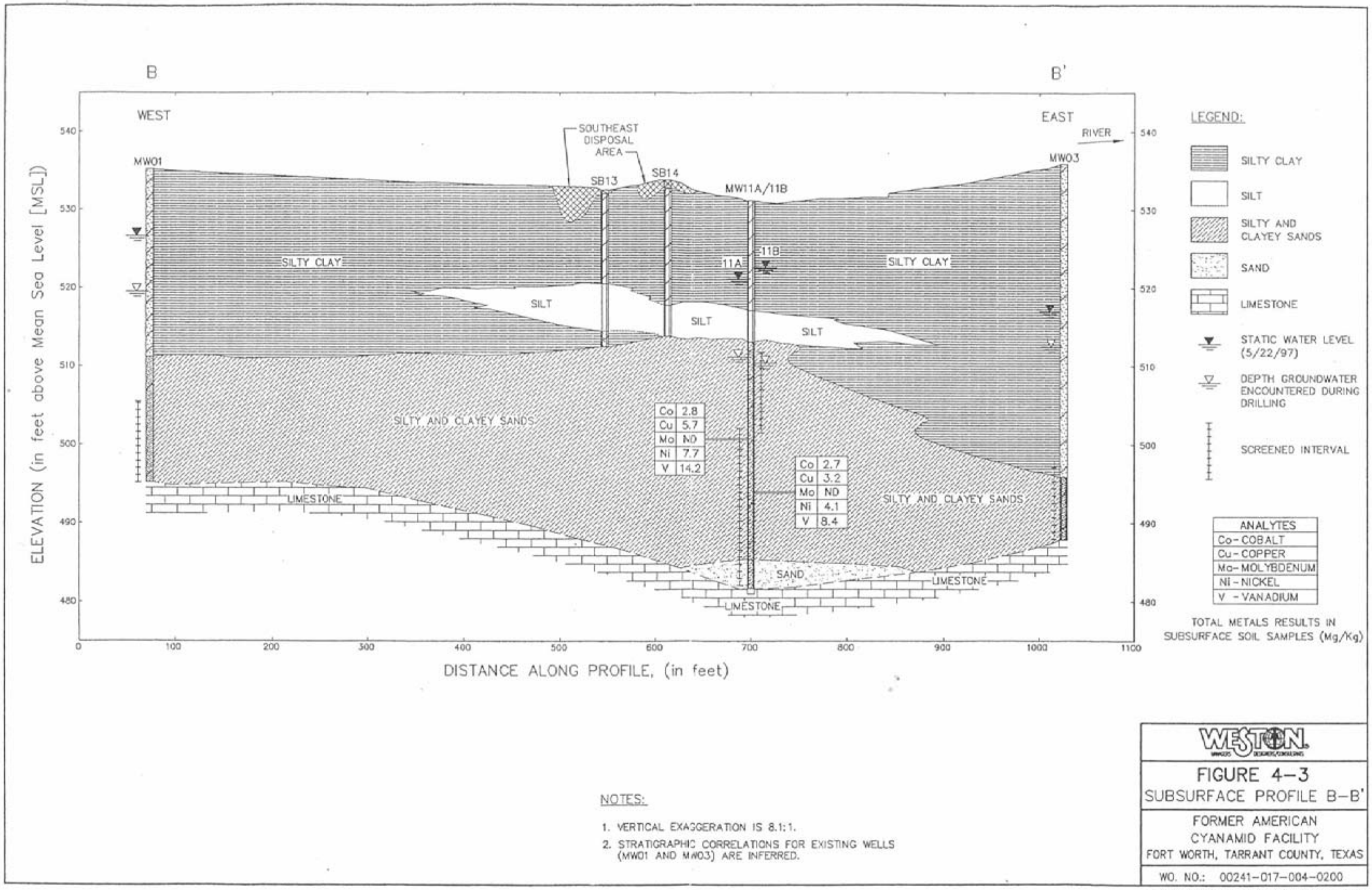
	water level (ft)				water level (ft)	
Clock time	MW14A*	MW13**		Clock time	MW14A*	MW13**
8:25 AM	21.48	21.58		11:25 AM	38.33	21.58
8:30 AM	26.30			11:35 AM	38.49	
8:35 AM	28.20			11:45 AM	38.73	
8:40 AM	29.74	21.56		11:55 AM	39.08	21.58
8:45 AM	31.03			12:05 PM	41.45	
8:50 AM	32.24			12:15 PM	41.65	
8:55 AM	33.20	21.56		12:25 PM	41.97	21.58
9:00 AM	33.40			12:40 PM	42.50	
9:05 AM	33.84			12:55 PM	42.81	21.58
9:10 AM	34.20	21.55		1:10 PM	43.76	
9:15 AM	34.62			1:25 PM	44.68	21.58
9:20 AM	34.90			1:40 PM	45.29	
9:25 AM	35.08	21.55		1:55 PM	45.82	21.58
9:35 AM	35.72			2:10 PM	46.19	
9:45 AM	36.14			2:25 PM	46.62	21.58
9:55 AM	36.47	21.55		2:40 PM	46.14	
10:05 AM	36.80			2:55 PM	46.86	21.58
10:15 AM	37.18			3:10 PM	47.35	
10:25 AM	37.42	21.56		3:25 PM	47.84	21.58
10:35 AM	37.57			3:40 PM	48.25	
10:45 AM	37.81			3:55 PM	48.59	21.58
10:55 AM	37.98	21.57		4:10 PM	46.15	
11:05 AM	38.13			4:25 PM	46.64	21.58
11:15 AM	38.23					

* Pumping well
** Observation well

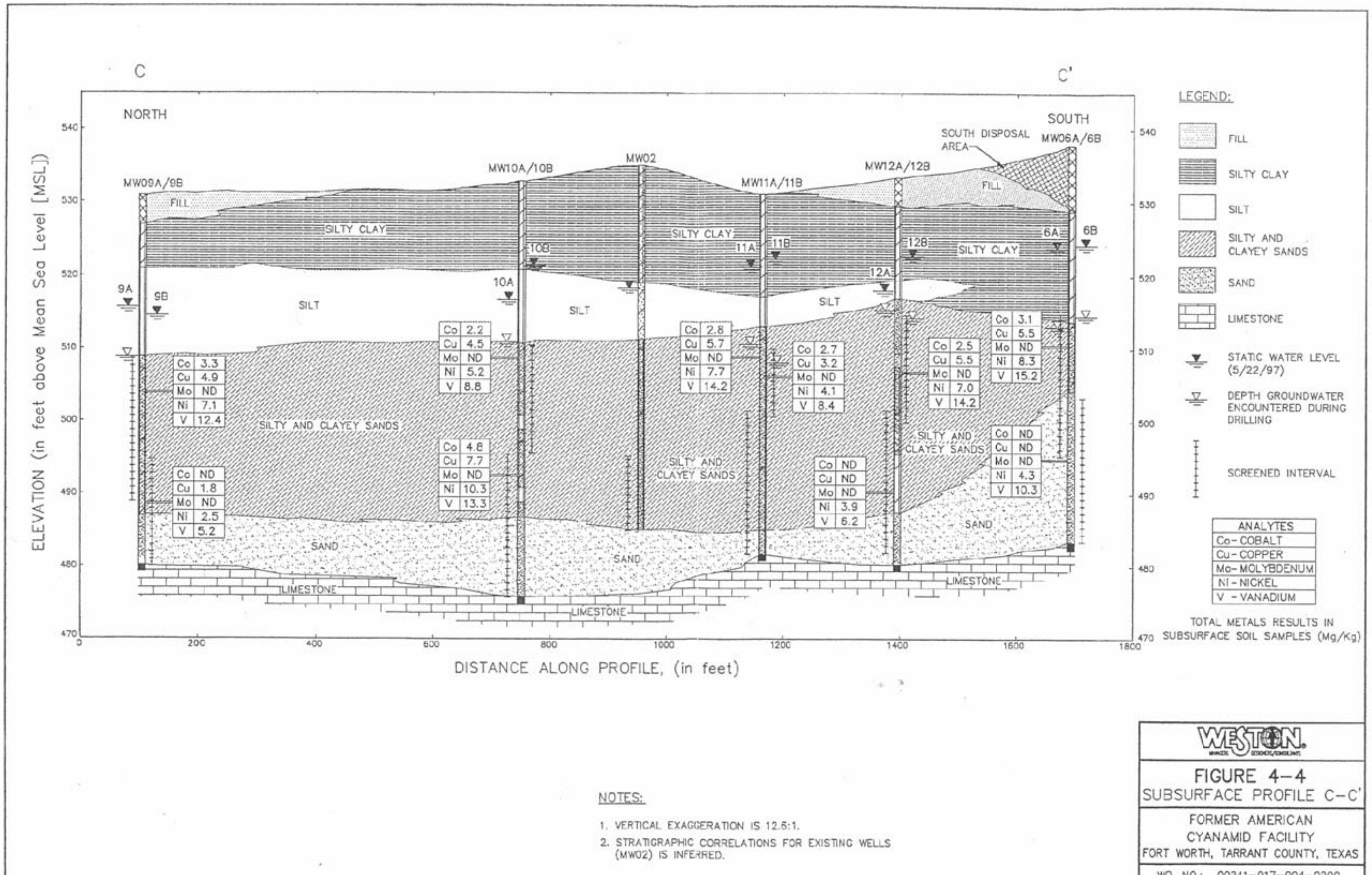
Table-4: Hourly rainfall (in) records (Apr-Dec 2006) from USGS station

Year	Month	Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	Total
2006	April	10															0.1										0.1
		15															0.1										0.1
		19																								0.8	0.8
		20		0.2	0.1		0.1													0.1							0.5
		21					0.3								0.1												0.4
		28														0.3	0.1	0.1								0.1	0.6
		29										0.1															0.1
	May	4						0.1	0.1					0.1													0.3
		5		0.1	0.5	0.2	0.1																		0.1	0.1	1.1
		6	0.1	0.2																							0.3
		18														0.1											0.1
	June	1																		0.8							0.8
		2												0.1													0.1
		17			0.3					0.1															0.9	0.2	1.5
		18										0.1															0.1
	July	4															0.8	0.6		0.1							1.5
		5							0.2	0.1	0.1								0.9	0.1		1.0					1.5
		31												0.1													0.1
	August	1													0.1												0.1
		3												0.2													0.2
		27																0.4		0.1							0.5
		28	0.1	0.2								0.1		0.1													0.5
	September	4			0.1		0.1		0.1	0.1	0.1	0.2		0.1						0.1	0.1		0.1				1.1
		11														0.1											0.1
		17														0.1	0.3		0.1		0.1						0.6
		23											0.2														0.2
	October	10								0.3	0.6	0.1															1.0
		15										0.1					0.1								0.1		0.3
		16				0.8	0.1	0.2	0.1																		1.2
		25	0.1																								0.1
	Novomber	5																						0.2		0.2	0.4
		6	0.7	0.1		0.1																					0.9
		27																0.1									0.1
		29																			0.2		0.1		0.1		0.4
		30	0.6	0.3																							0.9
	December	1											0.1														0.1
		19																	0.1								0.1
		20		0.1					0.1	0.1																	0.3
		24															0.1			0.1		0.1		0.1	0.1		0.5
		25			0.1																						0.1
		29												0.1	0.1	0.2			0.5	0.2		0.6	0.2				1.9

APPENDIX-B



Subsurface profile running West to East along B-B'



Subsurface profile running North to South along C-C'

Drilling Log

IT CORPORATION
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Monitoring Well **CFW-2**

Project	*Former LaGrave Field Area*
Owner	*City of Fort Worth*
Location	*North Jones Street, Fort Worth, Texas*
Proj. No.	*828765*
Surface Elev.	
Total Hole Depth	*27.5 ft.*
Diameter	*4 in.*
Top of Casing	
Water Level Initial	
Static	
Screen: Dia	*2 in.*
Length	*22.5 ft.*
Type/Size	*0.010 in.*
Casing: Dia	*2 in.*
Length	*5 ft.*
Type	*Sch 40 PVC*
Fill Material	*20/40 sand*
Rig/Core	*Mobile Drill B-59*
Drill Co.	*TSS*
Method	*Hollow stem auger*
Driller	*Terry Perryman*
Log By	*Kim Wallace-Wymore*
Date	*06-05-2001*
Permit #	
Checked By	*Jane Lomas*
License No.	

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	PID (ppm)	Sample ID	Blow Count/ % Recovery	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
0.0'–0.5'				Conc.	0.0'–0.5' – CONCRETE
0.5'–5.0'	195 0		100%	CL	0.5'–5.0' – CLAY – Black, slightly stiff
5.0'–10.0'	0 0 0		40%	CL	5.0'–10.0' – CLAY – Dark brown, dry
10.0'–15.0'	0 0.1		10%	CL	10.0'–15.0' – CLAY – Light brown, dry
15.0'–20.0'	1.2 1.5		70%	CL	15.0'–20.0' – CLAY – Light brown, with small pebbles, moist
20.0'–25.0'	1.8		60%	SC	20.0'–25.0' – CLAYEY SAND – Reddish brown, wet
25.0'–26.0'	4.9		50%	SC	25.0'–26.0' – CLAYEY SAND – Reddish brown, wet
26.0'–27.5'				LS	26.0'–27.5' – LIMESTONE – Weathered, refusal at 27.5 feet
					End of boring.

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Drilling Log

Monitoring Well **CFW-3**

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *Northeast 6th Street, Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ______ Total Hole Depth *25 ft.* Diameter *4 in.*
Top of Casing ______ Water Level Initial ______ Static ______
Screen: Dia *2 in.* Length *20 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *06-06-2001* Permit # ______
Checked By *Jane Lomas* License No. ______

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	Well Completion	PID (ppm)	Sample ID	Blow Count/ % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
-2							
0						Conc	0.0'-0.5' – CONCRETE
		0.9				GP	0.5'-1.0' – GRAVEL and reddish brown SAND
2				80%		CL	1.0'-5.0' – CLAY – Black, dry
4		3.2					
6		1.9				CL	5.0'-10.0' – CLAY – Dark brown, dry
8		1.4		100%			
10						CL	10.0'-14.0' – CLAY – Light brown, dry
12		1.4		100%			
14		1.5				CL	14.0'-15.0' – CLAY – Light brown, moist
16		1.5				CL	15.0'-20.0' – SANDY CLAY – Light brown, wet
18		0.9		50%			
20						SC	20.0'-24.0' – CLAYEY SAND – Reddish brown, wet
22		0.8		50%			
24		0.7				LS	24.0'-25.0' – LIMESTONE – Weathered, refusal at 25 feet
26							End of boring.
28							
30							

Drilling Log

IT CORPORATION
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Monitoring Well **CFW-6**

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *North Jones Street Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ______ Total Hole Depth *30 ft.* Diameter *4 in.*
Top of Casing ______ Water Level Initial ______ Static ______
Screen: Dia *2 in.* Length *25 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *08-07-2001* Permit # ______
Checked By *Jane Lomas* License No. ______

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	Well Completion	PID (ppm)	Sample ID	Blow Count/ % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
0.0–0.5						Conc	0.0'-0.5' - CONCRETE
0.5–1.5		229				GW	0.5'-1.5' - GRAVEL
1.5–5.0		174		80%		CL	1.5'-5.0' - CLAY - Black, stiff
5.0–10.0		2.1 2.5		80%		CL	5.0'-10.0' - CLAY - Dark brown, dry
10.0–15.0		2.3 2.4		80%		CL	10.0'-15.0' - CLAY - Light brown, dry
15.0–20.0		24 129		80%		CL	15.0'-20.0' - CLAY - Light brown, wet
20.0–25.0		25 4.7		100%		CL	20.0'-25.0' - SANDY CLAY - Light brown, wet
25.0–30.0		8.6 4.6		100%		SC	25.0'-30.0' - CLAYEY SAND - Reddish brown, wet

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Drilling Log

Monitoring Well CFW-7

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *North Commerce Street Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ______ Total Hole Depth *30 ft.* Diameter *4 in.*
Top of Casing ______ Water Level Initial ______ Static ______
Screen: Dia *2 in.* Length *25 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *06-07-2001* Permit # ______
Checked By *Jane Lomas* License No. ______

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	PID (ppm)	Sample ID	Blow Count/ % Recovery	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
-2					
0				Conc	0.0'-0.5' - CONCRETE
				GW	0.5'-1.0' - GRAVEL
2	2.6		80%	CL	1.0'-5.0' - CLAY - Black
4	1.3				
6	0.0		80%	CL	5.0'-10.0' - CLAY - Dark brown, dry
8	0.0				
10	0.0		100%	CL	10.0'-15.0' - CLAY - Light brown, dry
12					
14	0.0				
16	0.0		100%	CL	15.0'-20.0' - CLAY - Light brown, wet
18	0.0				
20	0.1		80%	SC	20.0'-25.0' - CLAYEY SAND - Reddish brown, wet
22					
24	0.0				
26	1.5			SP	25.0'-27.0' - SAND - Reddish brown, wet
28	0.5		50%	LS	27.0'-30.0' - LIMESTONE - Weathered
30					

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Drilling Log

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Monitoring Well **CFW-8**

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *North Commerce Street, Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ______ Total Hole Depth *25 ft.* Diameter *4 in.*
Top of Casing ______ Water Level Initial ______ Static ______
Screen: Dia *2 in.* Length *20 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *06-07-2001* Permit # ______
Checked By *Jane Lomas* License No. ______

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	PID (ppm)	Sample ID	Blow Count/ % Recovery	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
0.0–0.5				Conc	0.0'-0.5' - CONCRETE
0.5–1.0	0.8			GW	0.5'-1.0' - GRAVEL
1.0–5.0	0.0		20%	CL	1.0'-5.0' - CLAY - Black, dry
5.0–10.0	1.5, 2.1		80%	CL	5.0'-10.0' - CLAY - Dark brown, dry
10.0–15.0	5.8, 16		10%	CL	10.0'-15.0' - CLAY - Light brown, moist
15.0–20.0	73, 13.2	15-17.5	70%	SC	15.0'-20.0' - CLAYEY SAND - Reddish brown, wet
20.0–25.0	15.0, 11.6		50%	LS	20.0'-25.0' - LIMESTONE - Weathered, refusal at 25 feet
25.0					End of boring.

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Drilling Log

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Monitoring Well **CFW-9**

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *Trinity River Levy, Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ______ Total Hole Depth *30 ft.* Diameter *4 in.*
Top of Casing ______ Water Level Initial ______ Static ______
Screen: Dia *2 in.* Length *25 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *06-08-2001* Permit # ______
Checked By *Jane Lomas* License No. ______

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	PID (ppm)	Sample ID	Blow Count/ % Recovery	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
0.0–5.0	1.8, 1.6		10%	CL	0.0'–5.0' – CLAY – Black, dry
5.0–10.0	1.4, 3.6		50%	CL	5.0'–10.0' – CLAY – Black, dry
10.0–15.0	4.5, 5.0		50%	CL	10.0'–15.0' – CLAY – Dark brown, dry
15.0–20.0	4.9, 4.9		50%	CL	15.0'–20.0' – CLAY – Dark brown, dry
20.0–25.0	4.8, 5.0		60%	CL	20.0'–25.0' – CLAY – Dark brown, moist
25.0–28.0	4.7		60%	CL	25.0'–28.0' – CLAY – Light brown, soft
28.0–30.0	4.5			CL	28.0'–30.0' – SANDY CLAY – Light brown, wet

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Drilling Log

Monitoring Well **CFW-10**

Project *Former LaGrave Field Area* Owner *City of Fort Worth*
Location *Trinity River Levy, Fort Worth, Texas* Proj. No. *828765*
Surface Elev. ____ Total Hole Depth *30 ft.* Diameter *4 in.*
Top of Casing ____ Water Level Initial ____ Static ____
Screen: Dia *2 in.* Length *25 ft.* Type/Size *0.010 in.*
Casing: Dia *2 in.* Length *5 ft.* Type *Sch 40 PVC*
Fill Material *20/40 sand* Rig/Core *Mobile Drill B-59*
Drill Co. *TSS* Method *Hollow stem auger*
Driller *Terry Perryman* Log By *Kim Wallace-Wymore* Date *06-08-2001* Permit # ____
Checked By *Jane Lomas* License No. ____

See Site Map For Boring Location

COMMENTS:

Depth (ft.)	Well Completion	PID (ppm)	Sample ID	Blow Count/ % Recovery	Graphic Log	USCS Class.	Description (Color, Texture, Structure) Trace < 10%, Little 10% to 20%, Some 20% to 35%, And 35% to 50%
-2							
0							
2		0.0		50%		CL	0.0'-5.0' - CLAY - Black, dry
4		0.0					
6		1.4		50%		CL	5.0'-10.0' - CLAY - Black, dry
8		2.6					
10							
12		2.9		70%		CL	10.0'-15.0' - CLAY - Dark brown, dry
14		2.9					
16		3.5		20%		CL	15.0'-20.0' - CLAY - Dark brown, dry
18		3.8					
20							
22		3.1		50%		CL	20.0'-25.0' - SANDY CLAY - Light brown, moist
24		0.7					
26		0.8		50%		CL	25.0'-28.0' - SANDY CLAY - Light brown, moist
28		0.5				CL	28.0'-30.0' - SANDY CLAY - Light brown, wet
30							

07/11/2001 lithlog-Mar,99

Page: 1 of 1

Cytec Industries - American Cyanamid
Station: MW17 - Well Construction Log

Geologist/Engineer	Jeff Criner				
Start Date	08/30/95	Time 0850	Drilling Method: Hollow Stem Auger	Northing	400213.64
End Date	08/30/95	Time 1530	Drilling Company: HSA	Easting	2051392.69
Air Monitoring Instrument	HVJ		Borehole Diameter: 11.0 *inches*	Ground Elevation	528.28
Observations:			Total Depth: 47.0 *feet*	Datum Elevation	528.28
				Completion	Flush Mount
				Well Casing	PVC
				Well Diameter	4.0 *inches*
				Total Well Depth	46.5 *feet*

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
	70			0.00	CL	dark brown, very stiff CLAYEY SILT, dry, non-plastic. Some calcareous nodules and partings with roots.	
1.0							
2.0	100			0.00		– becoming hard.	
3.0							
4.0	100			0.00			
5.0							
6.0	100			0.00			
7.0							
8.0	50			0.00			
9.0							
10.0	75			0.00	ML	brownish yellow, very stiff SILT, moist, non-plastic. Some clay and sand; brittle.	

Cytec Industries - American Cyanamid
Station: MW17 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
11.0							
12.0	75			0.00		– becoming stiff.	
13.0							
14.0	100			0.00		– becoming soft. Few shells.	
15.0							
16.0	80			0.00		– becoming stiff, slightly plastic. More clayey.	
17.0							
18.0	75			0.00			
19.0							
20.0	100			0.00			
21.0							
22.0	100			0.00		– becoming soft.	
23.0							
24.0	100			0.00		– becoming wet. Water in borehole.	

01/26/96 16:57 Station: MW17 Page: 2

Cytec Industries - American Cyanamid
Station: MW17 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
25.0							
26.0	100						
27.0							
28.0						Not sampled.	
29.0	80			0.00			
30.0							
31.0						Not sampled.	
32.0							
33.0							
34.0	100			0.00	SC	brownish yellow CLAYEY SAND, saturated, subrounded, fine grained, moderately sorted. same as above except more clay.	
35.0							
36.0						Not sampled.	
37.0							
38.0							
39.0				0.00	SP	brownish yellow SAND, saturated, subrounded, medium grained, poorly sorted.	MW17-51-1

Cytec Industries - American Cyanamid
Station: MW17 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
40.0							
41.0						Not sampled.	
42.0							
43.0							
44.0	75					Limestone fragments in bottom 6 inches.	
45.0							
46.0						Not sampled.	
47.0						LIMESTONE.	

Cytec Industries - American Cyanamid
Station: MW16 - Well Construction Log

Geologist/Engineer	Jeff Criner				
Start Date	08/29/95 Time 0930	Drilling Method	Hollow Stem Auger	Northing	401012.78
End Date	08/29/95 Time 1700	Drilling Company	HVJ	Easting	2050989.24
Air Monitoring Instrument	Miniram	Borehole Diameter	11.0 *inches*	Ground Elevation	526.29
Observations:		Total Depth	47.0 *feet*	Datum Elevation	526.29
				Completion	Flush Mount
				Well Casing	PVC
				Well Diameter	4.0 *inches*
				Total Well Depth	46.0 *feet*

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
	100			0.00	CL	dark brown, hard SILTY CLAY, dry, non-plastic. Grass roots at top 4 inches, small roots throughout core, calcareous nodules.	
1.0							
2.0	100			0.28		– becoming dark gray.	
3.0							
4.0	50			0.00			
5.0							
6.0	50			0.00		– becoming brownish yellow, very stiff.	
7.0							
8.0	70			0.00		– becoming moist. Silt partings.	
9.0							
10.0	75			0.00		– becoming dark brown.	

01/26/96 15:58 Station: MW16 Page: 1

Cytec Industries - American Cyanamid
Station: MW16 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
11.0							
12.0	100			0.00		– becoming stiff, low plasticity.	
13.0							
14.0	75			0.00			
15.0							
16.0	90			0.00		– becoming firm.	
17.0							
18.0	40			0.00		– becoming soft, medium plasticity.	
19.0							
20.0	100			0.00	ML	brownish yellow, soft SILT, moist, slightly plastic. Clayey silt.	
21.0							
22.0	100			0.00			
23.0							
24.0	80			0.00		– becoming stiff.	

01/26/96 15:59 Station: MW16 Page: 2

Cytec Industries - American Cyanamid
Station: MW16 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
25.0							
26.0	50			0.00		– becoming dark gray, loose, wet, with clay.	
27.0							
28.0	100			0.00		– becoming olive gray. Wet in fractures.	
29.0							
30.0	100			0.00		Wet in fractured part of core.	
31.0							
32.0	80			0.00	SC	olive gray, loose, wet, subrounded, fine grained, moderately sorted.	
33.0							
34.0	50			0.00			
35.0							
36.0	50			0.00		– becoming fine grained.	MW16-51-1
37.0							
38.0	50			0.00			
39.0							

Cytec Industries - American Cyanamid
Station: MW16 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
40.0	50			0.00	SP	olive gray SAND, saturated, subangular, medium grained, poorly sorted.	
41.0							
42.0	50					– becoming gray, loose, coarse grained, with limestone fragments.	
43.0							
44.0						Not sampled.	
45.0							
46.0							
47.0							

Auger refusal at 47 feet.

Cytec Industries - American Cyanamid
Station: MW13 - Well Construction Log

Geologist/Engineer	Jeff Criner				
Start Date	08/31/95	Time	0830	Drilling Method	Hollow Stem Auger
End Date	08/31/95	Time	1500	Drilling Company	HVJ
Air Monitoring Instrument	Miniram			Borehole Diameter	11.0 inches
Observations:				Total Depth	49.5 feet

Northing	400743.89
Easting	2050894.19
Ground Elevation	531.21
Datum Elevation	531.21
Completion	Flush Mount
Well Casing	PVC
Well Diameter	4.0 inches
Total Well Depth	47.5 feet

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
	100				CL	dark brown, hard SILTY CLAY, dry, non-plastic. Contains roots and few calcareous nodules.	
1.0							
2.0	100						
3.0							
4.0	80			0.11			
5.0							
6.0	50			0.04			
7.0							
8.0	50			0.03		very stiff.	
9.0							
10.0	75			0.00		hard.	

04/14/97 17:58 Station: MW13 Page: 1

Cytec Industries - American Cyanamid
Station: MW13 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
						hard.	
11.0							
12.0	100			0.00	ML	brownish yellow, stiff SILT, dry, brittle, with clay.	
13.0							
14.0	100			0.00			
15.0							
16.0	100			0.00			
17.0							
18.0	75			0.00		moist.	
19.0							
20.0	50			0.00		firm.	
21.0							
22.0	25			0.00		soft.	
23.0							
24.0							

04/14/97 17:59 Station: MW13 Page: 2

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
						soft.	
25.0						Water in borehole.	
26.0	0					No recovery.	
27.0							
28.0	100			0.00		soft, moist.	
29.0							
30.0	100			0.00		dark brown, wet.	
31.0							
32.0	80			0.00			
33.0							
34.0	100			0.00		loose.	MW13-51-1
35.0							
36.0	100			0.00			
37.0							
38.0	0					No recovery.	
39.0							

Cytec Industries - American Cyanamid
Station: MW13 - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
						loose.	
40.0	80			0.00		saturated. More sandy.	
41.0							
42.0	0					No recovery.	
43.0							
44.0	75			0.00			
45.0							
46.0	75			0.00			
47.0							
48.0							
	80			0.00		LIMESTONE.	
49.0							
49.5							

Cytec Industries - American Cyanamid
Station: MW10A - Well Construction Log

Geologist/Engineer	Diane Williams		
Start Date	09/16/95	Time	0810
End Date	09/16/95	Time	1515
Air Monitoring Instrument	Miniram		

Drilling Method	Hollow Stem Auger
Drilling Company	HVJ
Borehole Diameter	11.0 *inches*
Total Depth	57.5 *feet*

Northing	399987.78
Easting	2051018.28
Ground Elevation	532.85
Datum Elevation	532.85
Completion	Flush Mount
Well Casing	PVC
Well Diameter	4.0 *inches*
Total Well Depth	57.0 *feet*

Observations:

Nested with MW10B. Deep well.

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
	100			0.00	CL	brownish yellow, very stiff SILTY CLAY, moist, non-plastic. Little roots, trace caliche and small worms.	
1.0						– becoming dry. Bottom 6 inches contains some caliche.	
2.0	100			0.00		– becoming olive gray, hard.	
3.0							
4.0	100			0.00		– becoming very stiff, moist, low plasticity. Little caliche/calcified root tracings and roots.	
5.0							
6.0	90			0.00		– becoming brownish yellow, stiff, medium plasticity. Few caliche/roots.	
7.0							
8.0	90			0.00			
9.0							
10.0	90			0.00			

Cytec Industries - American Cyanamid
Station: MW10A - Well Construction Lcg

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
11.0							
12.0	80			0.00	ML	brownish yellow, stiff SILT, moist, medium plasticity. Few-little calcareous roots; some sand and clay.	
13.0							
14.0	80			0.00			
15.0							
16.0	100			0.00		Trace calcareous roots, little worm holes.	
17.0							
18.0	90			0.00		– becoming firm. More sand.	
19.0							
20.0	100			0.00			
21.0							
22.0	90			0.00	SM	brownish yellow SILTY SAND, loose, saturated, subrounded, fine grained, moderately sorted. Driller notes water in hole.	
23.0							
24.0	20			0.00			

01/26/96 13:13 Station: MW10A Page:

Cytec Industries - American Cyanamid
Station: MW10A - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
25.0							
26.0	70			0.00			
27.0							
28.0	70			0.00			
29.0							
30.0	50			0.00		– becoming subangular. Trace shell fragments.	
31.0							
32.0	75			0.00	ML	brownish yellow, stiff SILT, wet, medium plasticity. Some clay and sand; trace clacareous roots.	
33.0							
34.0	60			0.00	SM	brownish yellow SILTY SAND, saturated, subangular, coarse grained, moderately sorted. Some clay.	
35.0							
36.0							
37.0	60			0.00		– becoming subrounded, fine grained.	
38.0				0.00		No recovery.	
39.0							

01/26/96 13:13 Station: MW10A Page:

Cytec Industries - American Cyanamid
Station: MW10A - Well Construction Log

Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
40.0	40			0.00		More clay	
42.0	100			0.00	ML	brownish yellow SILT, saturated, with clay and sand.	MW10-51-1
44.0	100			0.00	SM	brownish yellow SILTY CLAY, saturated, subrounded, fine grained, moderately sorted.	
46.0	90			0.00	SP	brownish yellow SAND, saturated, coarse grained, poorly sorted. 3 inch layer of coarse sand/shell fragments. 4 inch layer of gravelly sand with shell fragments. Sand heaving. Not sampled.	

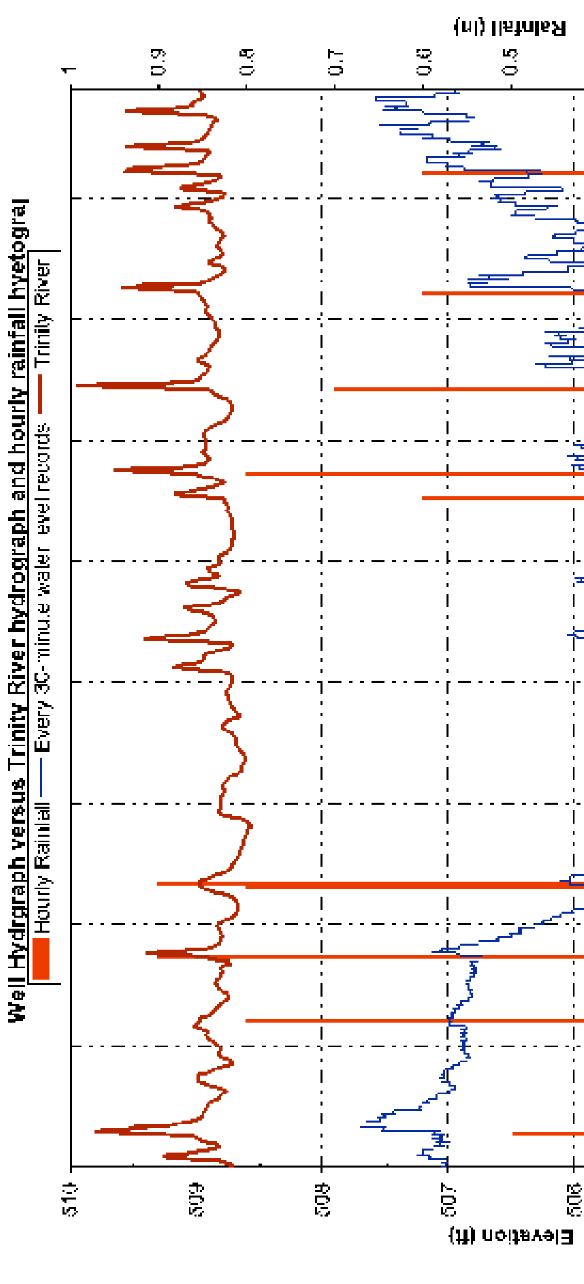
Depth scale: 40.0, 41.0, 42.0, 43.0, 44.0, 45.0, 46.0, 47.0, 48.0, 49.0, 50.0, 51.0, 52.0, 53.0

01/26/96 13:14 Station: MW10A Page:

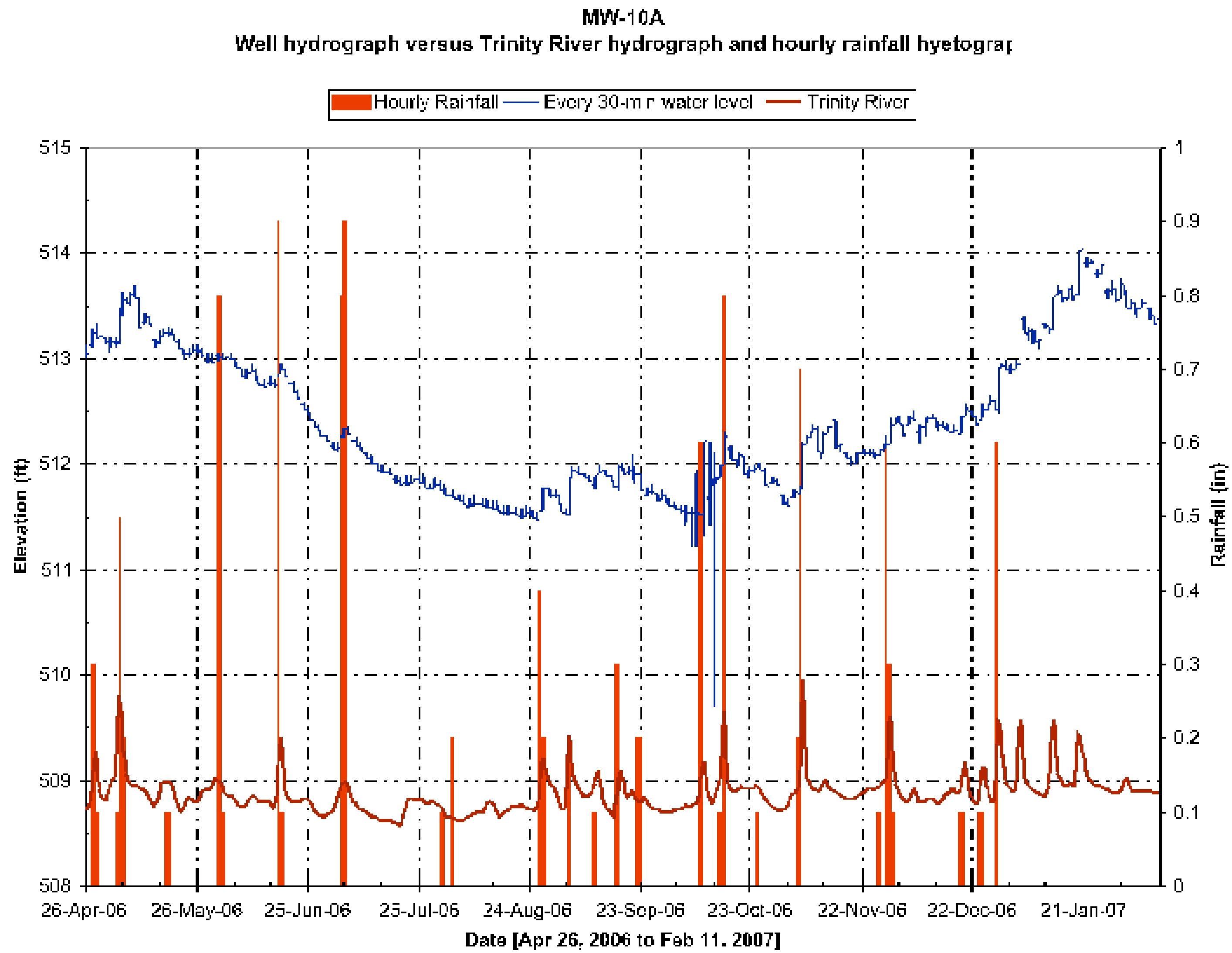
Cytec Industries - American Cyanamid
Station: MW10A - Well Construction Log

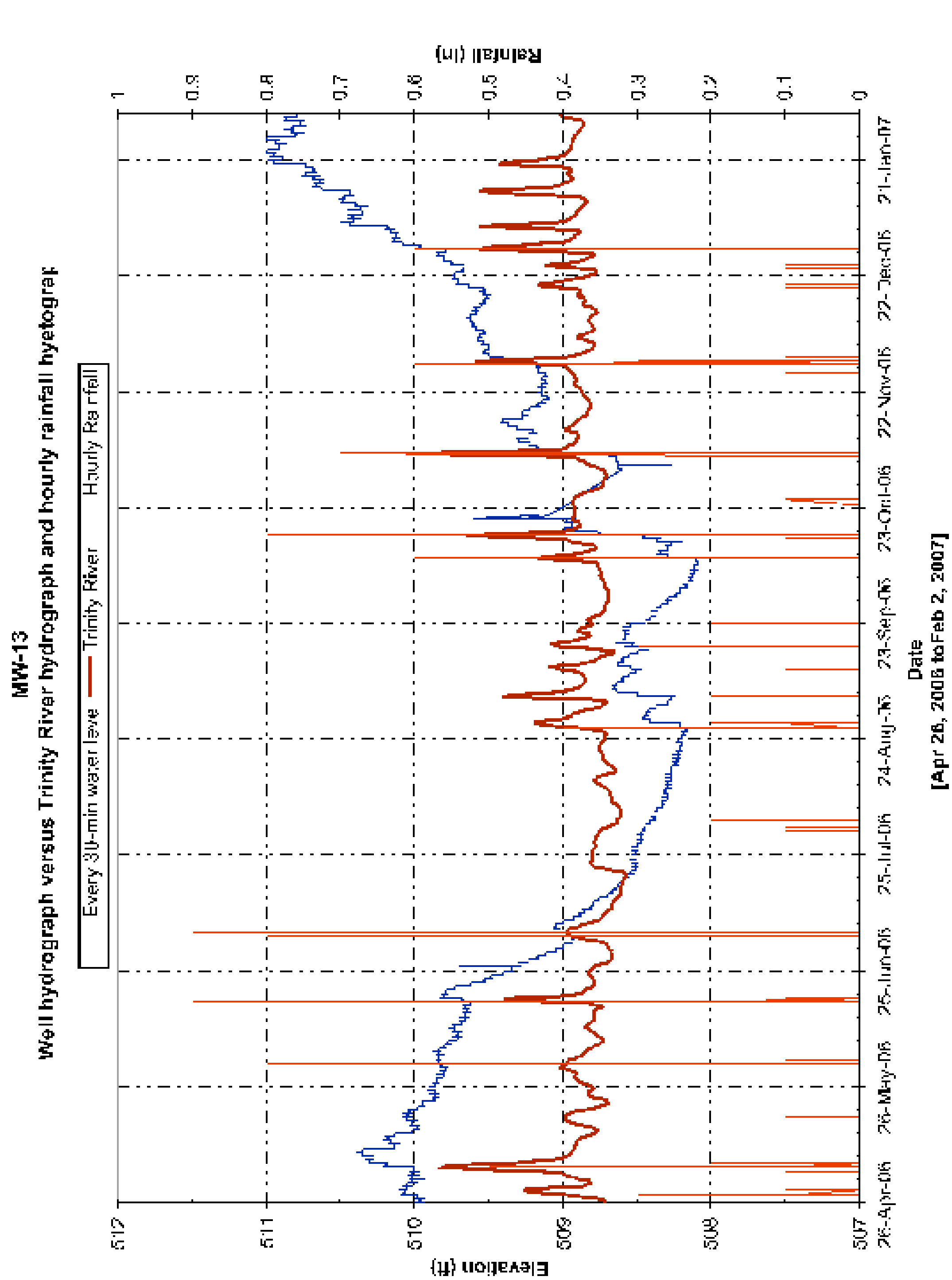
Depth (ft)	Interval (%Rec)	Log	Well	Monitor Instr.	USCS	Description	Sample ID
54.0							
55.0							
56.0	40			0.00		– becoming dark gray, subangular. Bottom 2 inches contains gravel.	
57.0						LIMESTONE, 1.5 inch fossiliferous lime mudstone. 50 blows/ 1.5 inch.	
57.5							

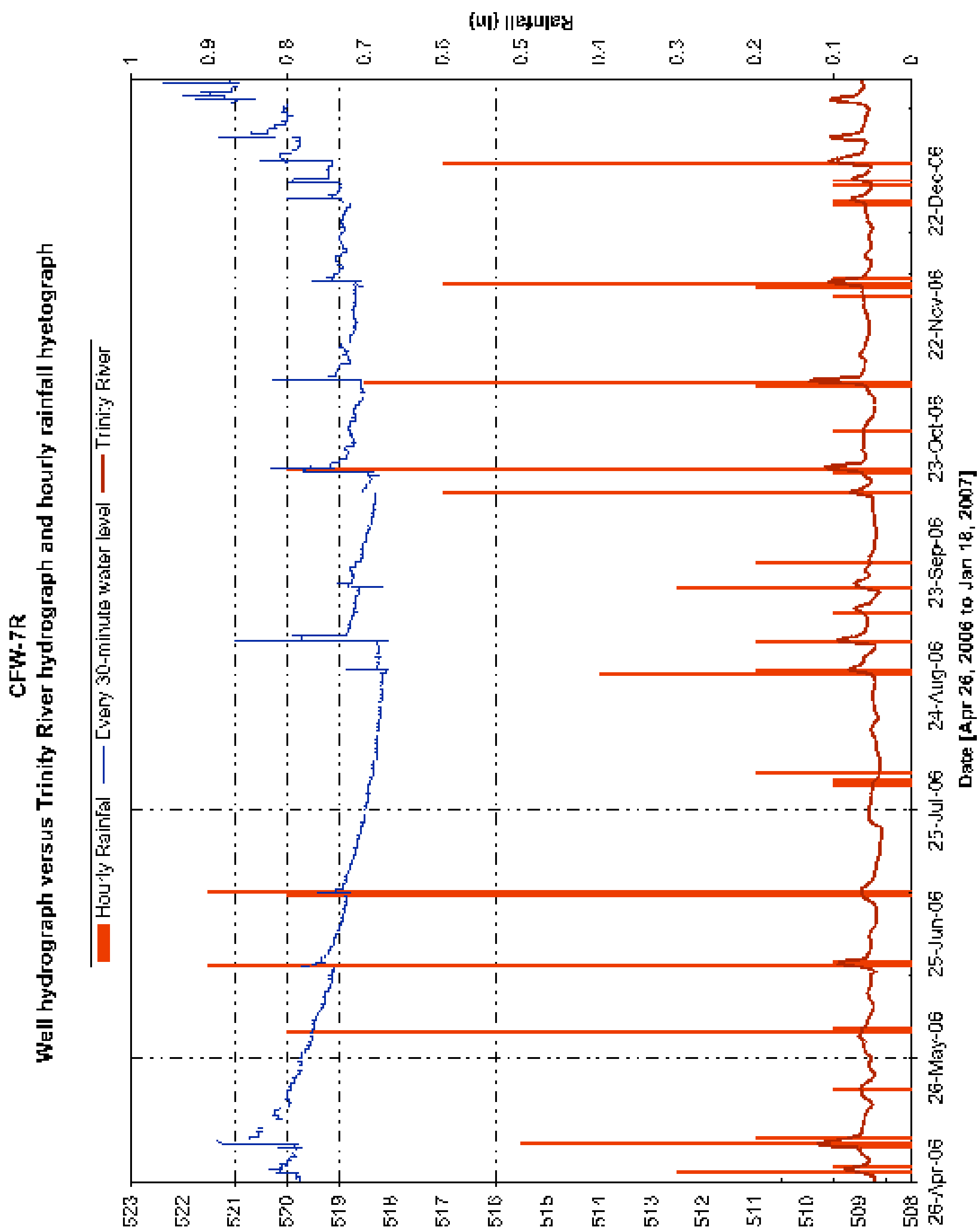
APPENDIX-C

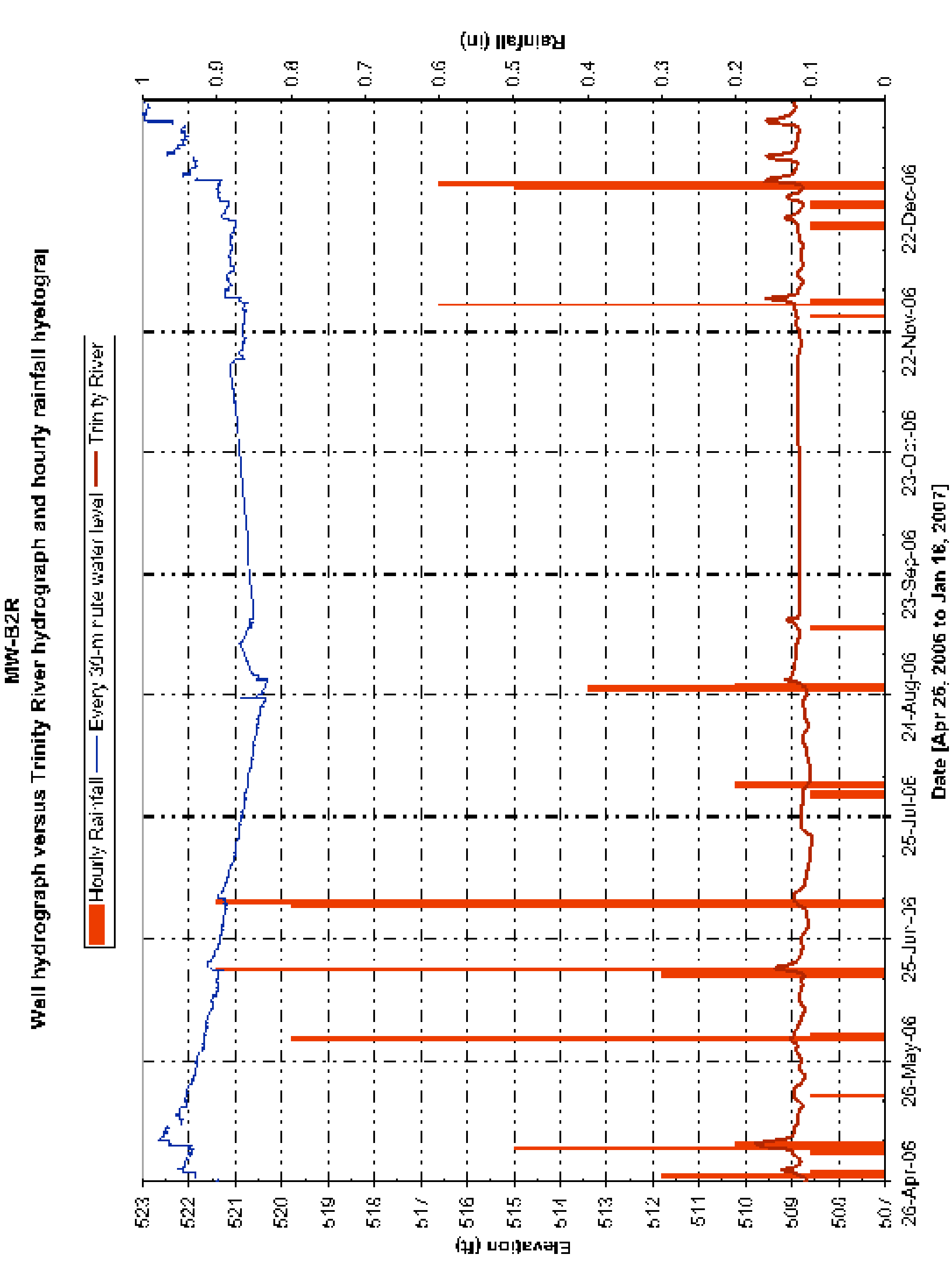


CFW-9
Well Hydrograph versus Trinity River hydrograph and hourly rainfall hyetograph
Hourly Rainfall
Every 30-minute water level records
Trinity River
Elevation (ft)
Rainfall (in)
Date [Apr 26, 2006 - Jan 18, 2007]
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06

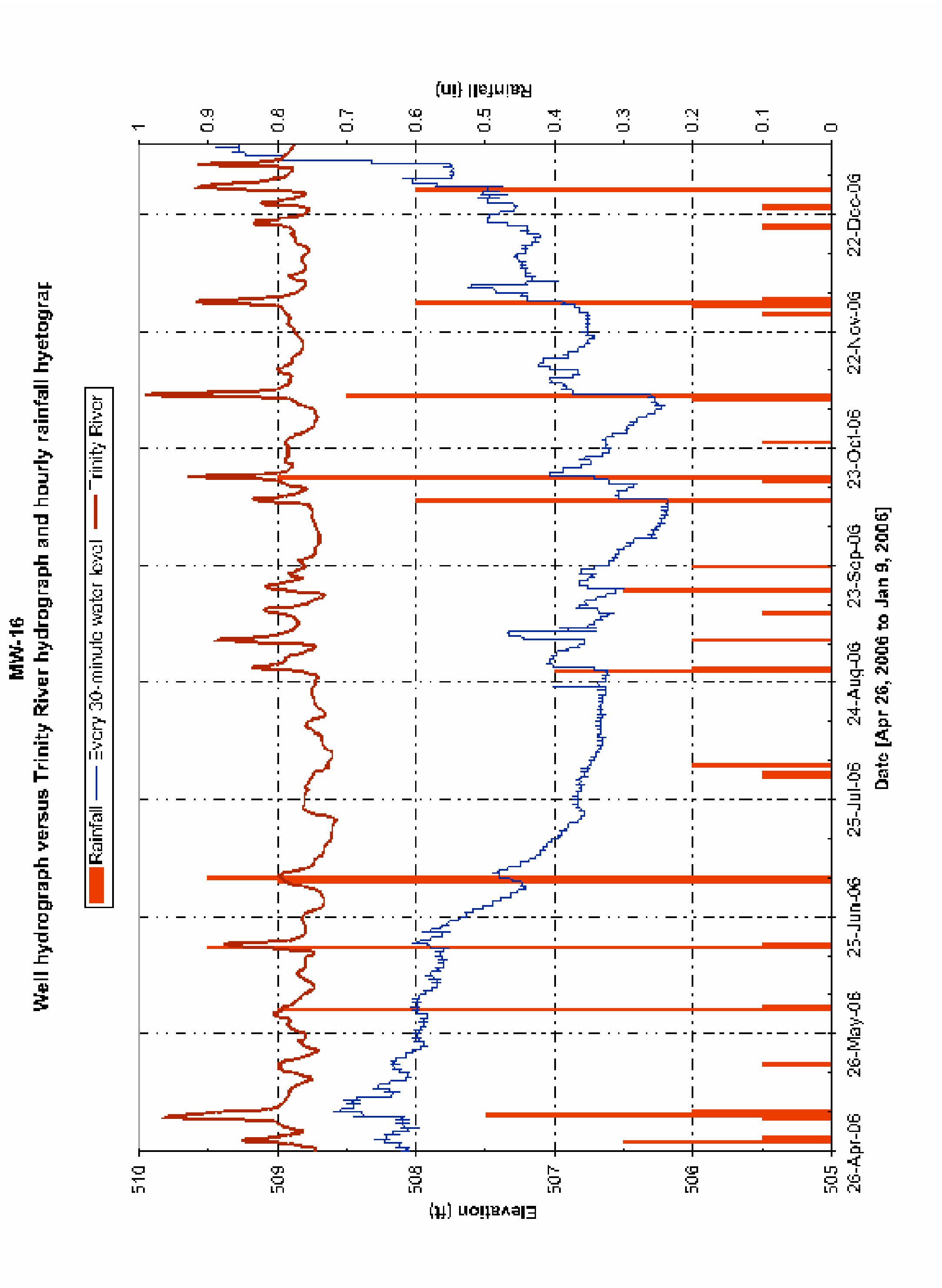

MW-10A
Well hydrograph versus Trinity River hydrograph and hourly rainfall hyetograp
Hourly Rainfall
Every 30-min water level
Trinity River
515
514
513
512
511
510
509
508
Elevation (ft)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Rainfall (in)
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
21-Jan-07
Date [Apr 26, 2006 to Feb 11, 2007]

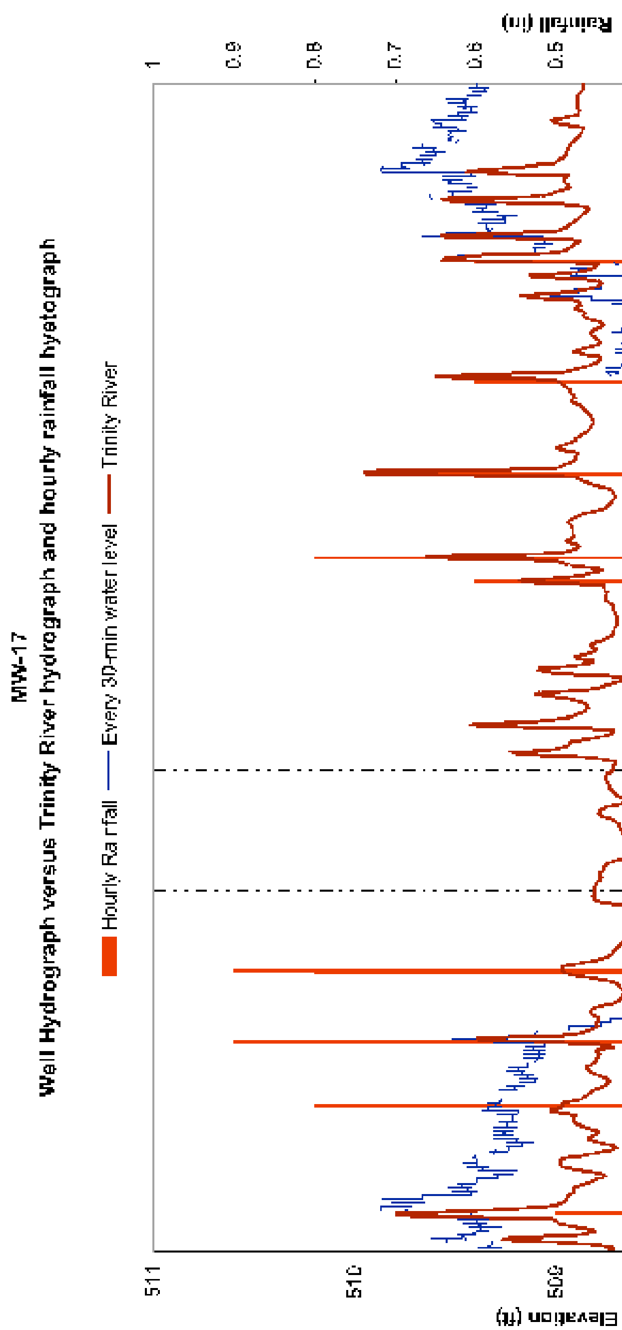

MW-13
Well hydrograph versus Trinity River hydrograph and hourly rainfall hyetograph
Every 30-min water leve
Trinity River
Hourly Rainfall
Elevation (ft)
507
508
509
510
511
512
Rainfall (in)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
21-Jan-07
Date
[Apr 26, 2006 to Feb 2, 2007]


CFW-7R
Well hydrograph versus Trinity River hydrograph and hourly rainfall hyetograph
Hourly Rainfall
Every 30-minute water level
Trinity River
Elevation (ft)
523
522
521
520
519
518
517
516
515
514
513
512
511
510
509
508
Rainfall (in)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
Date [Apr 26, 2006 to Jan 18, 2007]



MW-B2R
Well hydrograph versus Trinity River hydrograph and hourly rainfall hyetograph
Hourly Rainfall
Every 30-minute water level
Trinity River
Elevation (ft)
Rainfall (in)
523
522
521
520
519
518
517
516
515
514
513
512
511
510
509
508
507
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
Date [Apr 26, 2006 to Jan 16, 2007]


MW-16
Well hydrograph versus Trinity River hydrograph and hourly rainfall hyetograp
Rainfall
Every 30-minute water level
Trinity River
Elevation (ft)
Rainfall (in)
Date [Apr 26, 2006 to Jan 9, 2006]
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
505
506
507
508
509
510
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


MW-17
Well Hydrograph versus Trinity River hydrograph and hourly rainfall hyetograph
Hourly Rainfall
Every 30-min water level
Trinity River
Elevation (ft)
511
510
509
508
507
Rainfall (in)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
26-Apr-06
26-May-06
25-Jun-06
25-Jul-06
24-Aug-06
23-Sep-06
23-Oct-06
22-Nov-06
22-Dec-06
21-Jan-07
Date [Apr 26, 2006 to Feb 11, 2006]

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RESOURCES

LaGrave Field monitoring wells site map prepared by Enercon Services, 2005.

Historic groundwater monitoring records (1995-2006) from the City of Forth Worth

Public references reports prepared by Environmental Trainers, Inc., 2005.

3 Subsurface Profiles and well construction logs for all the wells in LaGrave

Hourly rainfall records (1995-2006) from the nearby USGS station 08048000

VITA

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Education:	Diploma, Keih Bahri Secondary School, 1995 Asmara, Eritrea
	Bachelor of Science, Geology, 2000 University of Asmara, Asmara, Eritrea
Professional Experience:	Field Assistant, July – Aug 1997 Ashanti Gold Field Co., Adi-Hageray, Ethiopia
	Junior Geologist, Oct 1999 – Sept 2000 Geological Survey of Eritrea, Asmara, Eritrea
	Geologist, Jan 2004 - June 2004 Sub-Sahara Resources, Debaruwa, Eritrea
	Teaching Assistant, Oct 2000 - Dec 2004 Department of Geology, University of Asmara Asmara, Eritrea
	Graduate Assistant, Jan 2005 – May 2007 Department of Geology, Texas Christian University Fort Worth, Texas

ABSTRACT

GROUND WATER LEVEL STUDIES AT LAGRAVE FIELD MONITORING WELLS AND THEIR SENSITIVITY TO RECHARGE FROM RAINFALL AND THE TRINITY RIVER, FORT WORTH, TEXAS

By Simret Tsighehannes Hagos, M.Sc., August 2007
Department of Geology
Texas Christian University

Thesis Advisor: Dr. Michael Slattery, Professor of Geology and
Director of Environmental Sciences Program

This project was launched with the key objectives of studying the characteristics of the aquifer at the Paddock bend floodplain and its reaction to possible recharges from falling rainfall and the nearby Trinity River.

This aquifer is composed of different alluvial layers such as silt, clay and sand which are perched on top of a layer of relatively impermeable limestone. They are in hydraulic contact with the Trinity River and they have a variable vertical and aerial extent. An attempt made to estimate the hydraulic conductivity suggests that this alluvial aquifer has a very low (70.4m/year) hydraulic conductivity which is related to its clay-silt dominated subsurface composition.

Groundwater is encountered at a depth of 9 to 25 ft below the ground surface with the highest elevation (525 ft above mean seal level) of the water table on the western part of the project site. The water level map and the data collected through the monitoring network in the area show that groundwater flows in a northeasterly direction toward the Trinity River.

Detailed analysis of the water level hydrographs and hourly rainfall hyetographs for the period of this research show the seasonal fluctuation of the water level in the aquifer with water level falling in the summer and then rising in the fall. Furthermore, the strong correlation of the water level changes with the rainfall suggests that such water level changes are the result of groundwater recharge from the percolating rain. Such water level rises from individual storm events, how ever, are very small compared to the amount of rainfall and the aquifer response is slow and the water level changes are small due to due to the low degree of infiltration of rainwater from through the aquifer materials.

Groundwater recharge from the Trinity River seems to have a very negligible effect on the water level in view of their hydraulic head differences as well as the hydraulic conductivity of the aquifer materials which are in contact with Trinity River. During the period of this research, the Trinity River Elevation remained almost stable through time while the groundwater elevations became very low during summer and early fall. Therefore, there could have been slight degree of groundwater recharge from the river during such dry seasons where the rate of evapotranspiration is very high and the amount of rainfall is very low.