SUMMARY OF GROUNDWATER FLOW DIRECTIONS,
HILLCREST NEIGHBORHOOD, CORPUS CHRISTI, TEXAS

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INTRODUCTION

The purpose of this summary is to describe fundamental aspects about the movement of groundwater and groundwater flow directions at the Hillcrest neighborhood in Corpus Christi, Texas. The Hillcrest neighborhood is located between Interstate 37 and the Corpus Christi industrial canal, and is situated east of petrochemical industries including Flint Hills Resources, L.P. (Flint Hills) and CITGO Refining and Chemicals Company, L.P. (CITGO). Questions about groundwater movement have led the U.S. Environmental Protection Agency (EPA) to review related technical information and prepare this summary and the attachment describing its findings about the directions of groundwater movement beneath the Hillcrest neighborhood.

BACKGROUND

Water occurring beneath the surface of the ground in saturated geologic materials (e.g., soil, sediment, and rock) is called *groundwater*, and when saturated geologic material can produce or transmit useable quantities of water, it is called an *aquifer*. The aquifer described in this summary, for the Hillcrest neighborhood, occurs within clay, silt, sand, and gravel deposited by river and coastal processes. These sediments are distinguished by their geologic characteristics and ages, and occur within a geologic formation called the Deweyville Formation.

Groundwater does not usually remain stationary, but moves or flows underground according to forces acting on the groundwater. At the Hillcrest neighborhood and surrounding area, the main forces affecting groundwater movement are gravity and external pressure. Gravity is related to the natural slope of the sediments making up the shallow aquifer beneath the neighborhood, and external pressure is related to changes in pressure caused by pumping wells which alter natural groundwater flow directions. An important hydraulic feature of the area is the Corpus Christi industrial canal which serves as a boundary where groundwater exits the shallow aquifer and discharges to surface water.

The most direct and accurate method of determining the direction of groundwater movement is by measuring the elevation of groundwater at multiple locations over the aerial extent of an aquifer. Measurements are plotted on a map of the area and lines are drawn to connect points of equal elevation. These lines represent equal pressure between connected points and are called equipotential lines. The equipotential lines and map together are called an equipotential surface map. Groundwater moves along a flowpath perpendicular to equipotential lines and the direction of movement is from lines of higher value to lines of lower value (i.e., higher to lower elevation or pressure). Groundwater flow paths are usually shown by arrows on equipotential surface maps pointing in the direction of groundwater flow.

A number of equipotential surface maps and related data for the Hillcrest neighborhood and surrounding area were reviewed by EPA. These maps and data were from the U.S. Geological Survey, the Texas Bureau of Economic Geology, the Texas Department of Environmental Quality, the Texas Water Development Board, Flint Hills, CITGO, El Paso Corporation, Rosengarten, Smith, and Associates, Inc., Citizens for Environmental Justice, and various other published reports. Detailed information on EPA's findings are discussed in the attachment.

Because there can be changes in the factors influencing groundwater pressure, such as the numbers of wells pumping at any given time and effects from precipitation, groundwater elevations and thus equipotential surfaces and gradients can also change. To examine the relationship between changes in groundwater elevations over time and groundwater flow directions near the Hillcrest Neighborhood, EPA conducted a basic statistical analysis to assess flow directions by using data collected over a multi-year period. Specifically, the analysis used groundwater data to calculate the likelihood of lines of equal pressure existing between sets of groundwater monitoring wells. The calculation utilized 4-years of groundwater elevation data, reported as being collected on the same days during monitoring events from 2005-2009. More detailed information about this analysis is provided in the attachment.

CONCLUSIONS

The objective of this analysis was to determine and summarize the main groundwater flow direction at the Hillcrest Neighborhood in Corpus Christi. The findings are that groundwater flow beneath the Hillcrest neighborhood has usually been towards the Corpus Christi industrial canal, and that groundwater contamination from the Flint Hills Terminal 2 area has most likely moved into the Hillcrest neighborhood. The assessment was made primarily by reviewing existing information and by performing a statistical analysis to evaluate the likelihood of equipotential over a multi-year period. Groundwater in the southern part of the Hillcrest neighborhood will continue to be monitored for the contaminants of interest. Facility areas north of the Terminal 2 area are less likely to impact the Hillcrest neighborhood based on an analysis of groundwater data from 2005-2009.

Attachment

GROUNDWATER FLOW DIRECTIONS
HILLCREST NEIGHBORHOOD

FINDINGS

Based on information reviewed by EPA, the following conclusions were made regarding groundwater flow directions at the Hillcrest neighborhood.

- The main shallow groundwater flow direction beneath the Hillcrest neighborhood is northeast towards the Corpus Christi ship channel[1,2] (Figure 1).

- The main shallow groundwater flow beneath the portion of the Flint Hills and CITGO facilities adjacent Hillcrest neighborhood, is northeast towards the Corpus Christi ship channel[3,4,5,6,7].

- Some groundwater enters the Hillcrest neighborhood from the southern part of the Flint Hills Terminal 2 Area and moves towards the Corpus Christi ship channel[8,9].

- Flint Hills Resources has agreed to continue sampling monitoring wells MW-1 and MW-2 for at least two years. These wells are closest to the facility and during the April 2011 sampling, trichloroethene (TCE) was detected in MW-1 at a concentration of 11.9 µg/L. The screening level for TCE used during that sampling round was 15 µg/L. This level was based upon the potential for vapor intrusion in a residential setting.

- Basic statistical analysis suggests the further one goes to the north along the west boundary of the Hillcrest neighborhood, the less likely it becomes that shallow groundwater will move from the Flint Hills Resources and Citgo facilities towards the Hillcrest neighborhood.

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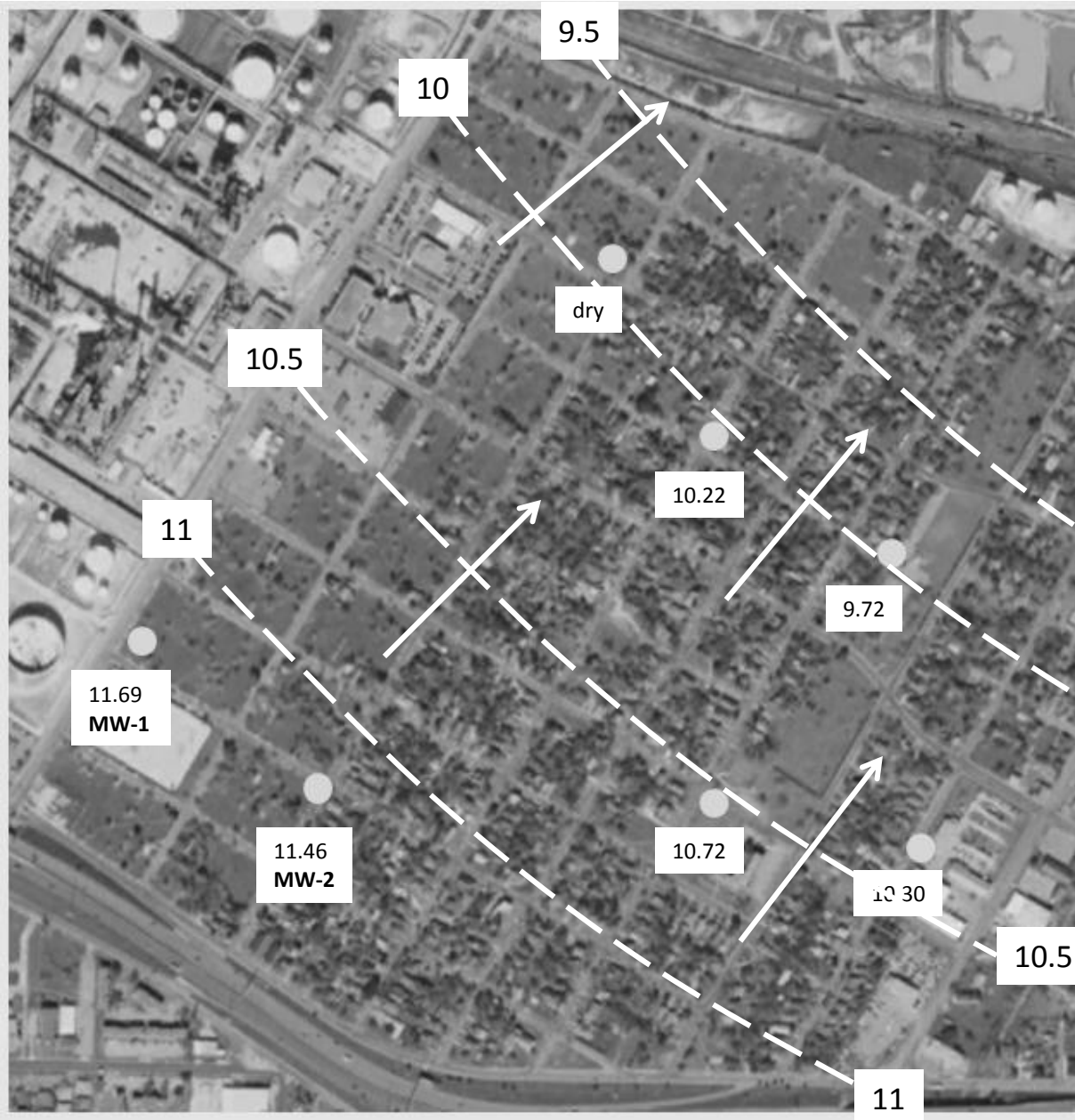
[1] Weston Solutions Inc., 2010
[2] EPA Equipotential Surface Map, S. Ellinger
[3] Flint Hills Resources, July 2009-June 2010
[4] Rosengarten, Smith, and Associates, April 2011
[5] Rosengarten, Smith, and Associates, October 2010
[6] Rosengarten, Smith, and Associates, 2010, Second Half 2009
[7] Rosengarten, Smith, and Associates, 2010, Second Half 2008
[8] Flint Hills Resources, July 2009-June 2010
[9] Weston Solutions Inc., 2010



Statistical Analysi

Method:

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- In this case, the x and y variables represent groundwater levels measured in different monitoring wells over 4-years. The stronger the linear relationship, the greater the likelihood of equal potential between the two groundwater monitoring wells. Thus, groundwater flow would tend to be perpendicular to a line between two wells with an *r* value of 1, -1, or relatively close to either value.

- Three pairs of wells were chosen to indicate equipotential and groundwater flow direction. They are: (i) IH37-11 and MW-51, (ii) IH37-11 and P-103, and (iii) IH37-11

[10] McClave and Dietrich, 1982

and MW-88 (Figure 2). These sets were chosen because they are oriented approximately both perpendicular to, and parallel to, the boundary of the Hillcrest Neighborhood and the industrial canal.

- Wells IH37-11 and MW-51 were used to see whether groundwater from the southern Terminal 2 area has typically moved towards the industrial canal or towards the Hillcrest Neighborhood. Wells IH37-11 and P-103, and IH37-11 and MW-88, were used to see whether groundwater along the eastern boundary of the Flint Hills and Citgo facilities has probably moved from facility areas towards the Hillcrest Neighborhood or the industrial canal.

Analysis:

- For the well set IH37-11 and MW-51, *r* indicates a moderately strong linear relationship (0.80) suggesting groundwater flow in the vicinity of those wells has been generally towards the Corpus Christi Ship Channel. However, facility data near the Hillcrest Neighborhood boundary still indicates a limited groundwater flow gradient towards the neighborhood. Scatter plots for two of the well sets are provided in Figures 3 and 4.

- For the well sets IH37-11 and P-103 (r = 0.69), and IH37-11 and MW-88 (r = 0.-30), these two r values indicate that the further one goes to the north along the west boundary, the less likely it becomes that groundwater has moved from the Flint Hills Resources and Citgo facilities towards the Hillcrest neighborhood. This analysis is meant as a general indication of flow and values for r could be different if data from other sets of wells had been used.

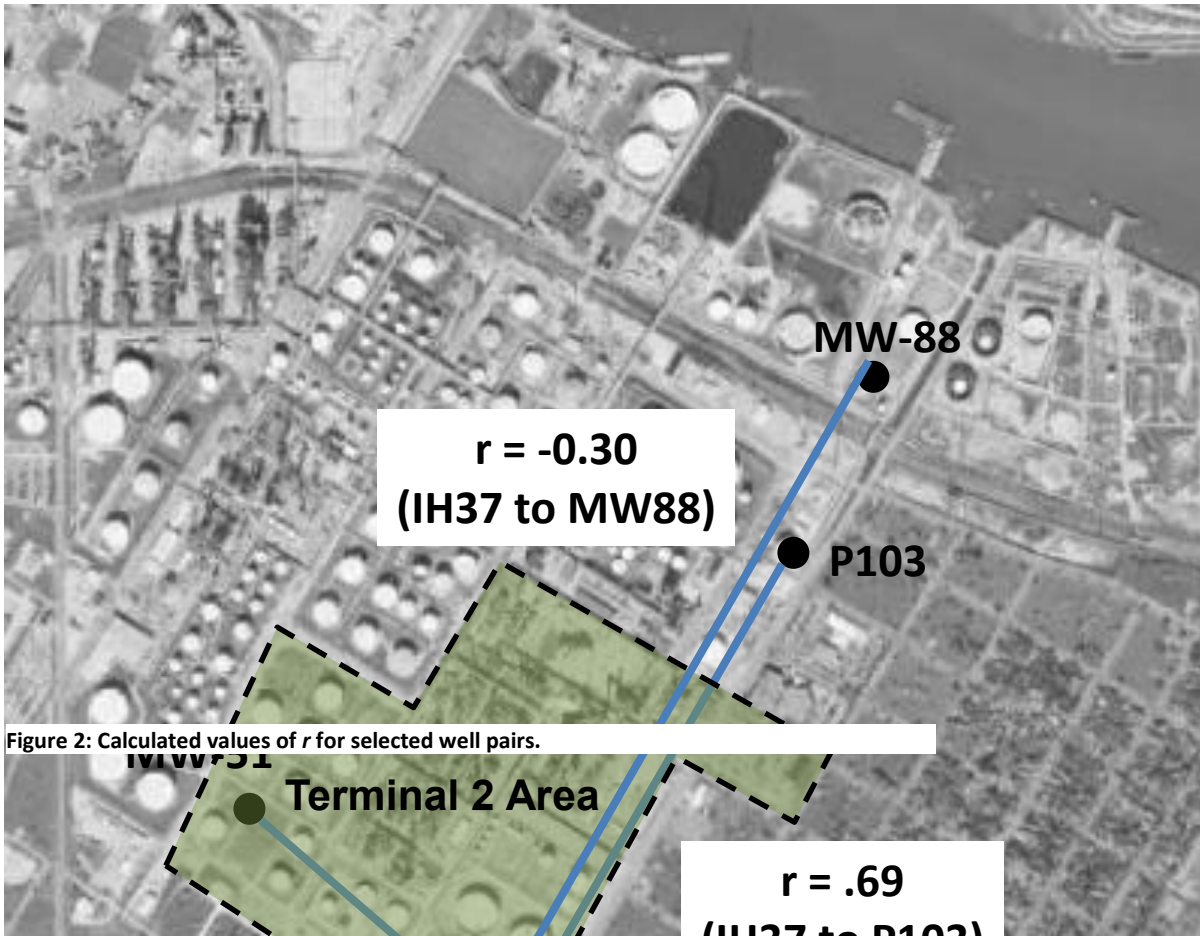

Figure 2: Calculated values of *r* for selected well pairs.

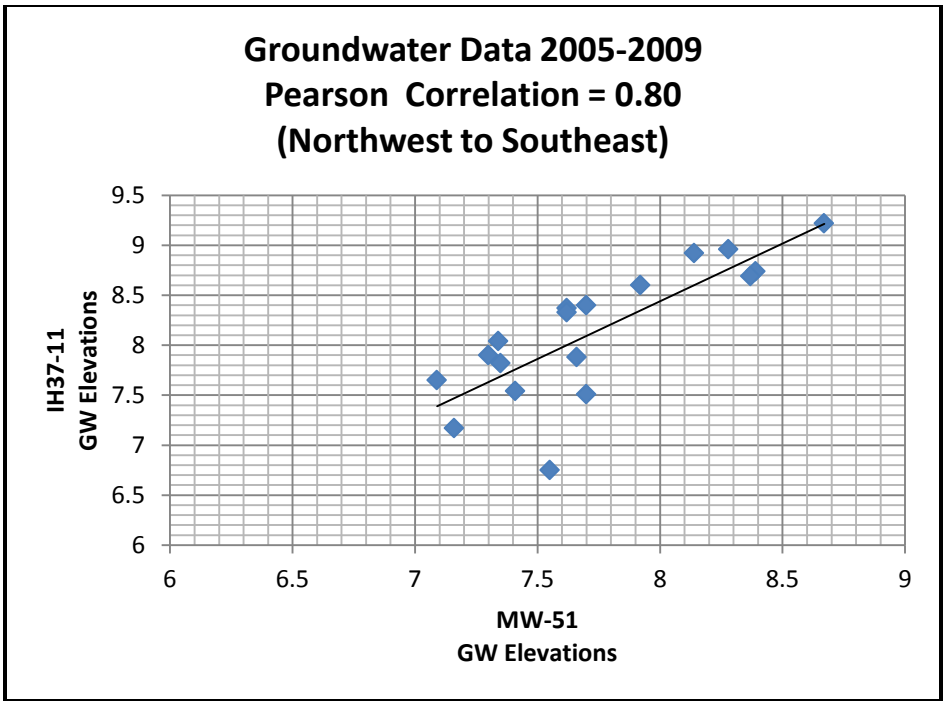

Figure 3

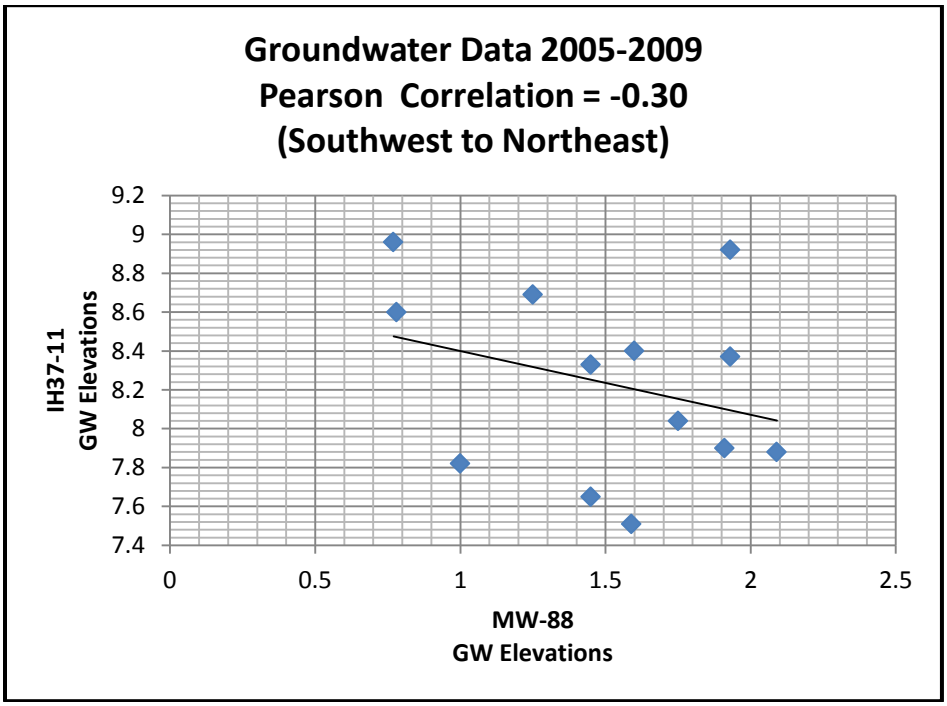

Figure 4

REFERENCES

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McClave, J.T., and Dietrich, F.H., 1982, Statistics, 2nd ed., Dellen Publishing Company, Santa Clara, California

Roengarten, Smith, and Associates, April 2011, Second Half 2010 Joint Semiannual Hydrocarbon Plume Status Report, Corpus Christi Ship Channel Inner Harbor Area, Corpus Christi, Nueces County, Texas

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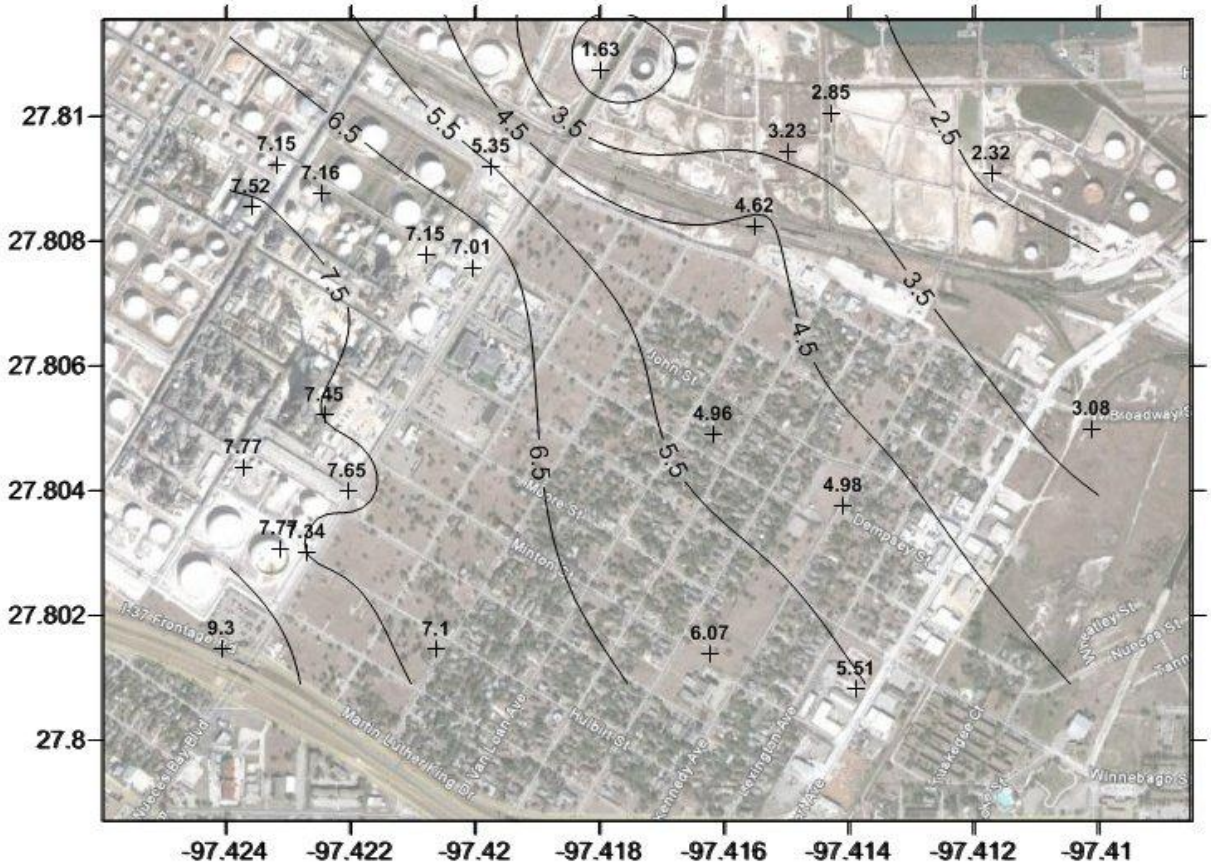
Weston Solutions Inc., 2010, Groundwater Investigation Report, Buffer Zone, FRH East Refinery

ADDENDUM

The following groundwater flow map was developed by using data from the Hillcrest neighborhood and with data from selected monitoring wells located at adjacent industrial facilities. Groundwater measurements for both the neighborhood and industrial facilities were taken on or about April 2011. The consistency shown between the April 2011 map and the flow map developed for the Feb. 7, 2012 report (above), suggests changes are not needed in the conclusions provided in the Feb. 7 report.