

**ELEVATION CHANGES
IN THE
CITY OF LONG BEACH
NOVEMBER 2003 TO MAY 2004**

**PREPARED
FOR
LONG BEACH CITY COUNCIL
BY
THE DEPARTMENT OF OIL PROPERTIES**

CONTENTS

	<u>Page</u>
I. SUBSIDENCE AND REBOUND SURVEY ANALYSIS	
Elevation Change – November 2003 to May 2004.....	1
Elevation Change – May 2003 to May 2004.....	2
Use of Global Positioning System (GPS).....	3
II. APPENDIX	
Brief History of Long Beach Subsidence	4
Survey Accuracy	5
Elevation Change Map Construction	6
Bench Mark and Net Injection Graphs, Harbor District	6
Bench Mark and Net Injection Graphs, Ocean Boulevard and Offshore Drilling Islands	7
III. ELEVATION CHANGE MAPS	<u>Figures</u>
November 2003 to May 2004.....	1
May 2003 to May 2004.....	2
BENCH MARK AND NET INJECTION GRAPHS	
Harbor District, Fault Blocks II-VI	3-7
Coastal Areas and Offshore Drilling Islands, Fault Blocks VI through 90S	7-12

ELEVATION SURVEY ANALYSIS

The City of Long Beach semi-annual elevation survey of the Civic Center, Central City, Harbor, Alamitos Bay and Naples areas was conducted during May 2004. Changes in elevation that occurred since the last two surveys, November 2003 and May 2003, are discussed in this report. The results presented are both within and outside the influences of the Department of Oil Properties (DOP).

Elevation Change – November 2003 to May 2004 (Figure 1)

Elevations throughout the Civic Center, Central City, Alamitos Bay and Naples areas remained stable or increased slightly in elevation during the 6-month period. A minor elevation increase of 0.05 feet (0.60 inches) occurred along Cherry Avenue south of 7th Street and extended into the offshore. City of Long Beach elevations outside of the oil-impacted areas were stable for the period. Minor elevation increases in geologically active areas outside the Wilmington Oil Field indicate that this six-month period was an “up survey period” caused by non-oil influences.

The Harbor District had three areas of localized minor elevation loss. An elevation loss of up to -0.030 feet (-0.36 inches) occurred on Pier T due to construction adjacent the old Navy dry dock. An elevation loss of -0.033 feet (-0.396 inches) was measured along the southernmost wharf of Pier J outside the oil field limits. Elevation loss was also measured along Henry Ford Avenue in the Pier A steam flood area.

Elevations continued to decline over the curtailed Tar II steam flood area around Henry Ford Avenue on Pier A. A loss of up to -0.038 feet (-0.456 inches) was measured at the HNJN Permanent GPS Station. The steam flood, initiated by Union Pacific Resources Company in the late 1980's, was terminated by the Department of Oil Properties in February 1999 because of negative surface elevation impact caused by extremely high oil reservoir temperatures heating and compacting shale layers overlying those deep reservoirs. The DOP implemented increased water injection and production rates to

hasten heat withdrawal and maintain reservoir pressure. Currently the DOP is studying realignment of injection to further increase heat withdrawal.

Except for Grissom, the Oil Islands remained stable having no significant elevation change. Grissom increased in elevation by 0.05 feet (0.60 inches).

Elevation Change – May 2003 to May 2004 (Figure 2)

For the most part, elevations throughout the Civic Center, Central City, Alamitos Bay and Naples areas, remained stable or increased slightly in elevation during the 12-month period. A minor elevation increase of 0.05 feet (0.60 inches) occurred along Ocean Avenue and the beach between Alamitos and Cherry Avenues. Immediately north of the Civic Center along Pine Avenue between Anaheim and 7th Streets a minor elevation loss of up to -0.045 feet (-0.54 inches) occurred. This area may have been impacted by non-unit oil operations.

In the Harbor District, up to -0.089 feet (-1.068 inches) of elevation were lost on Piers A, S and T. The elevation loss was centered in Fault Block II and extended throughout Fault Block III to the west side of Fault Block IV. This loss can be attributed to the continued shale compaction resulting from reservoir over-heating by the now terminated steam flood in Fault Block II surrounding Henry Ford Ave, and the loss of rebound from earlier years' over-injection into Fault Blocks III and IV. A localized elevation loss of up to -0.033 feet (-0.396 inches) occurred at the south end of Pier J at the edge of the oil field.

The oil islands remained stable for the 12-month period.

Use of Global Positioning System (GPS)

This is the fifth consecutive GPS Elevation Survey. Accuracy, performance and results have reached expectations. The report is based solely upon bench mark elevation data generated by GPS satellite equipment. GPS elevation measurements have been demonstrated to be reliable and as accurate as the spirit leveling which it replaced. The

field data collection time has been reduced by more than 50 percent, and the 800 spirit leveled bench marks have been reduced to approximately 200 GPS bench marks. (Reference: Appendix, Survey Accuracy, and pg. 5)

APPENDIX

Brief History of Long Beach Subsidence

Long Beach and the general vicinity have a history of regional subsidence (losses of elevation) since 1929. Elevation changes were small amounting to an average of about -0.036 feet (-0.43 inches) per year until about 1939. Geologic movement such as the Long Beach Earthquake of March 1933 altered this average rate at times. The reason for this slight regional subsidence or slight elevation loss is not fully understood. Contributing causes appear to be groundwater withdrawal from aquifers in the Long Beach area, regional basin sediment compaction, and tectonic effects.

Development of the Wilmington Oil Field began in 1936. Oil operations accelerated subsidence and created a 29-foot deep subsidence bowl centered in the Wilmington-Long Beach Harbor area near Bench Mark 8772 (Figure 5). Development of the Ranger Zone west of Pine Avenue and its extension seaward in 1947 started the first definitive subsidence in the Central Business District that could be attributed to oil production.

Repressuring operations began in the 1950's. By 1965, subsidence stopped throughout the Long Beach portion of the Wilmington Oil Field. Some bench marks have actually recovered over one foot in elevation. This is known as rebound. As an example, from 1960 to 1970, Bench Mark No. 1735 near the corner of Ocean Boulevard and Magnolia Avenue recovered approximately one foot of elevation.

In the 1990's, a large Harbor redevelopment project on Pier A destroyed several bench marks that overlaid the now curtailed steam flood project. Elevation losses in the area were suspected and the destruction of these bench marks made it difficult to monitor any changes. In 1998 after the bench marks were replaced, additional well bore investigations determined that subsurface compaction of the deep shale intervals due to high temperatures was occurring above the steam flooded zones. The Fault Block II

Tar Zone Steam Flood was terminated in 1999 and cold-water injection was initiated. The forced cooling of the deep formations will be a long term project.

The Alamitos Bay and Naples area had losses in elevation prior to development of the adjacent oil operations. These original small losses were most likely due to the regional affects of basin sediment compaction and tectonic movements along the Newport-Inglewood Fault Zone. Later, the coastal strip from Civic Center eastward to the Alamitos Bay Peninsula lost elevation due to oil and gas production from the West Wilmington Oil Field and possibly the adjacent oil fields. This region has rebounded due to Long Beach Unit water injection that began in 1965.

Survey Accuracy

The May 2002 Elevation Leveling Campaign marked the conversion from spirit, first and second order rod leveling to GPS measurement of City and Harbor bench mark elevations. Through the GPS contractor, Condor Earth Technologies, Inc. (Condor), a network of eleven permanent real-time GPS base stations and a central data collection and processing center were installed within the City of Long Beach. Several existing non-City operated stations were integrated into the new network. The Public Works Department, Bureau of Engineering surveyors utilize mobile GPS equipment linked to the base stations to measure approximately 200 City and Harbor bench marks, down from the previous 800 bench marks.

Through statistical analysis of satellite, base station, and mobile instrument geometries, and a previous coincident spirit leveling and GPS bench mark elevation survey, City surveyors and Condor estimate the accuracy of GPS elevations to be 6 - 8 millimeters (0.02 feet or 0.24 inches), equal to or better than the prior spirit leveling. Areas are considered to be stable where elevation change is less than 0.02 feet (0.24 inches).

Studies by the City's subsidence control engineers and geologists, and consultants show that the bench marks may at times rise and fall somewhat rhythmically city-wide in such a manner as to make an entire survey either optimistic or pessimistic. These

elevation changes are random and not well understood. Repressuring operations and the resulting rebound can mask the rise or fall pattern. Surface elevations in a rebounded area can be expected to fluctuate under changing water flood conditions. Because of these fluctuations, conclusions based upon short-term survey data should be viewed with caution. Short-term survey data are useful for possible early detection and confirmation of subsidence trends or relative elevation changes but should not be accepted without consideration of the above factors. Annual survey data tend to average these fluctuations and depict a more dependable picture of the relative movements of bench marks.

Elevation Change Map Construction (Figure 1 and 2)

All data are presented as contour lines showing the average change in surface elevation during a particular time period. For example, any point along a line reading 0.05 feet (0.60 inches) on an Elevation Change Map gained an elevation of one-twentieth of a foot or six tenths of inch during that period. The small hachures along contour lines point towards a loss in elevation.

Bench Mark and Net Injection Graphs, Harbor District (Figures 3 - 7)

The bench marks are normalized to mean sea level. Bench marks are plotted each time they are surveyed and are shown on a graph with a history of net injection for that same area and time. The net injection is the amount of water injected into the reservoirs that underlie that particular bench mark minus the gross fluid produced from the reservoirs in barrels per day. The graphs only cover the last 20 years of net injection and bench mark monitoring.

In general, these graphs show a good correlation between the net injection and elevation change. For example, an increase in net injection is usually followed by an increase in elevation. There tends to be a lag time of months between the net injection change and the subsequent elevation change. The elevation plots of benchmarks on Figures 3 through 7 in the Harbor District illustrate surface elevation fluctuations that

can be expected to occur under the dynamic reservoir conditions experienced in extremely mature water flooding operations.

Bench Mark and Net Injection Graphs, Ocean Boulevard and the Offshore Drilling Islands (Figures 7 – 12)

The last 20 years of elevation changes and accompanying net injection histories are shown on Figures 7 through 12 for bench marks located along Ocean Boulevard and on the offshore drilling islands. The elevation changes at Ocean Boulevard near Magnolia Avenue are shown by the graph of Bench Mark 1735 and Bench Mark 1215 on Figure 7. Bench Mark 225 on Figure 11 shows surface elevation changes on the Alamitos Bay Peninsula. Bench Mark 938 monitors elevation changes on Naples Island.

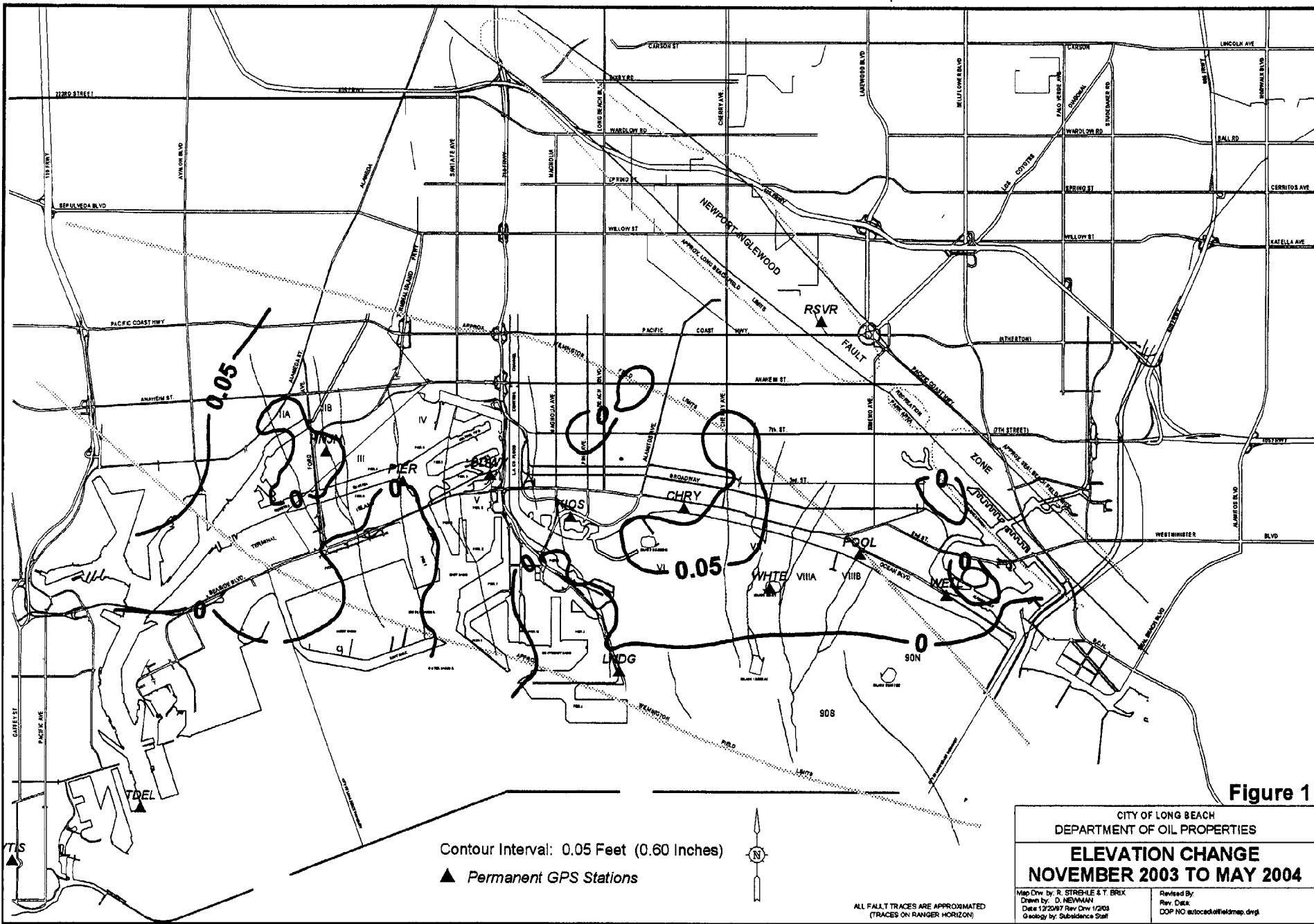


Figure 1

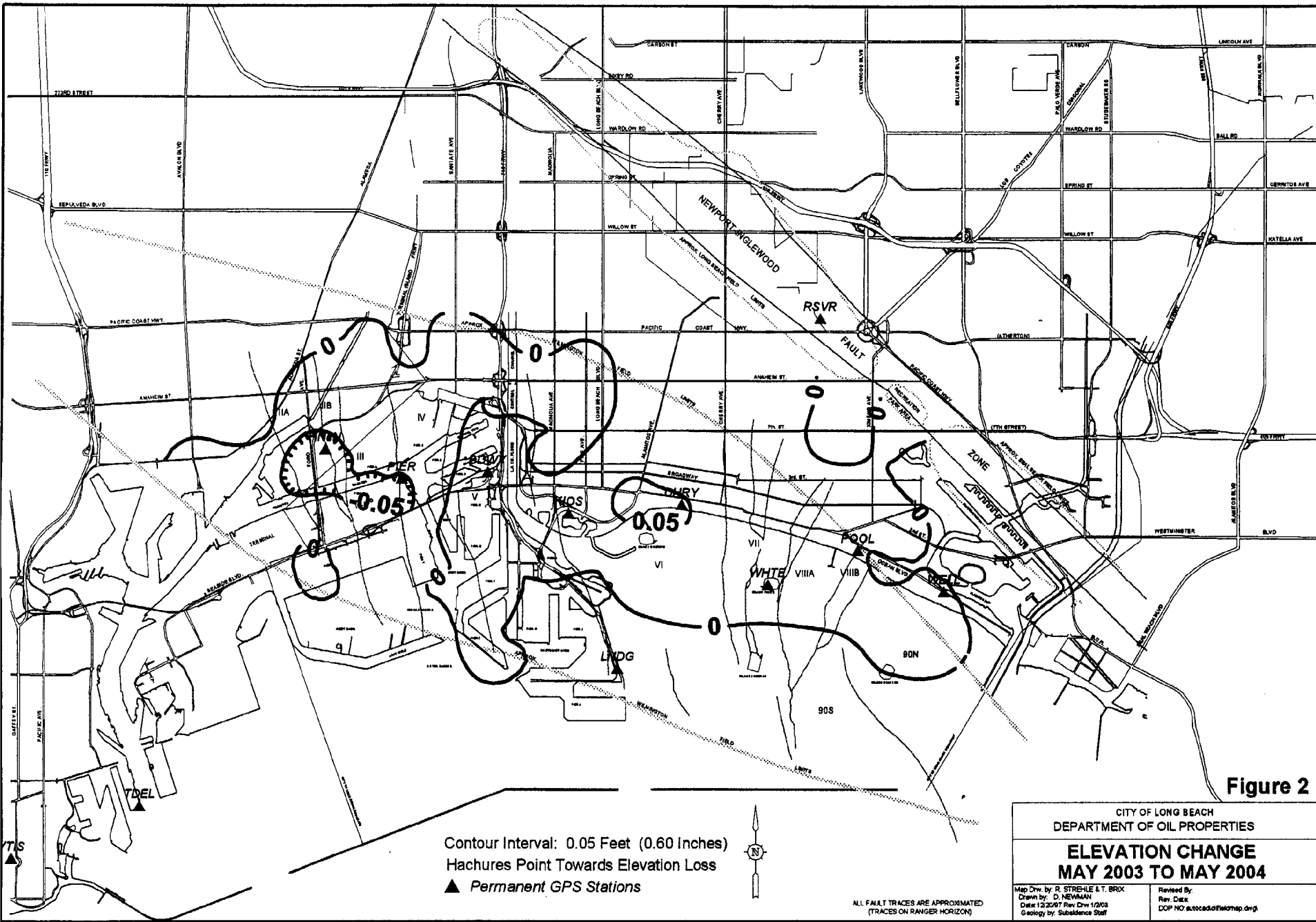


Figure 2

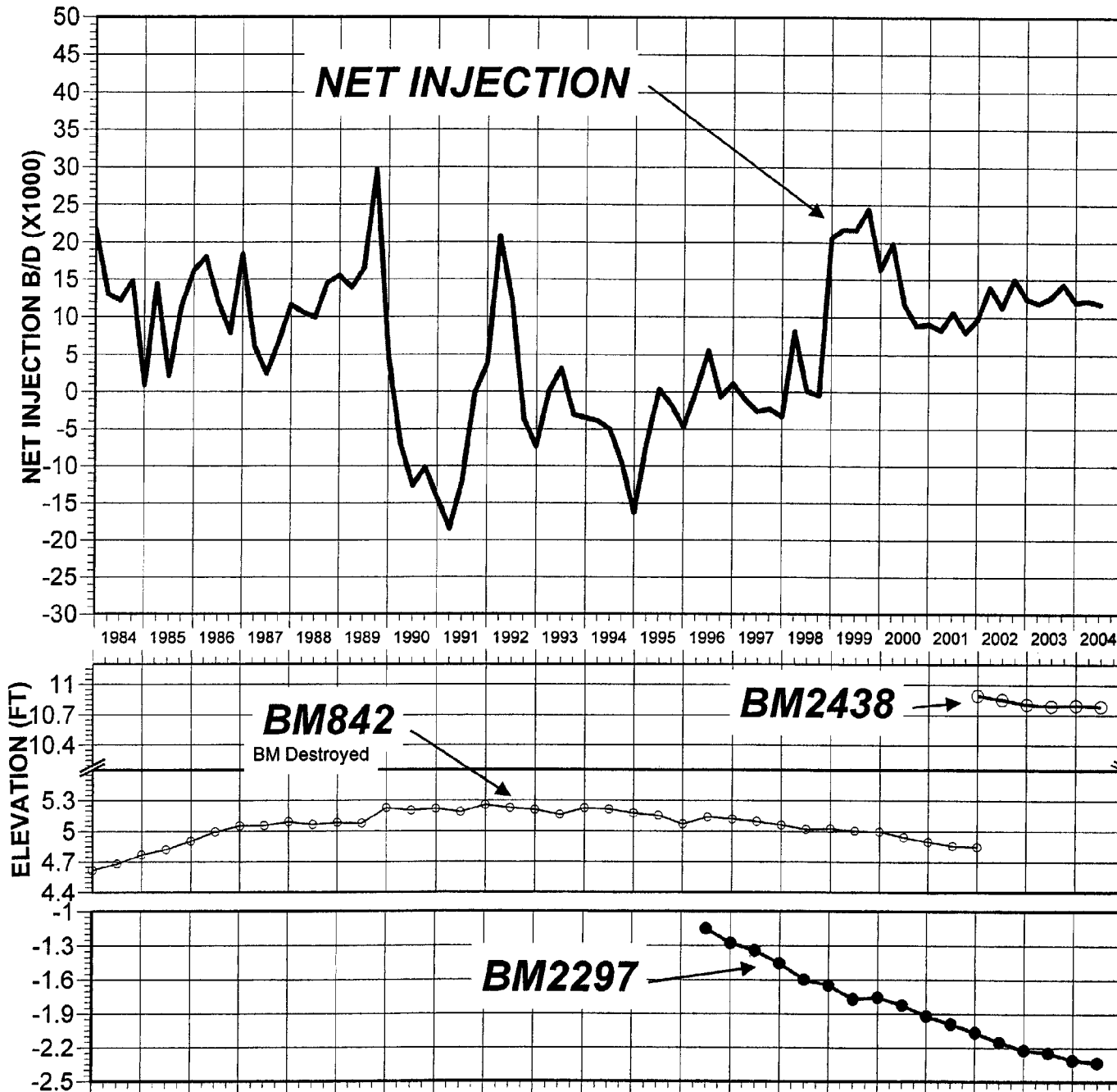
Contour Interval: 0.05 Feet (0.60 Inches)
 Hachures Point Towards Elevation Loss
 ▲ Permanent GPS Stations



CITY OF LONG BEACH DEPARTMENT OF OIL PROPERTIES	
ELEVATION CHANGE MAY 2003 TO MAY 2004	
Map Drawn by: R. STREHLE & T. BRUX Drawn by: D. NEWMAN Date: 12/20/07 Rev: Draw 1/2/03 Geology by: Subsidence Staff	Revised By: Rev. Date: DOP NO. a:\ccad00\filomsp.dwg

ALL FAULT TRACES ARE APPROXIMATED
(TRACES ON RANGER HORIZON)

TOPKO FBII A & B SEG. 1 & 2



Location Map

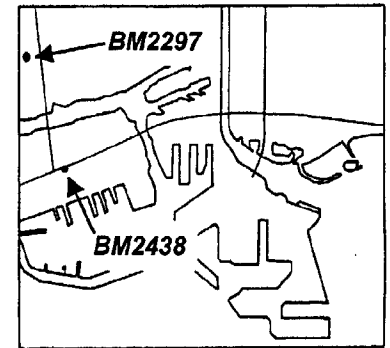
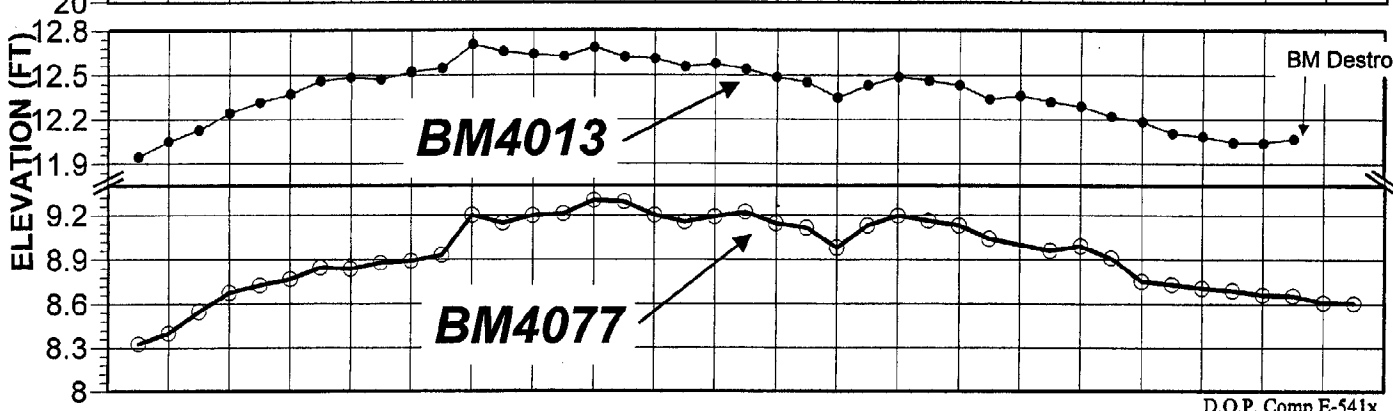
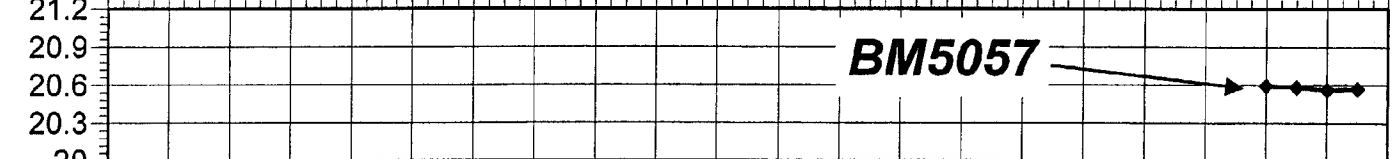
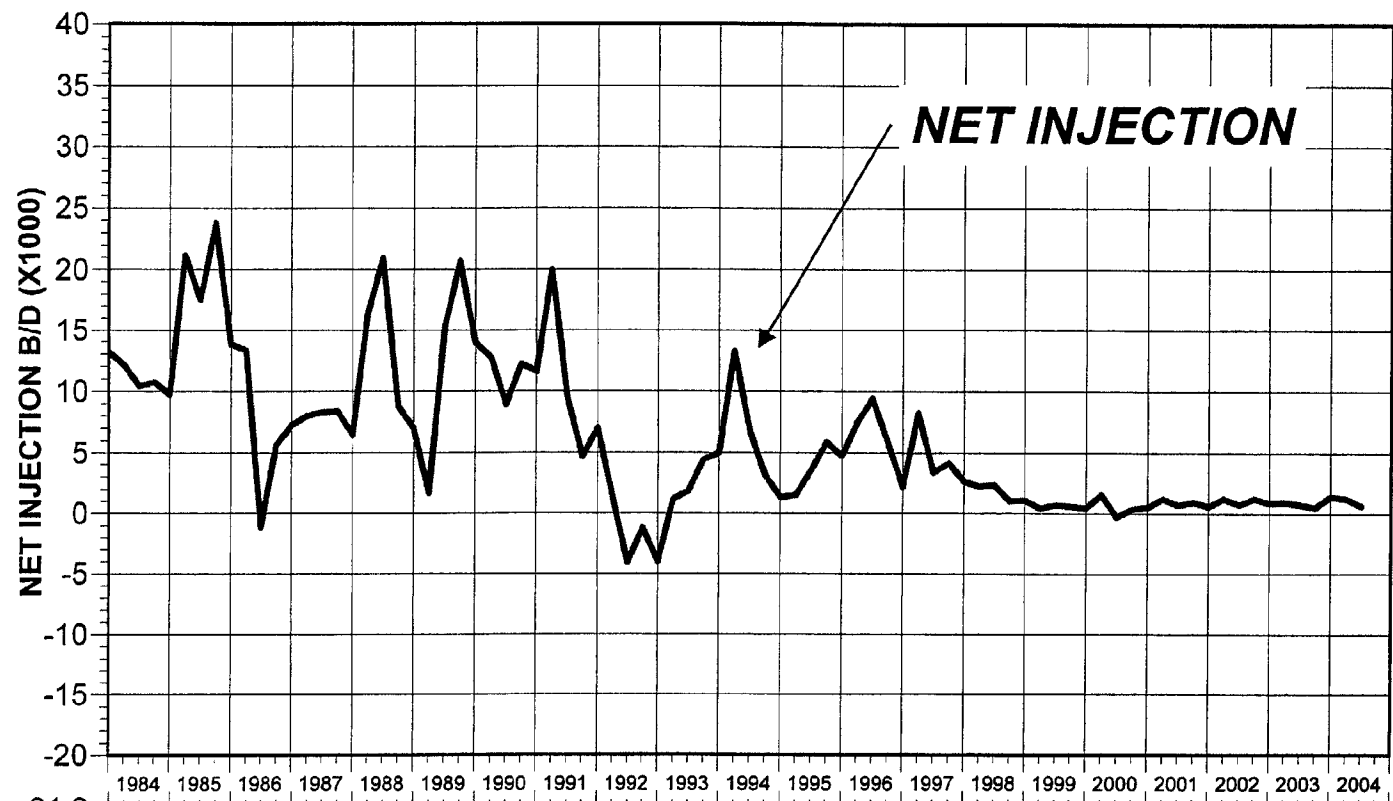
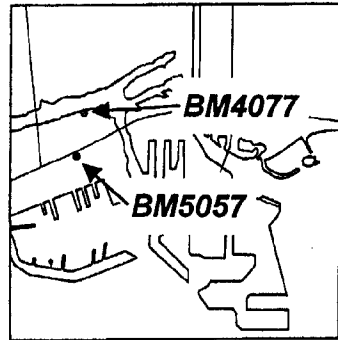


FIGURE 3

TOPKO FB III SEG. 1 & 2



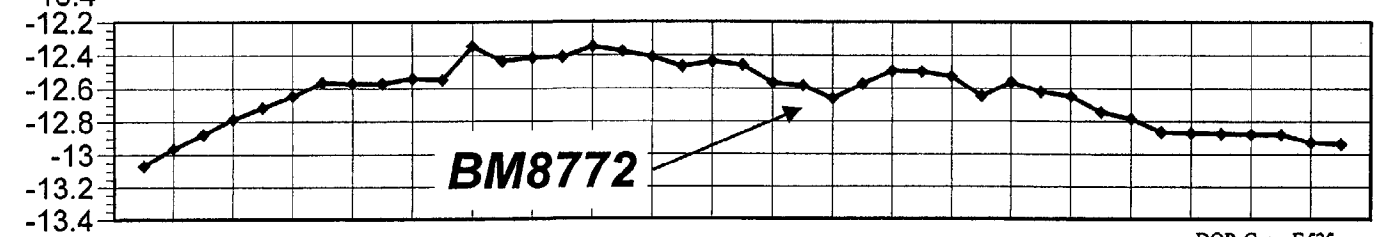
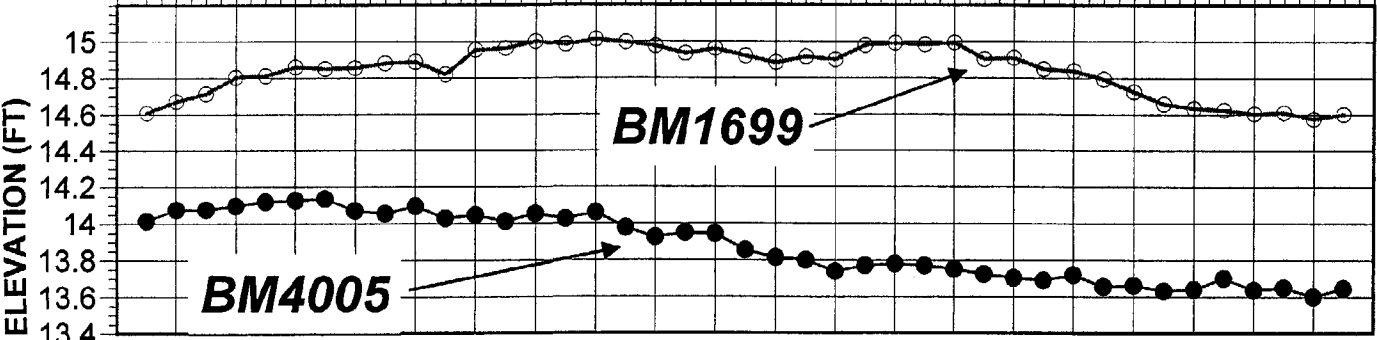
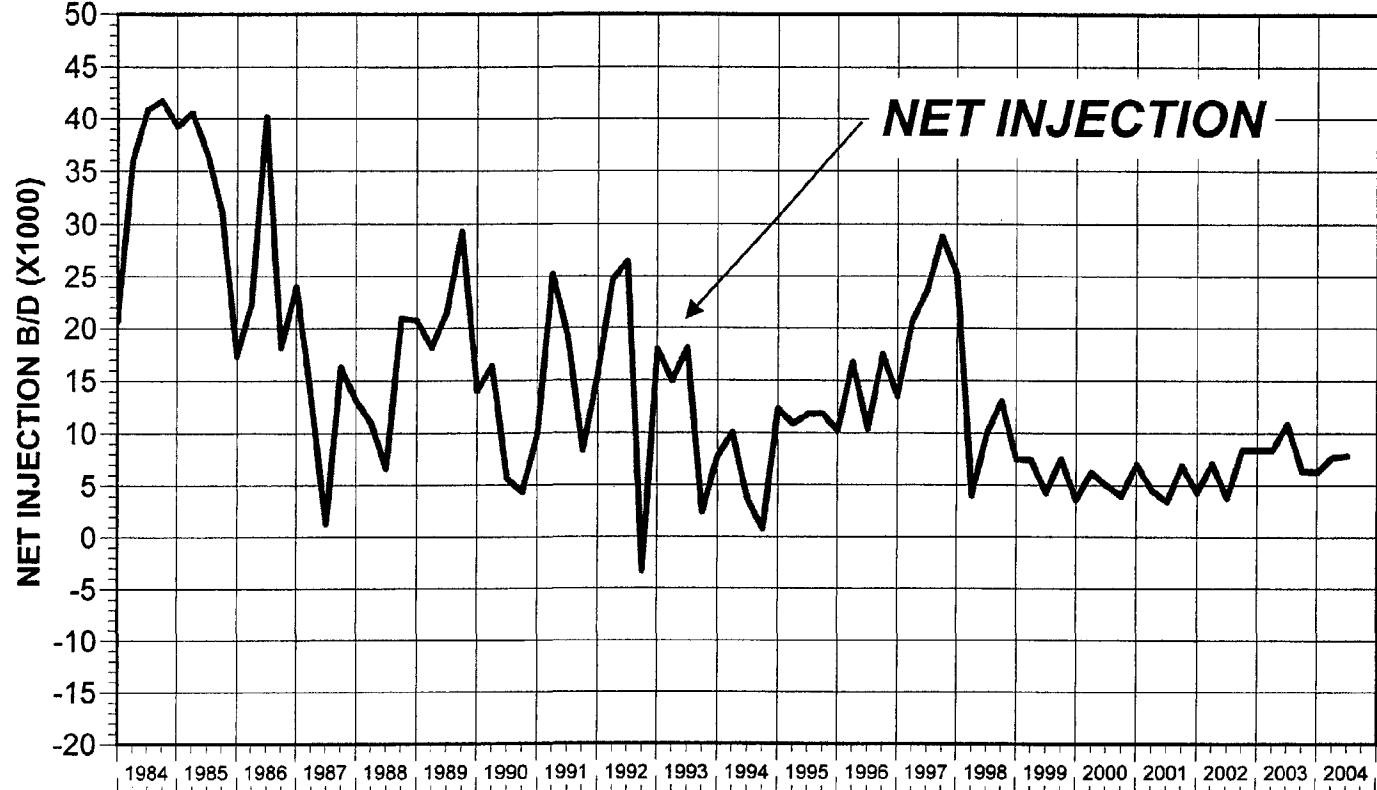
Location Map



D.O.P. Comp E-541x
Rev. DN 8/26/04

FIGURE 4

TOPKO FB IV SEG. 1, 2 & PARCEL "L"



Location Map

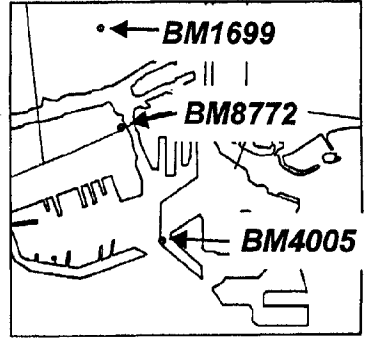
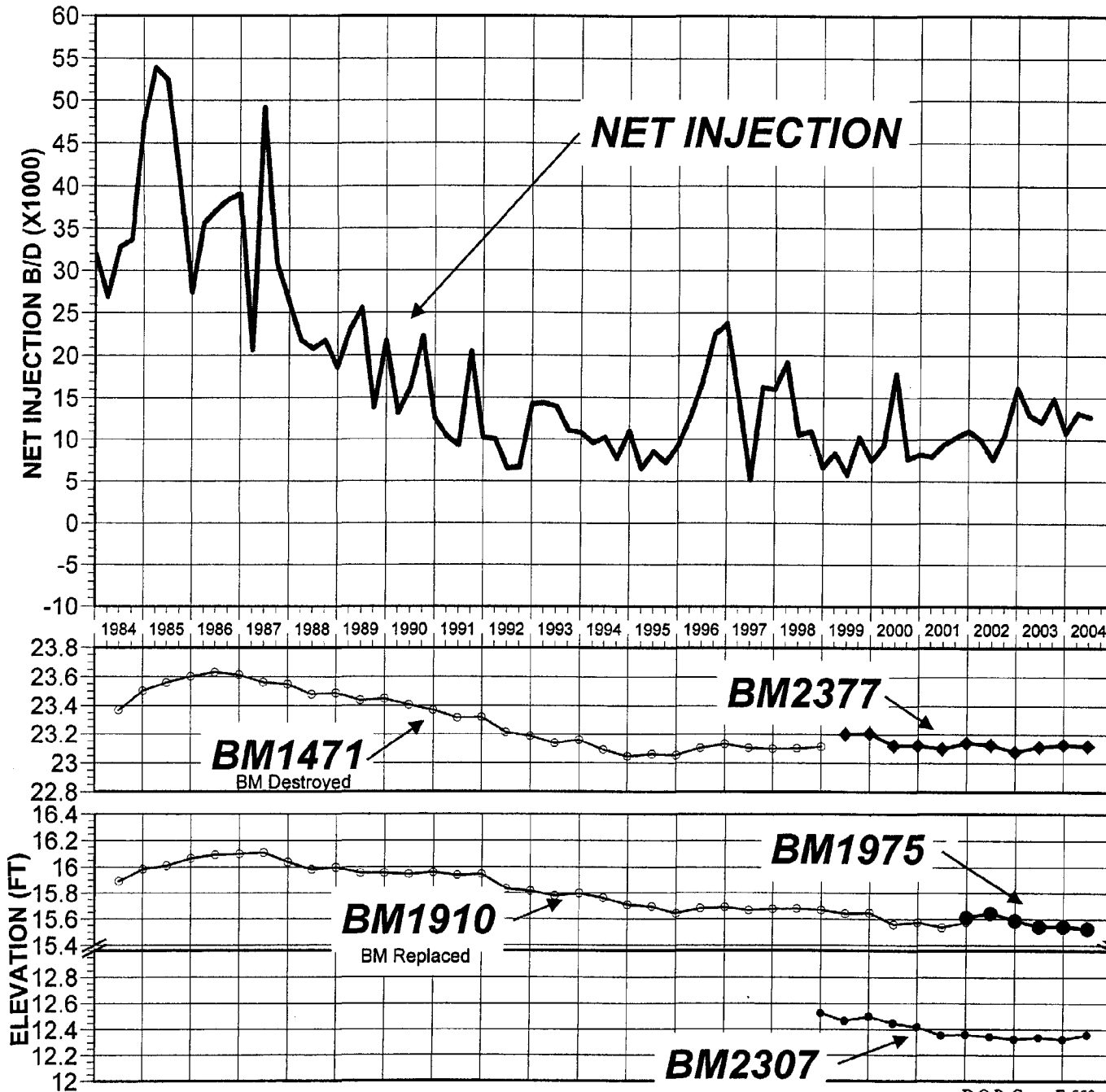


FIGURE 5

DOP. Comp E-535x
Rev. DN8/26/04

TOPKO FB V SEG. 1 & 2

Unit & Non-Unit



Location Map

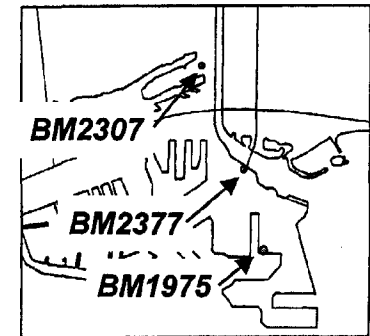
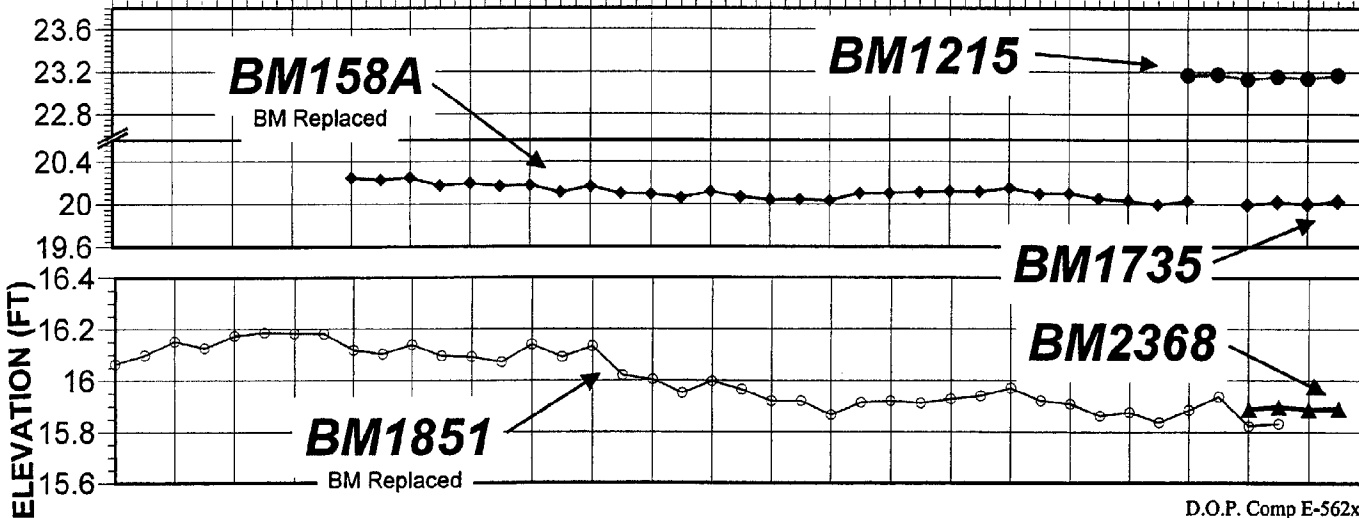
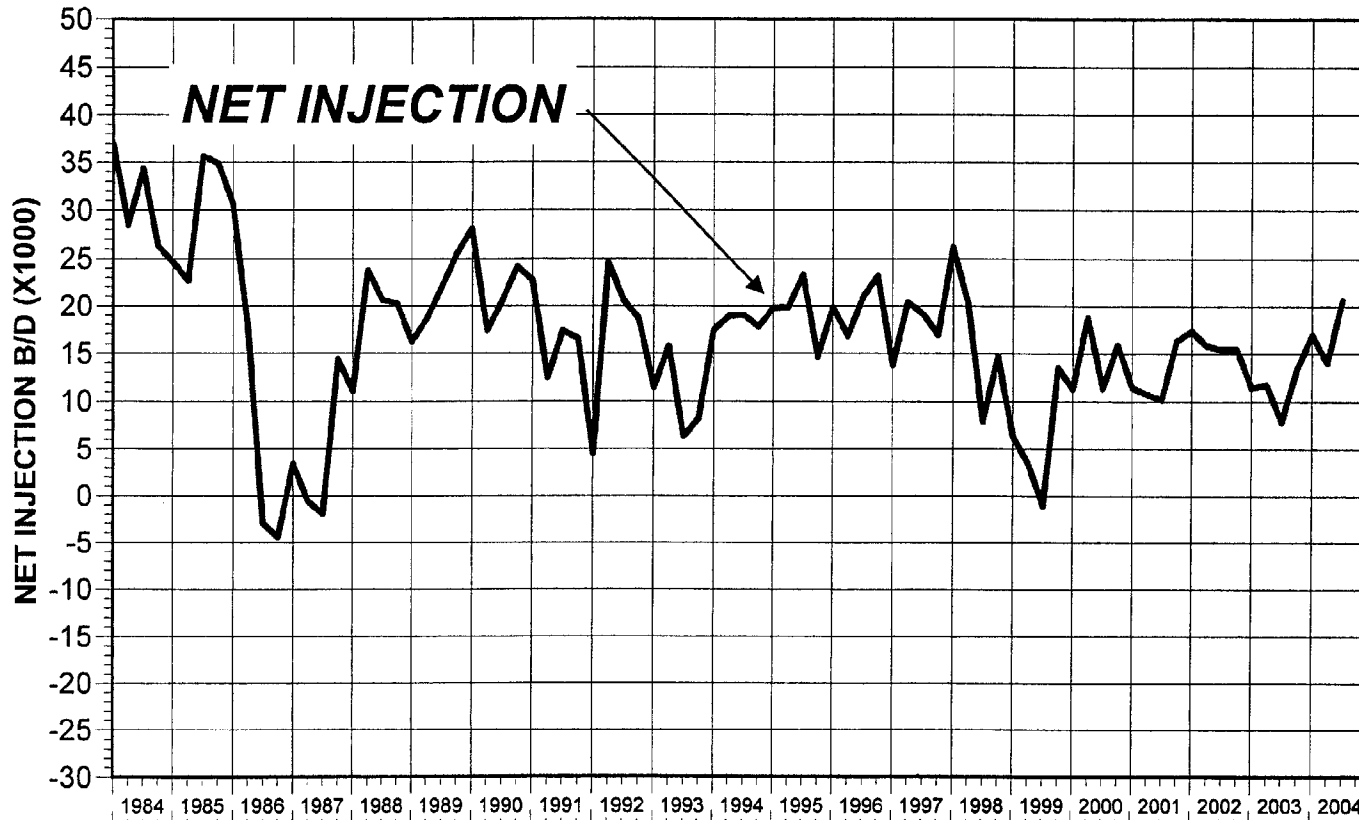


FIGURE 6

THUMS-TOPKO FB VI



Location Map

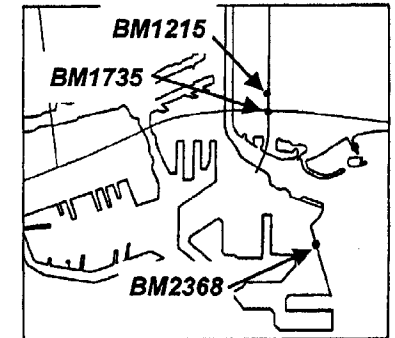
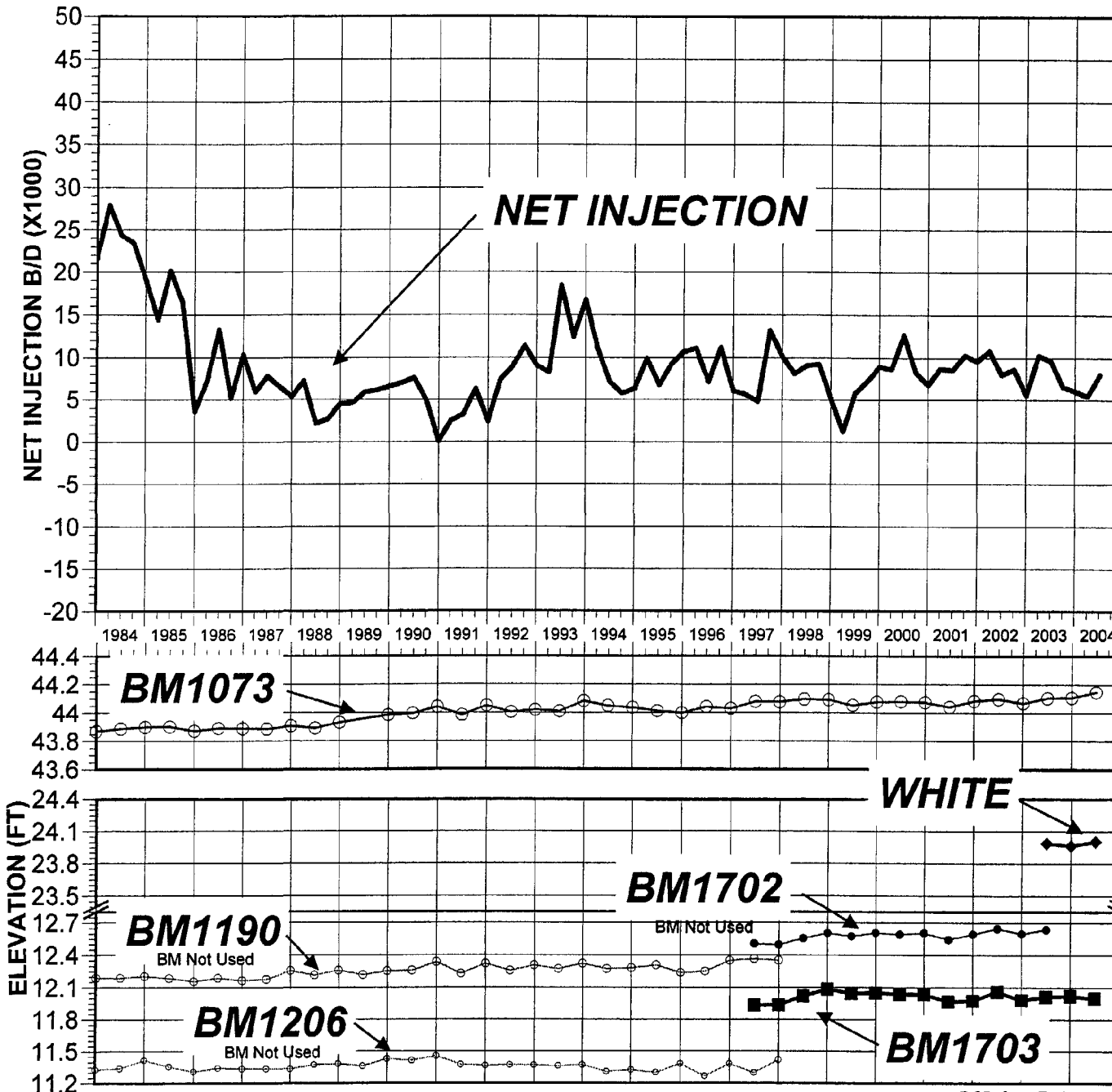


FIGURE 7

THUMS, FB VII



Location Map

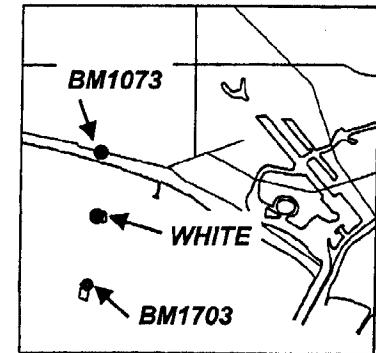
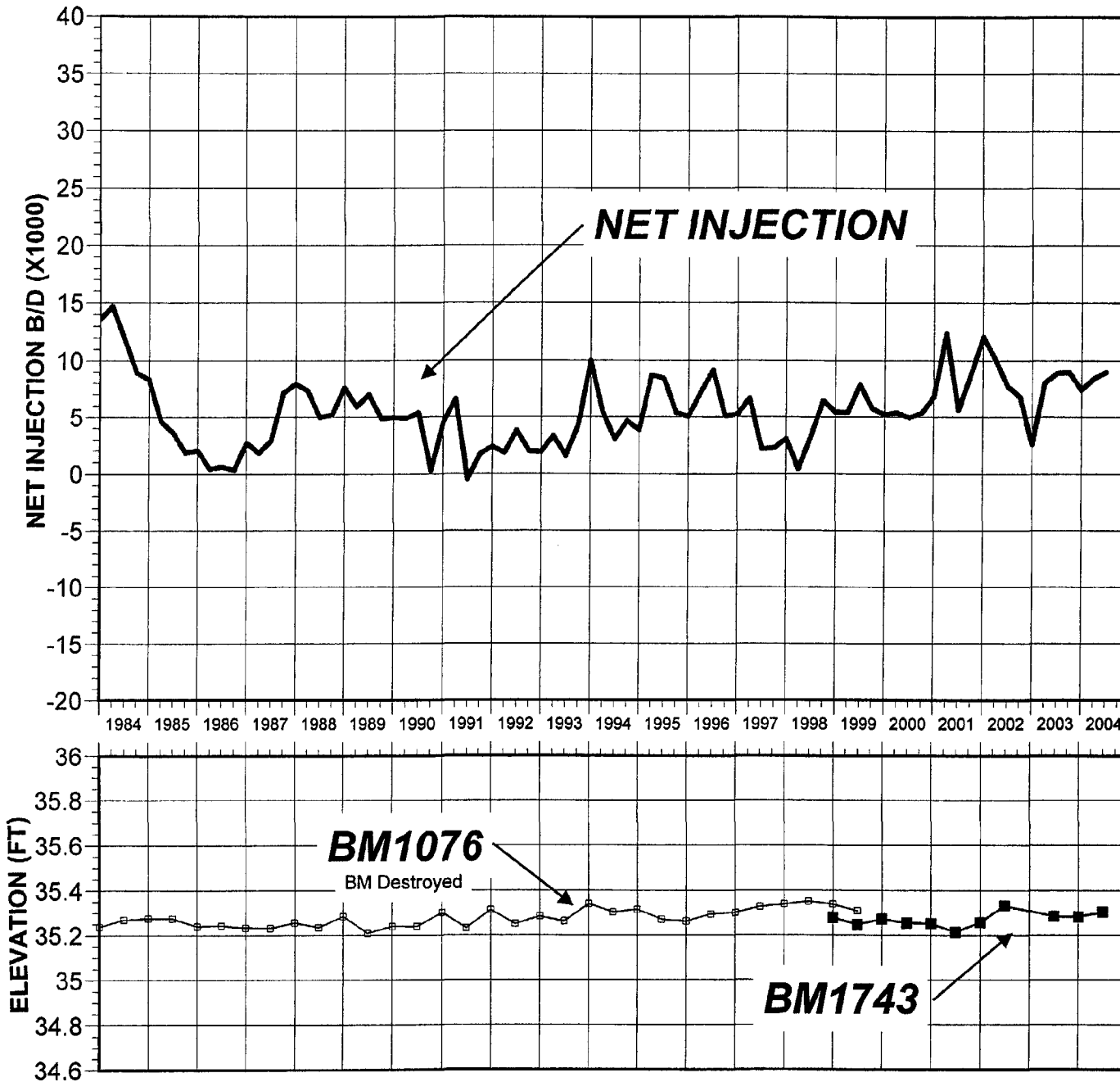


FIGURE 8

THUMS FB VIIIA



Location Map

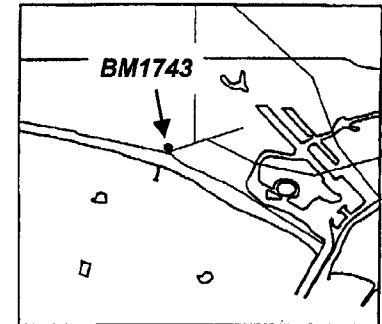
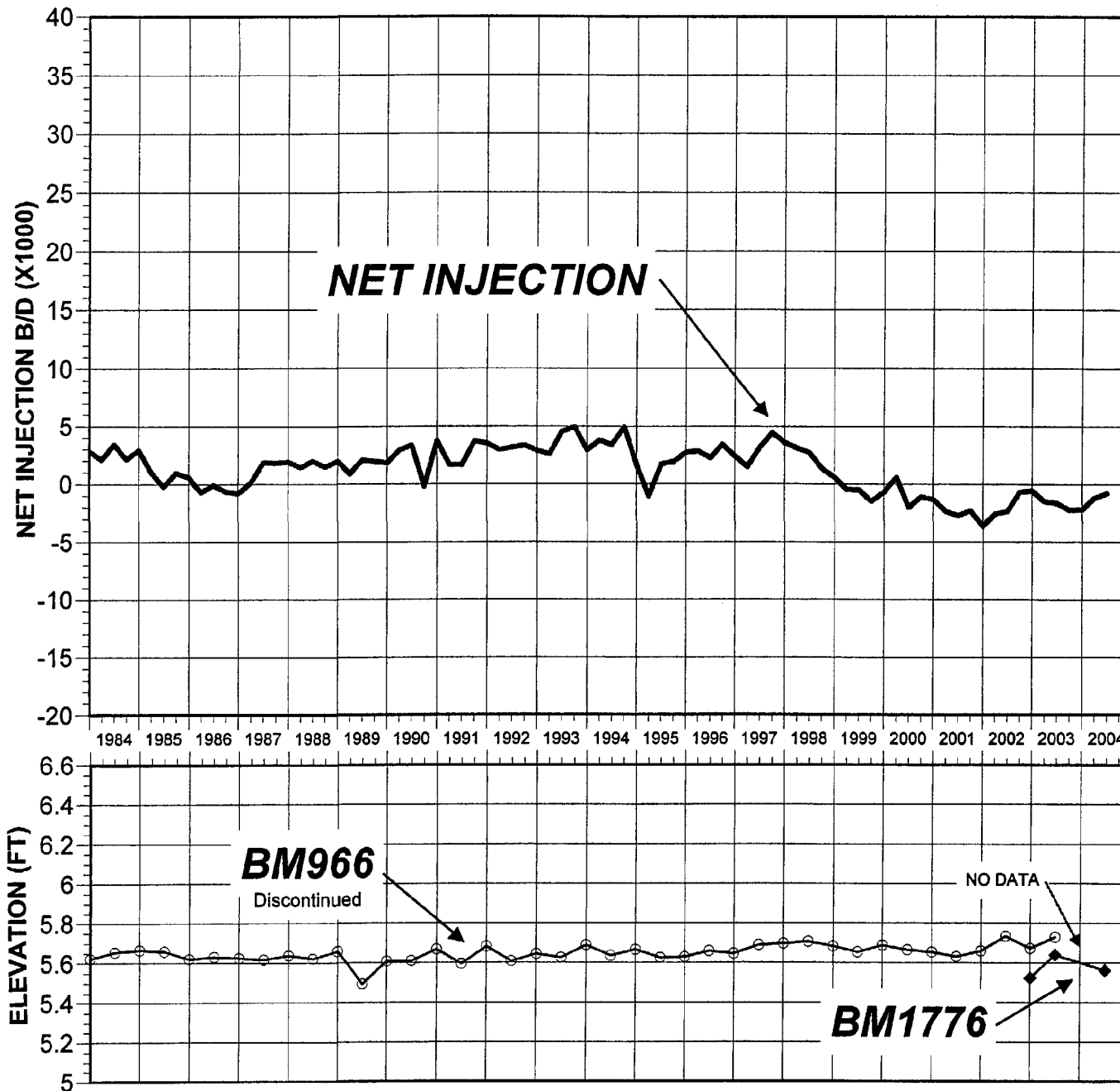


FIGURE 9

THUMS FB VIIIB



Location Map

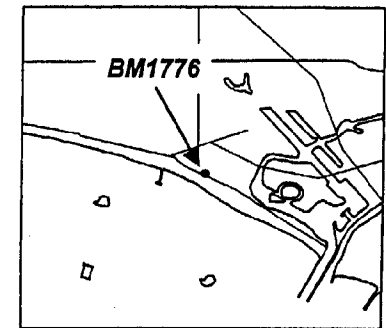
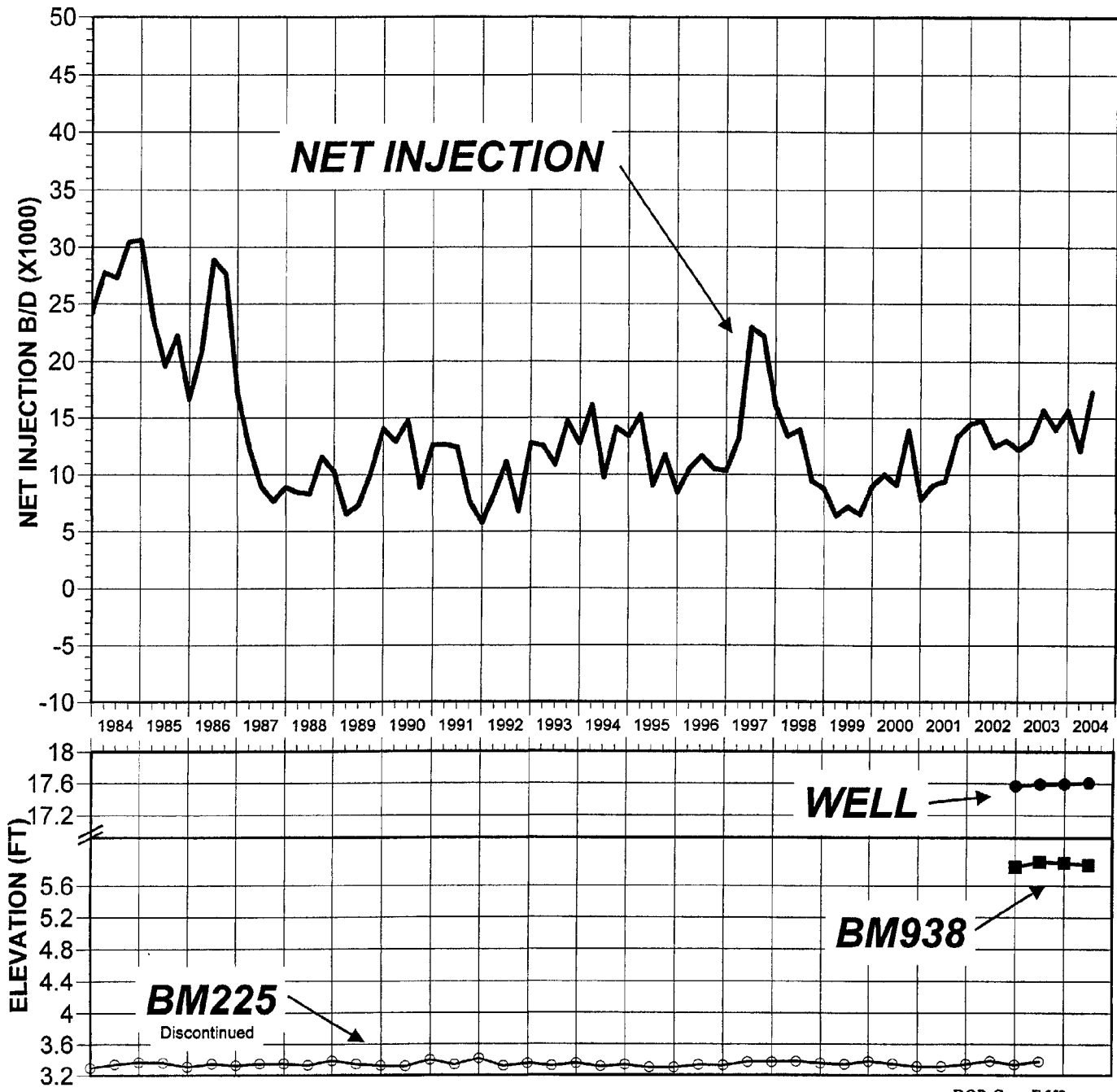


FIGURE 10

THUMS FB 90N



Location Map

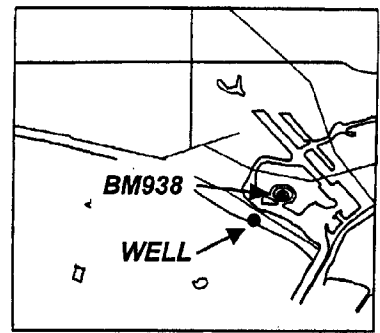
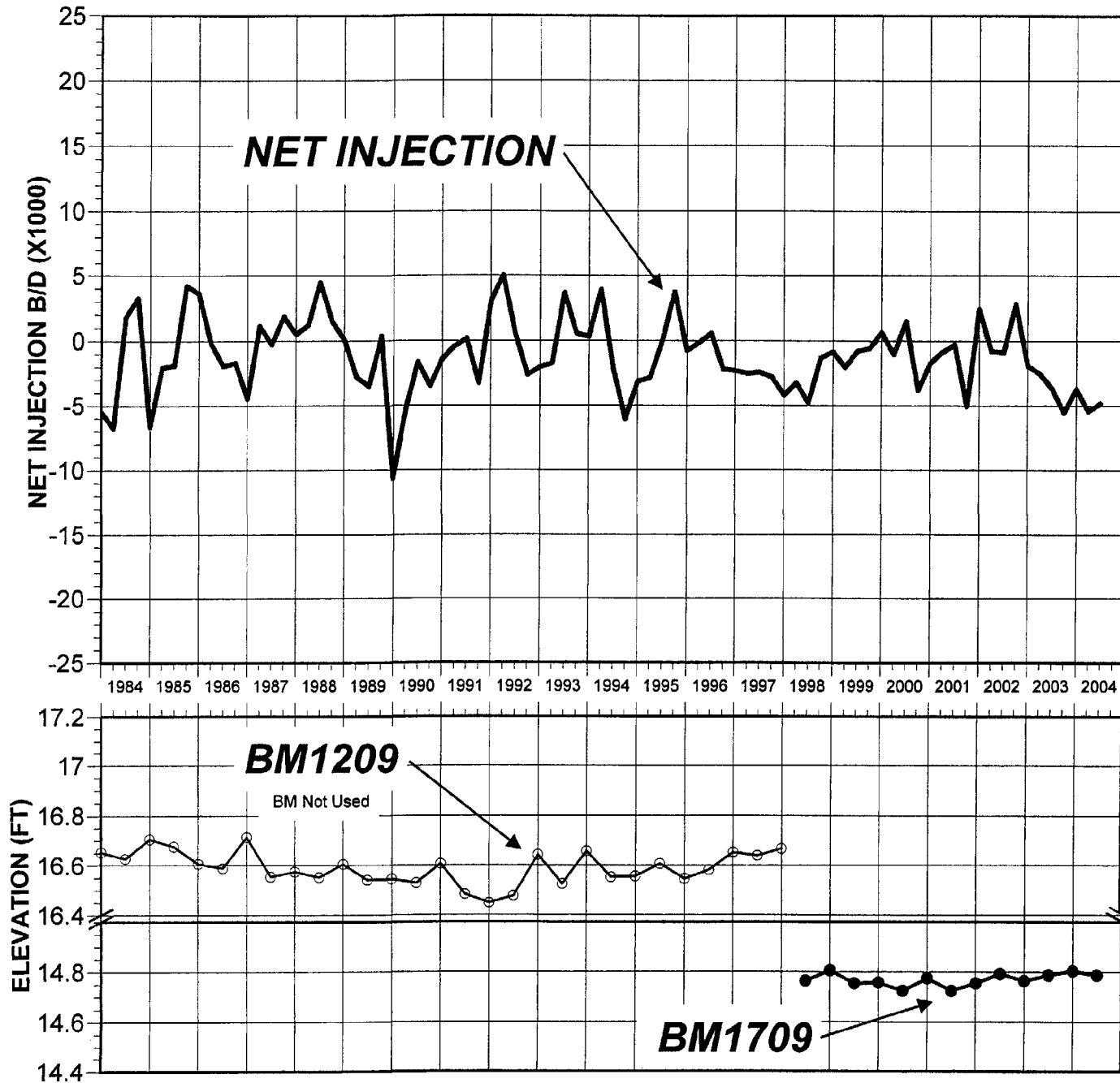


FIGURE 11

DQP, Comp E-552x
Rev: DN8/26/04

THUMS FB 90S



Location Map

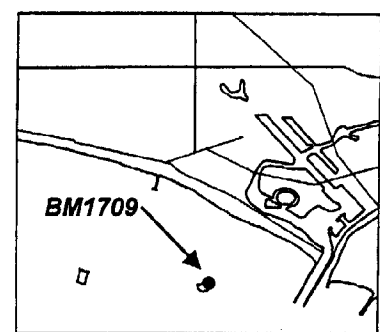


FIGURE 12