C-18

ELEVATION CHANGES
IN THE
CITY OF LONG BEACH

MAY 2004 TO NOVEMBER 2004

PREPARED

FOR

LONG BEACH CITY COUNCIL

BY

THE DEPARTMENT OF OIL PROPERTIES

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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 November 2004. Changes in elevation that occurred since the last two surveys, May 2004 and November 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 – May 2004 to November 2004 (Figure 1)

Elevations throughout the Civic Center, Central City, Alamitos Bay and Naples areas remained stable or increased slightly in elevation during the six-month period. A minor localized elevation increase of 0.05 feet (0.60 inches) occurred west of Cherry Avenue along Ocean Boulevard to the shoreline. City of Long Beach elevations outside of the oil impacted areas were stable for the period. Minor elevation changes in geologically active areas outside the Wilmington Oil Field indicate that this six-month period was a "stable" or slightly "up" survey.

The Harbor District was stable having no or only minor elevation increase. The most significant elevation change was a localized elevation increase of up to 0.062 feet (0.744 inches) on Pier G. Minor elevation increases were also measured at Pier C and Pier E.

Elevations continued to decline over the curtailed Tar II steam flood area around Henry Ford Avenue on Pier A where lower elevations were recorded in both Fault Blocks II and III. A loss of up to -0.056 feet (-0.672 inches) was measured west of 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 the reservoirs. The DOP implemented increased water injection and production rates to hasten heat withdrawal and maintain reservoir pressure. The DOP is studying realignment of the cold-water injection to accelerate heat withdrawal.

The Oil Islands are interpreted as being stable, having no significant elevation change.

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

Elevations throughout the Civic Center, Central City, Alamitos Bay and Naples areas remained stable or slightly increased in elevation by up to 0.063 feet (0.756 inches) during the 12-month period. A localized elevation increase of 0.100 feet (1.20 inches) occurred along Ocean Avenue and the beach between Alamitos and Cherry Avenues. Geologically active zones outside the oil-impacted areas indicate the one-year period to be a positive elevation period.

The Harbor District also experienced increasing elevations except in Fault Blocks II and III adjacent to and overlying the Tar II steam flood. A maximum increase of 0.066 feet (0.792 inches) was recorded at permanent GPS Station BDWY at the northernmost edge of Pier E. The only elevation loss was centered in Fault Block II and extended into Fault Block I and III. This loss can be attributed to the continued shale compaction resulting from reservoir overheating by the now terminated steam flood area in Fault Block II surrounding Henry Ford Ave, and the loss of rebound from earlier years' over injection into Fault Block III. The one year maximum loss in elevation was –0.085 feet (-1.020 inches) at permanent GPS Station HNJN.

Islands Grissom and White increased in elevation by up to 0.075 feet (0.90 inches). Islands Freeman and Chaffee had no elevation change.

Use of Global Positioning System (GPS)

This is the sixth consecutive GPS Elevation Survey. Accuracy, performance and results have reached expectations. This report is based solely upon bench mark elevation data generated by GPS satellite equipment. GPS elevation measurements have been demonstrated to be reliable and more accurate than 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 240 GPS bench marks.

Two new permanent GPS Stations, PUMP and VTIS, were installed between the May and November 2004 Elevation Surveys. These stations complete the DOP operated thirteen (13) station Long Beach Deformation Network.

(Reference: Appendix, Survey Accuracy; 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-feet 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 was occurring above the steam flooded zones due to high temperatures. 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 thirteen 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's Bureau of Engineering surveyors utilize mobile GPS equipment linked to the base stations to measure approximately 240 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 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) that is 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 and 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.

<u>Bench Mark and Net Injection Graphs, Ocean Boulevard and the Offshore Drilling Islands</u> (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.

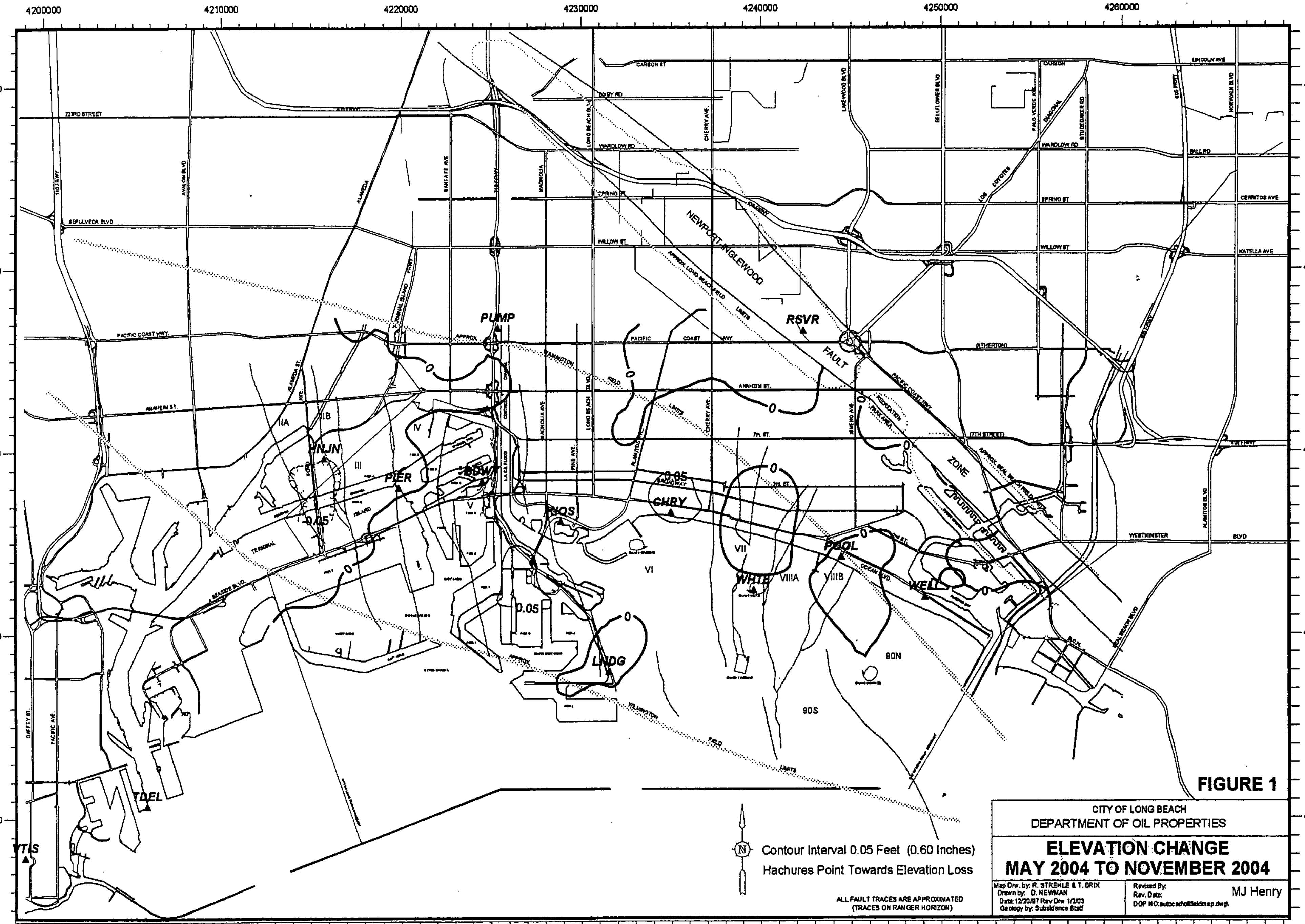

FIGURE 1
CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES
ELEVATION CHANGE
MAY 2004 TO NOVEMBER 2004
Contour Interval 0.05 Feet (0.60 Inches)
Hachures Point Towards Elevation Loss
ALL FAULT TRACES ARE APPROXIMATED
(TRACES ON RANGER HORIZON)
MJ Henry
NEWPORT-INGLEWOOD
FAULT
ZONE
PUMP
RSVR
HNJN
PIER
BDWY
CHRY
POOL
WHTE
WELL
LNDG
TDEL
VTIS
CARSON ST
LINCOLN AVE
WARDLOW RD
SPRING ST
WILLOW ST
SEPULVEDA BLVD
PACIFIC COAST HWY
ANAHEIM ST.
7th ST.
WESTMINSTER
CERRITOS AVE
KATELLA AVE
OCEAN BLVD.
4200000
4210000
4220000
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4260000
4050000
4040000
4030000
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4010000

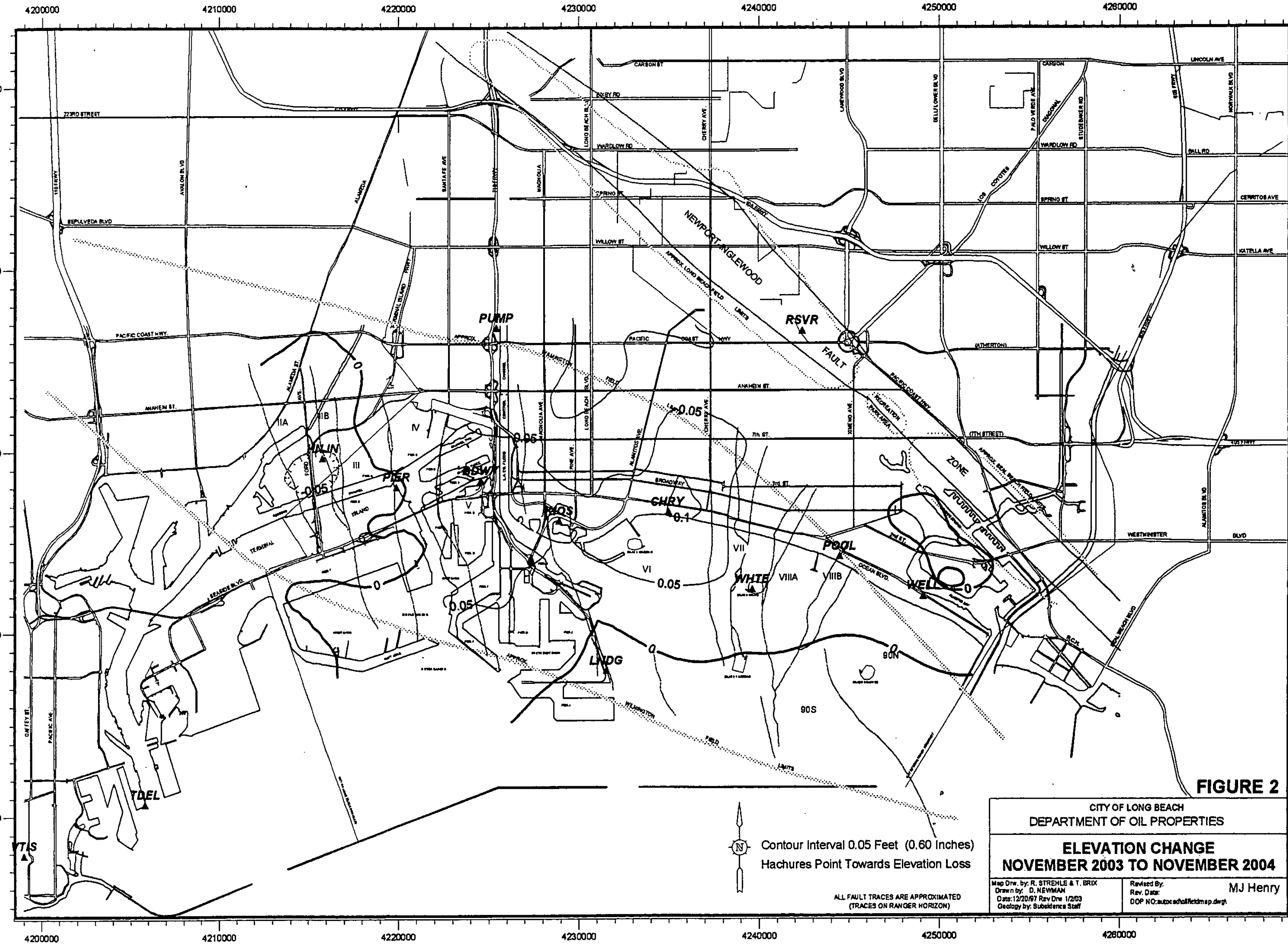
FIGURE 2
CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES
ELEVATION CHANGE
NOVEMBER 2003 TO NOVEMBER 2004
Map Drw. by: R. STREHLE & T. BRIX
Drawn by: D. NEWMAN
Revised By:
Rev. Date:
MJ Henry
Geology by: Subsidence Staff
Contour Interval 0.05 Feet (0.60 Inches)
Hachures Point Towards Elevation Loss
ALL FAULT TRACES ARE APPROXIMATED
(TRACES ON RANGER HORIZON)
NEWPORT-INGLEWOOD
FAULT
ZONE
PUMP
RSVR
PIER
CHRY
POOL
WHTE
WELL
LHDG
TDEL
VTIS
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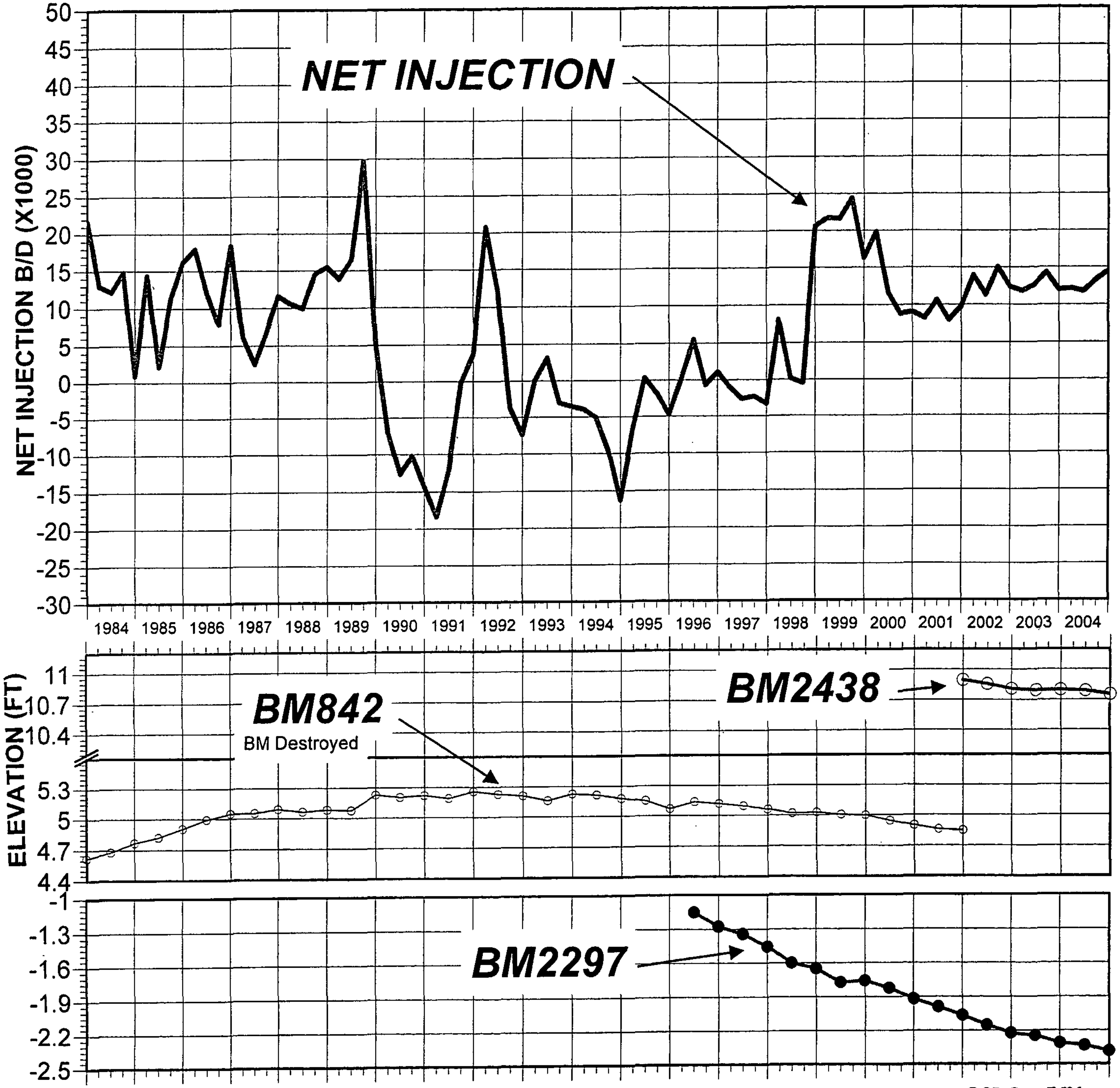
4040000
4030000
4020000
4010000



TOPKO
FBII A & B
SEG. 1 & 2

Location Map

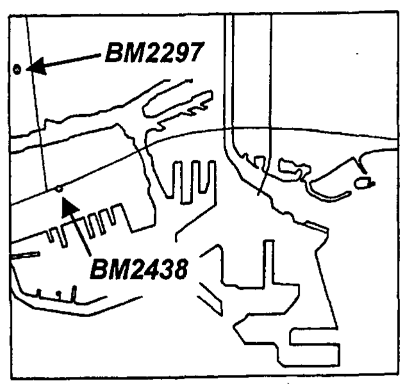
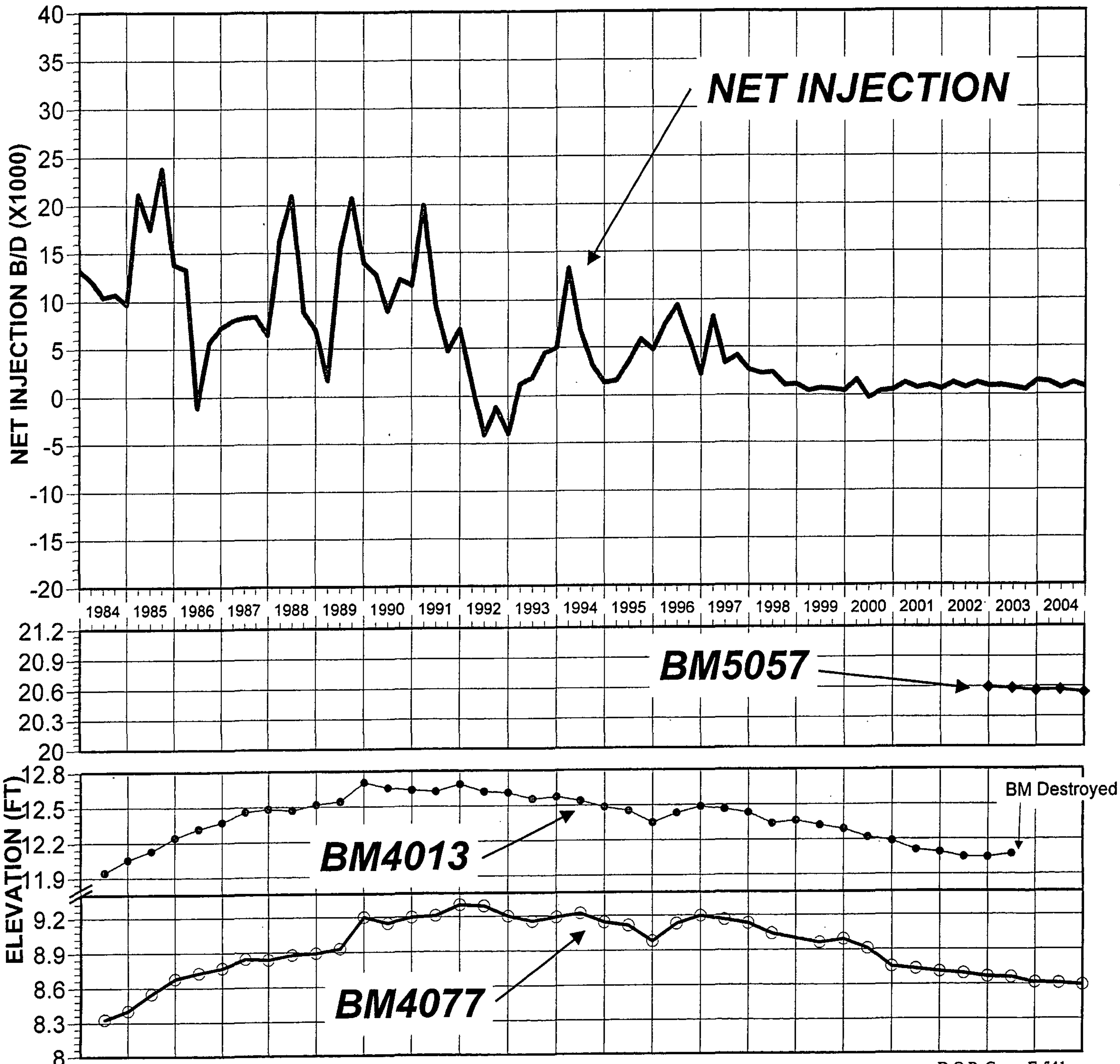


FIGURE 3

D.O.P. Comp E-536x
Rev: DN 2/02/05

TOPKO
FB III
SEG. 1 & 2



D.O.P. Comp E-541x
Rev. DN 2/02/05

Location Map

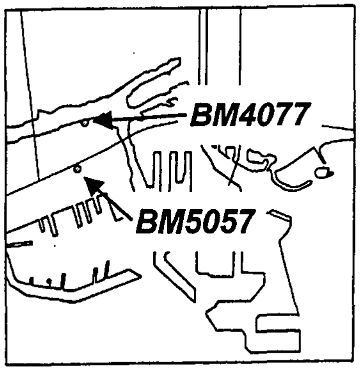
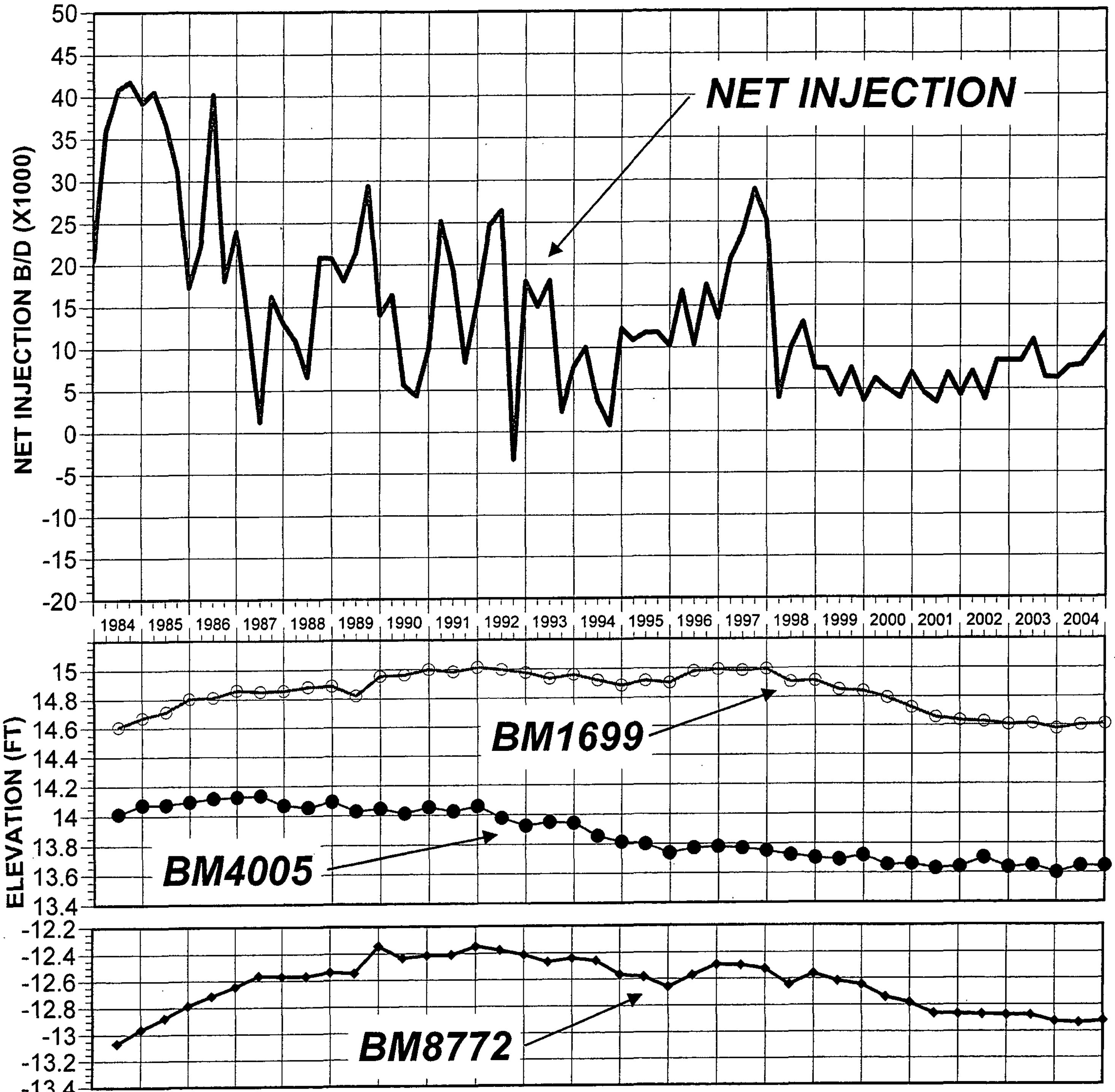


FIGURE 4

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



Location Map

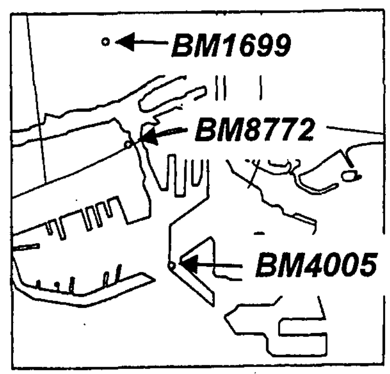
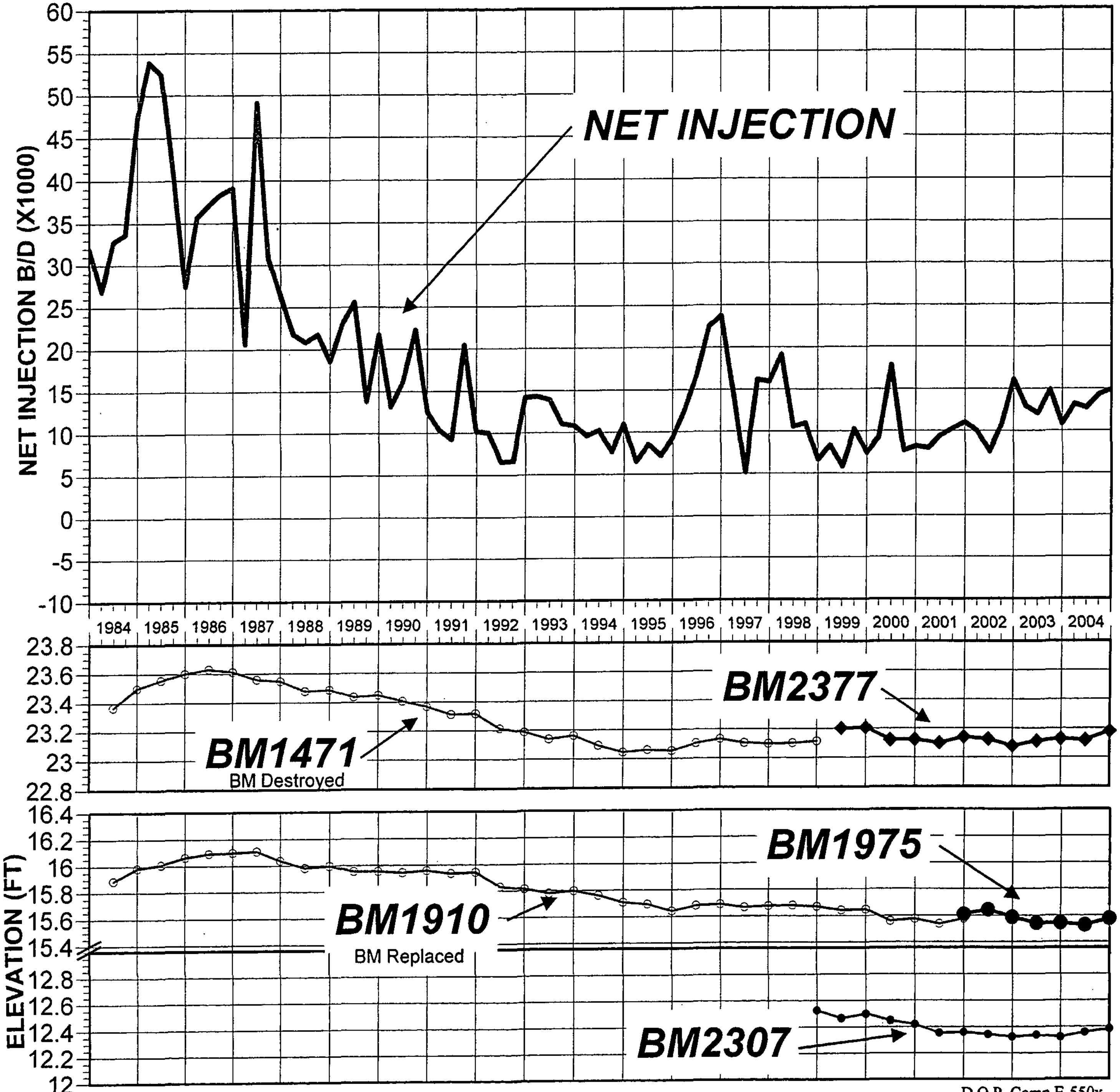


FIGURE 5

D.O.P. Comp E-535x
Rev: DN2/02/05

TOPKO
FB V
SEG. 1 & 2

Unit & Non-Unit



D.O.P. Comp E-550x
Rev. DN 2/02/05

Location Map

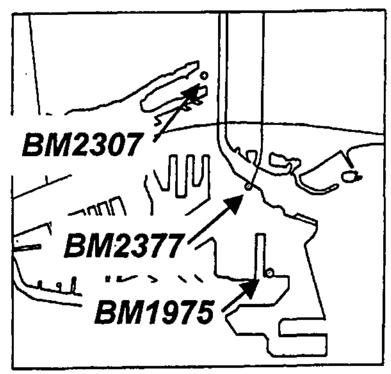
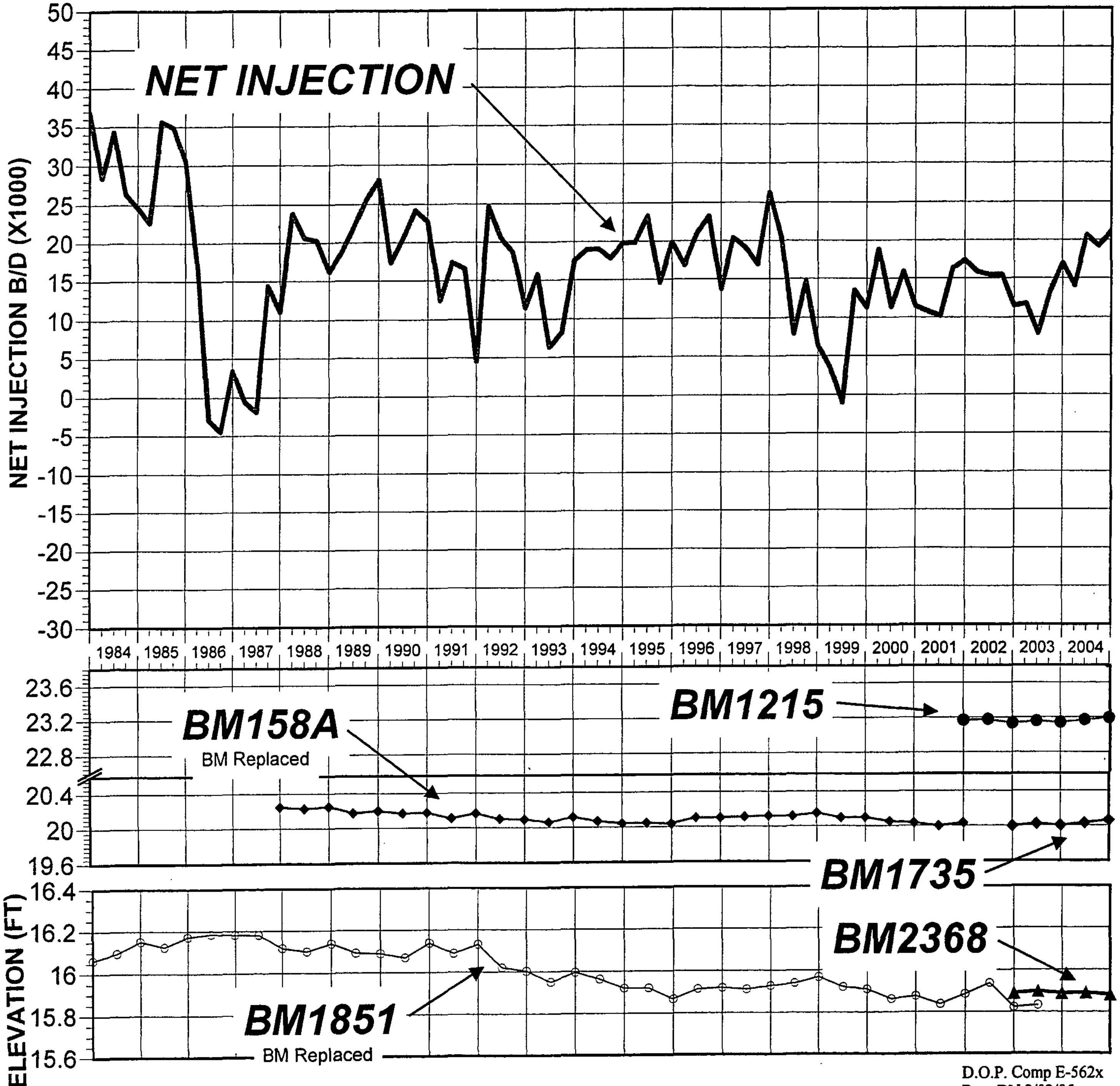


FIGURE 6

THUMS-TOPKO
FB VI



D.O.P. Comp E-562x
Rev. DN 2/02/05

Location Map

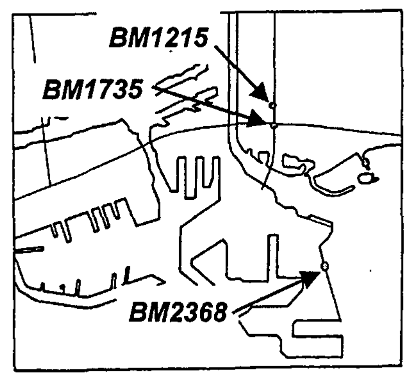
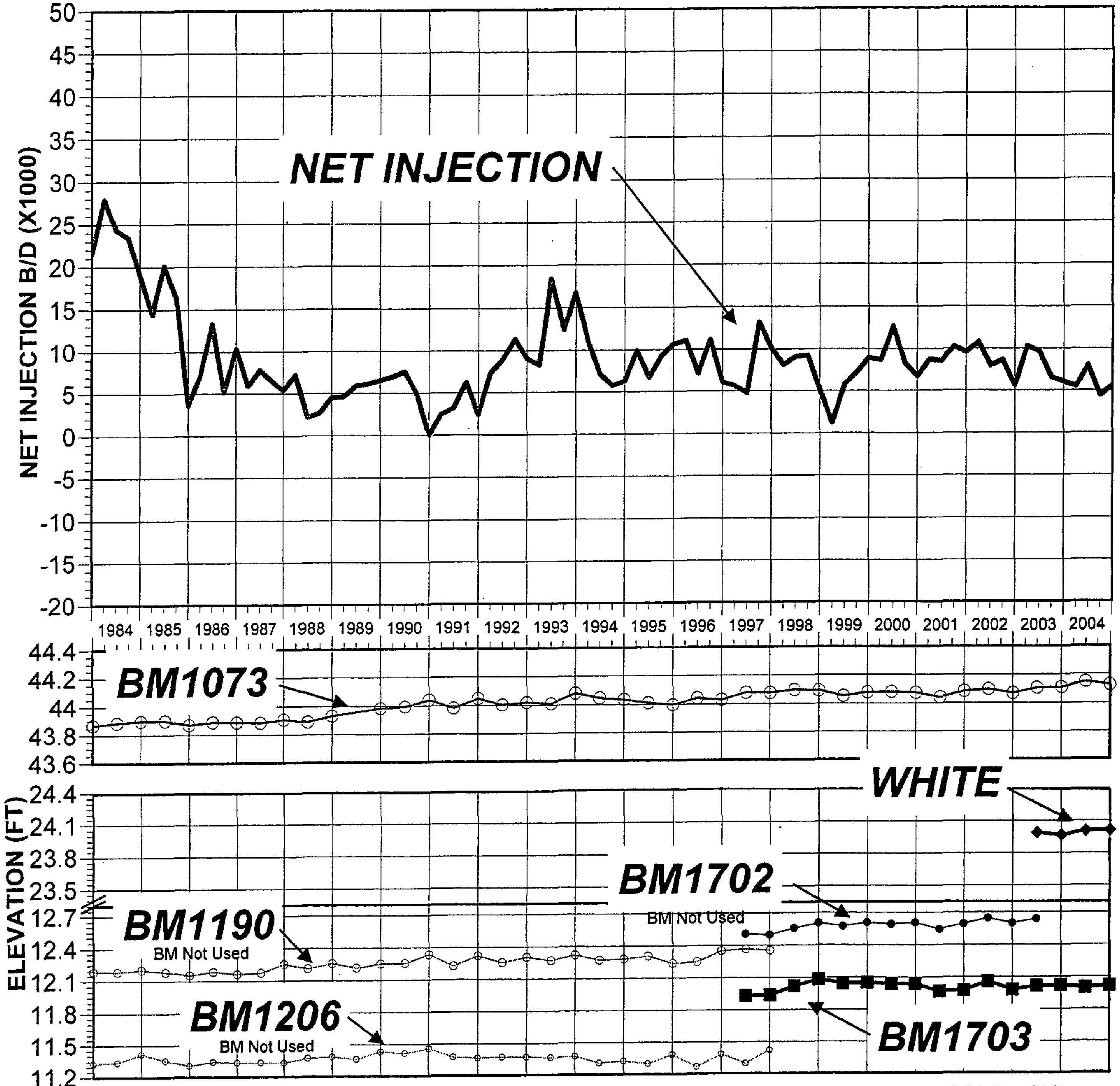


FIGURE 7

THUMS, FB VII



Location Map

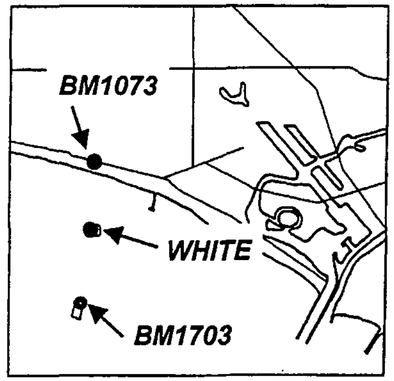
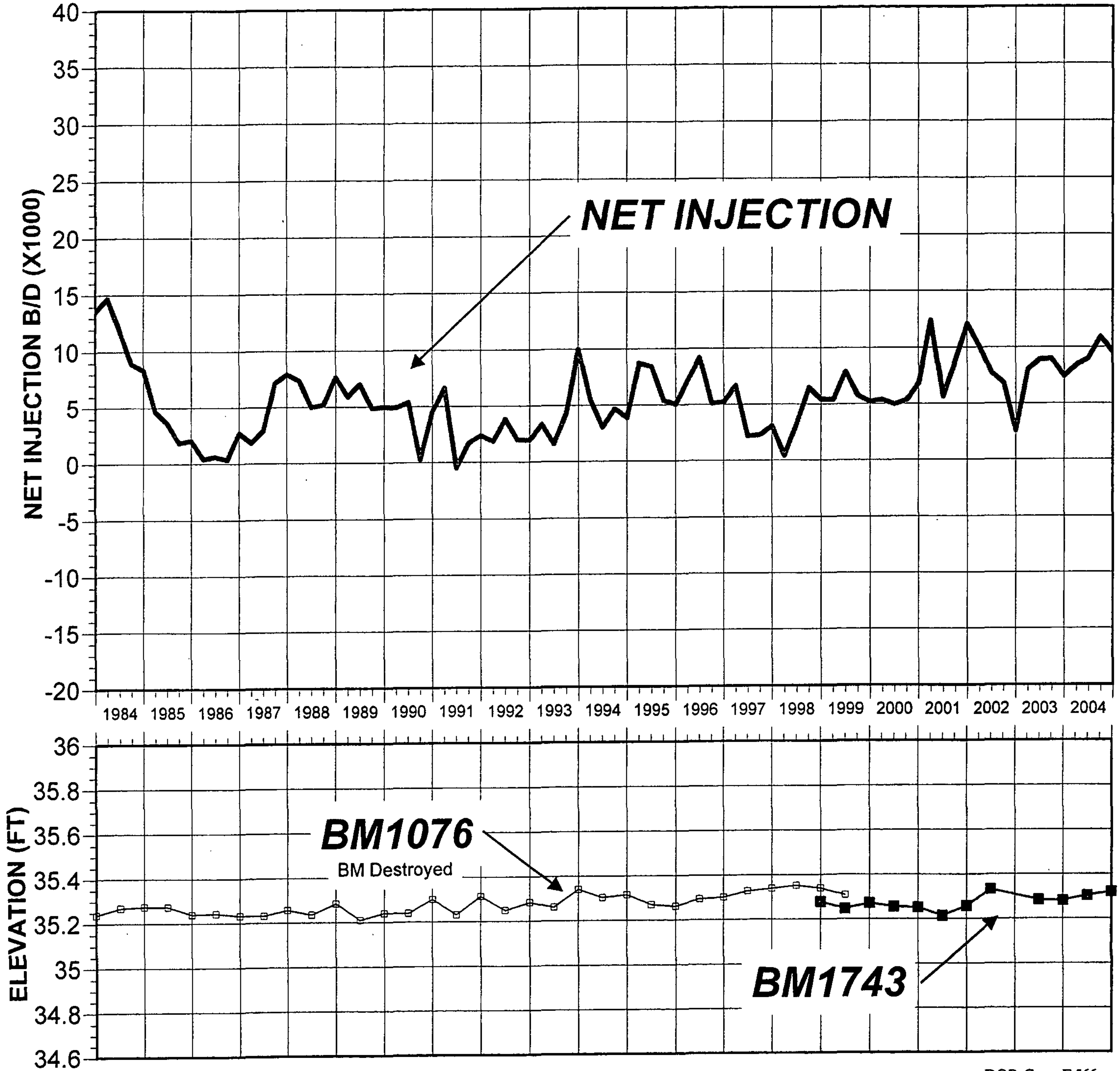


FIGURE 8

DOP. Comp E-563x
Rev: DN 2/02/05

THUMS FB VIIIA



Location Map

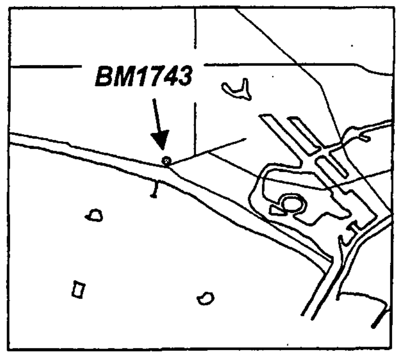
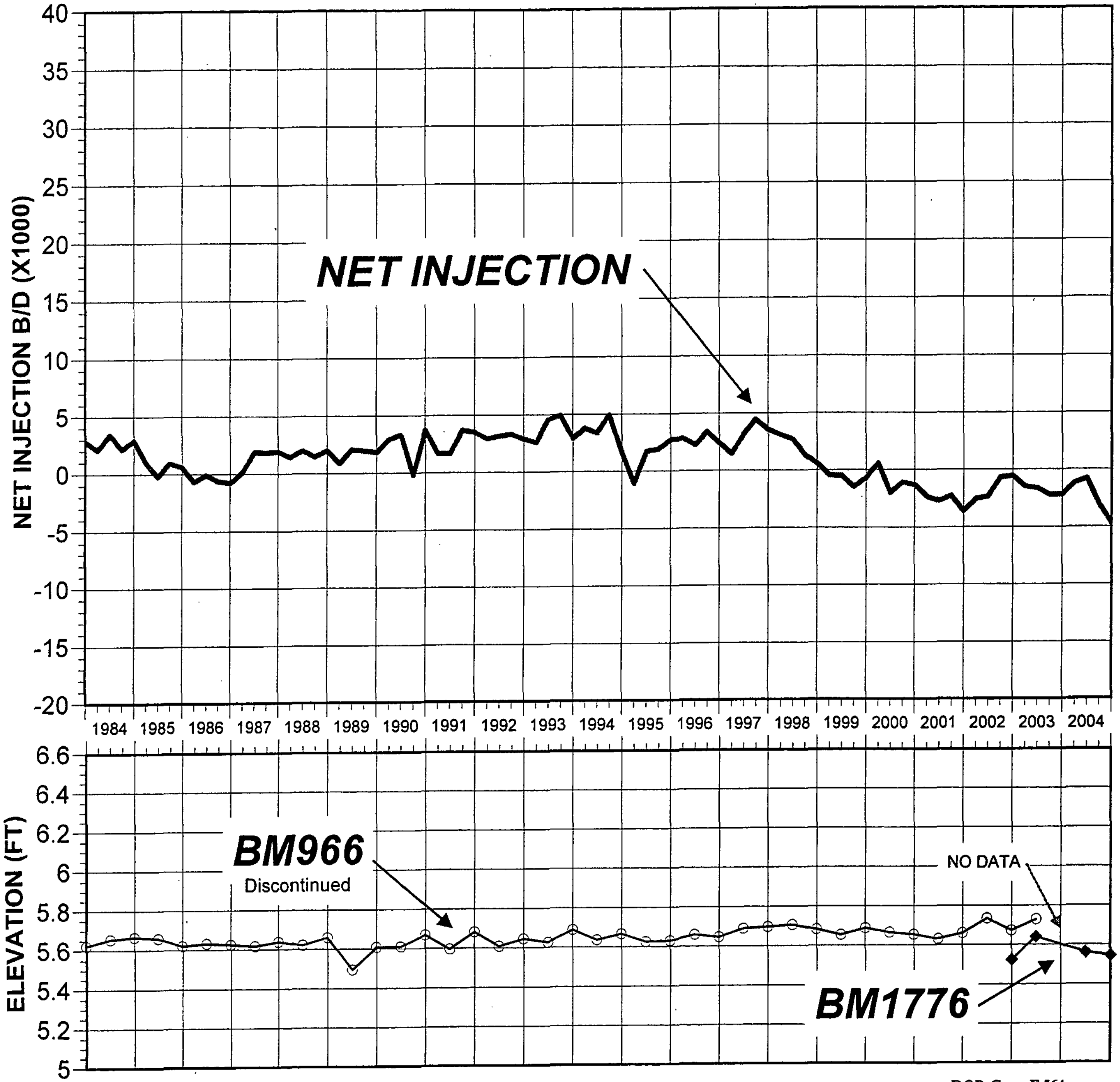


FIGURE 9

D.O.P. Comp E-566x
Rev: DN 2/02/05

THUMS FB VIIIB



D.O.P. Comp E-564x
Rev: DN 2/02/05

Location Map

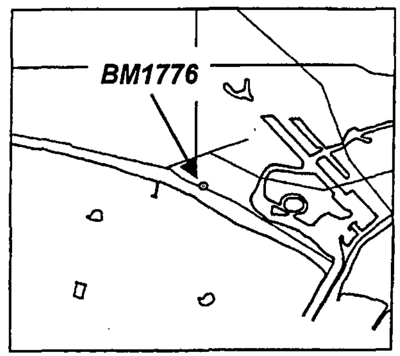


FIGURE 10

THUMS FB 90N

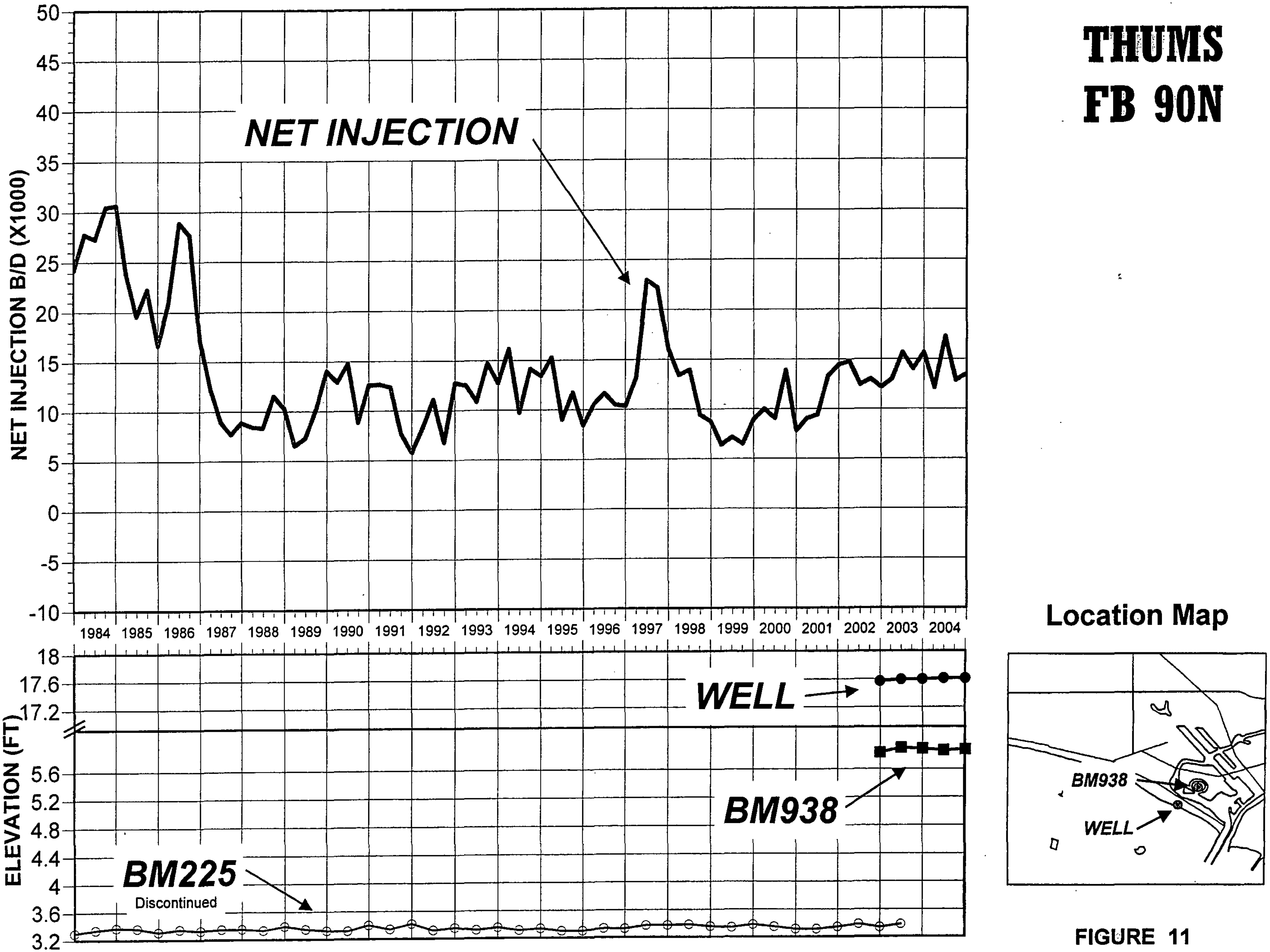
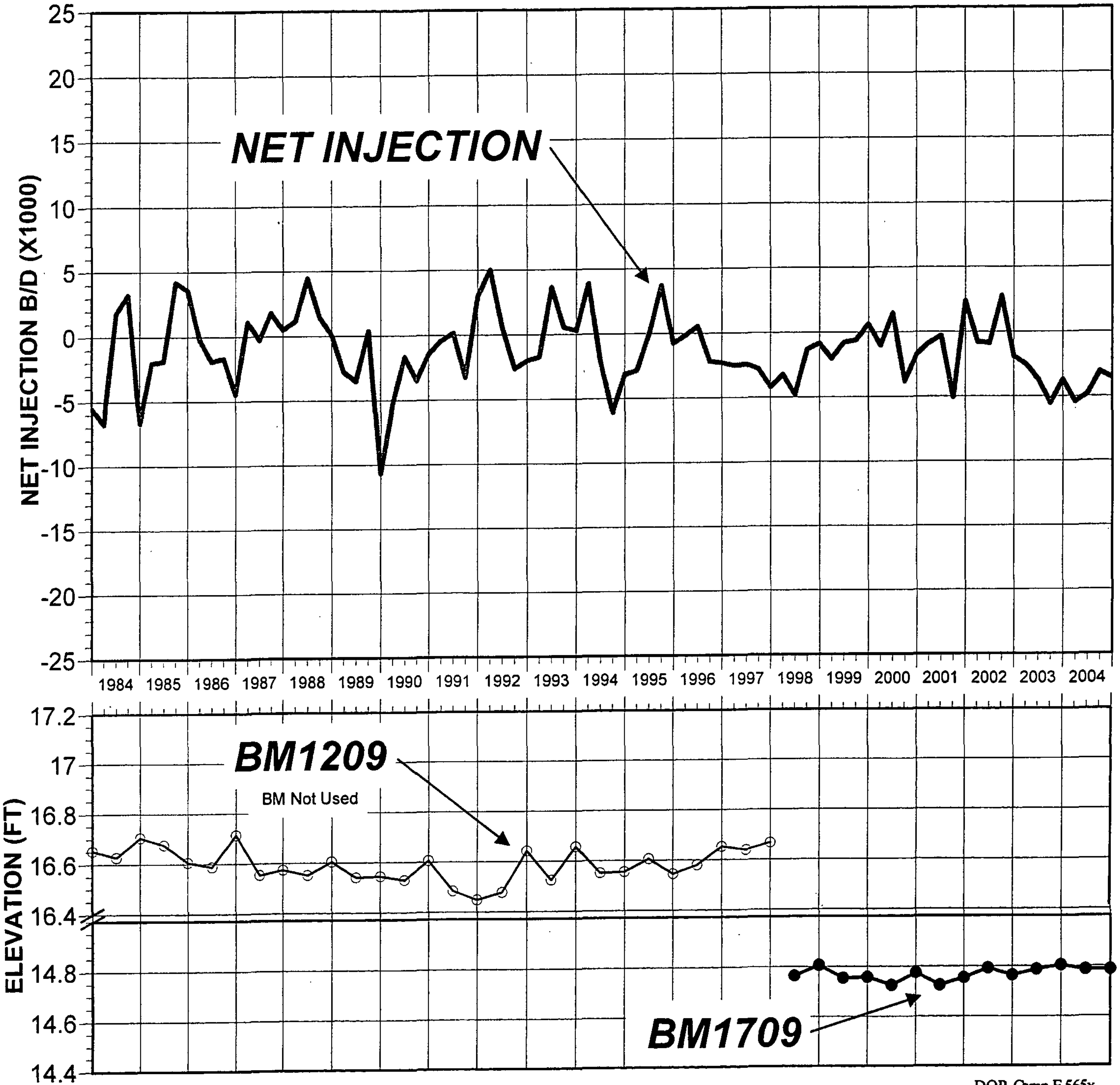


FIGURE 11

DOP. Comp E-552x
Rev: DN2/02/05

THUMS FB 90S



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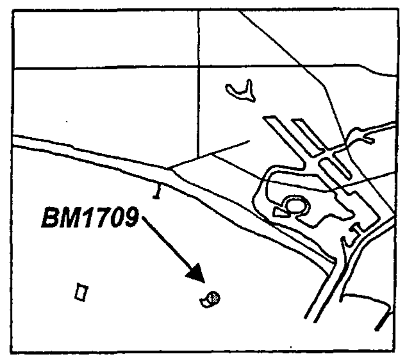

FIGURE 12

D.O.P. Comp E-565x
Rev: DN 2/02/05