C-17

ELEVATION CHANGES
IN THE
CITY OF LONG BEACH

MAY 2005 TO NOVEMBER 2005

PREPARED

FOR

LONG BEACH CITY COUNCIL

BY THE

LONG BEACH GAS AND OIL
DEPARTMENT

CONTENTS

ELEVATION SURVEY ANALYSIS

The City of Long Beach semi-annual elevation survey of the Civic Center, Central City, Harbor, Alamitos Bay, Naples and offshore areas was conducted during November 2005. Changes in elevation that have occurred since the last two surveys, November 2004 and May 2005, are discussed in this report. The results in this report reflect elevation changes both within and beyond the scope of oilfield operations. Some changes are due to natural geologic factors.

Elevation Change – May 2005 to November 2005 (Figure 1)

Elevations throughout the Civic Center, Central City, Alamitos Bay, and Naples areas were stable during the six-month period. A minor elevation increase of 0.040 feet (0.48 inches) occurred in the Civic Center area. A minor increase of 0.032 feet (0.38 inches) was measured at Naples. Elevations in the City of Long Beach beyond the boundaries of the Wilmington Oil Field were also stable for the period. Minor elevation changes in geologically active areas outside the Wilmington Oil Field indicate that this six-month period was a slightly "up" period.

The Harbor District remained stable except for two areas of minor elevation loss. A loss of 0.040 feet (0.48 inches) occurred along Ocean Boulevard at the Pier T overpass, in the middle of Fault Block III. A localized elevation loss of 0.030 feet (0.36 inches) was measured on the northern section of Pier D. These elevation changes were due to increased oil production and realignment of water injection in the Harbor District.

Elevations continued to decline in Fault Block II, over the curtailed Tar II steam flood area around Henry Ford Avenue on Pier A. A loss of up to 0.098 feet (1.18 inches) was measured at Henry Ford Ave on the north side of the Cerritos Channel. The steam flood, initiated by Union Pacific Resources Company in the late 1980's, was terminated by the Department of Oil Properties (DOP) 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 Long Beach Gas and Oil Department (LBGO) is studying realignment of the cold-water injection to accelerate heat withdrawal.

The Oil Islands in the offshore area were stable, except for a minor elevation loss of 0.036 feet (0.43 inches) at Island White. The change was due to a localized water injection shutdown on the Island.

<u>Elevation Change – November 2004 to November 2005</u> **(Figure 2)**

Elevations throughout the Civic Center, Central City, Alamitos Bay, and Naples areas remained stable or slightly increased during the 12-month period. A localized minor elevation increase of up to 0.059 feet (0.79 inches) occurred throughout the Civic Center area. Geologically active zones outside the oil-impacted areas indicate the one-year period to have been an "up" elevation period (see Appendix).

The Harbor District was stable during the 12-month period except in the western area of Piers D and T. On Pier D a loss of 0.063 feet (0.76 inches) was observed. A loss of 0.079 feet (0.95 inches) was measured at Ocean Blvd. on Pier T. These elevation changes were due to increased oil production and realignment of water injection in the Harbor District.

The areas overlying Fault Blocks II and III, on Piers A, S, and T, continued to lose elevation through the 12-month period. The one-year maximum elevation loss of 0.151 feet (1.81 inches) was centered at Henry Ford Ave on the north side of the Cerritos Channel. This loss can be attributed to the continued shale compaction resulting from reservoir overheating by past steam flood operations in Fault Block II surrounding Henry Ford Ave. Fault Block III losses were due to increased oil production with realignment of water injection coupled with loss of rebound from past over injection.

All four of the Oil Islands were stable through the period.

Use of Global Positioning System (GPS)

This is the eighth 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.

The two new permanent GPS Stations, PUMP and VTIS, have improved the accuracy of the system. These stations complete the LBGO 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 minor 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 the 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. The coastal strip rebounded slightly due to water injection from the offshore Oil Islands 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 210 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, 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.

<u>Elevation Change Map Construction</u> (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 an inch during that period. The small hachures along contour lines point towards a loss in elevation.

<u>Bench Mark and Net Injection Graphs, Harbor District</u> (Figures 3 - 8)

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 9 – 13)

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.

The results presented are both within and outside the influences of the Long Beach Gas and Oil Department.

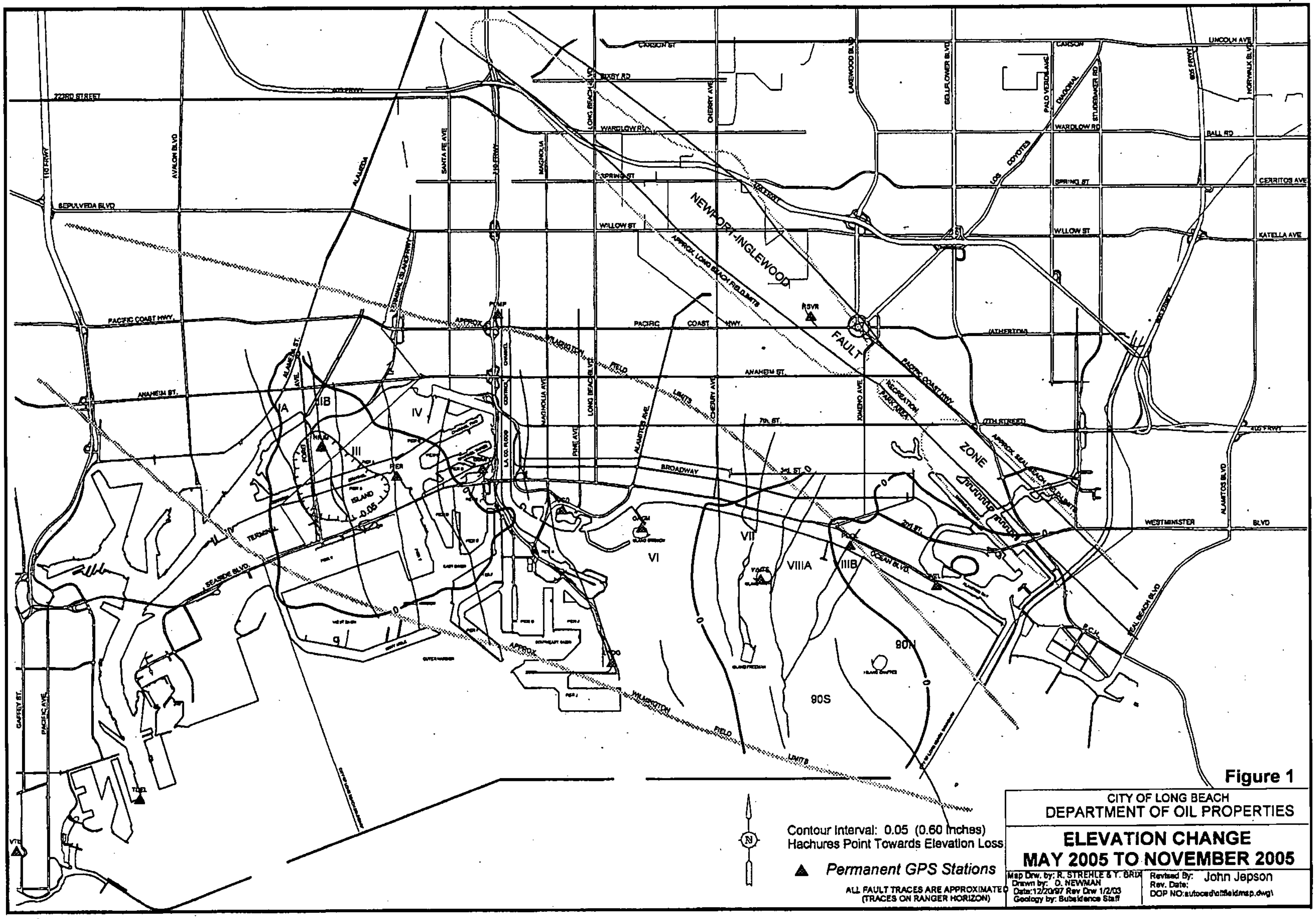


Figure 1
CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES
ELEVATION CHANGE
MAY 2005 TO NOVEMBER 2005
Contour Interval: 0.05 (0.60 inches)
Hachures Point Towards Elevation Loss
Permanent GPS Stations
ALL FAULT TRACES ARE APPROXIMATED
(TRACES ON RANGER HORIZON)
Revised By: John Jepson
NEWPORT-INGLEWOOD
FAULT
ZONE
PACIFIC COAST HWY.
ANAHEIM ST.
7th ST.
BROADWAY
WESTMINSTER
SEASIDE BLVD.
OCEAN BLVD.
WILMINGTON FIELD LIMITS
IA
IIB
III
IV
VI
VII
VIIIA
IIIB
90N
90S

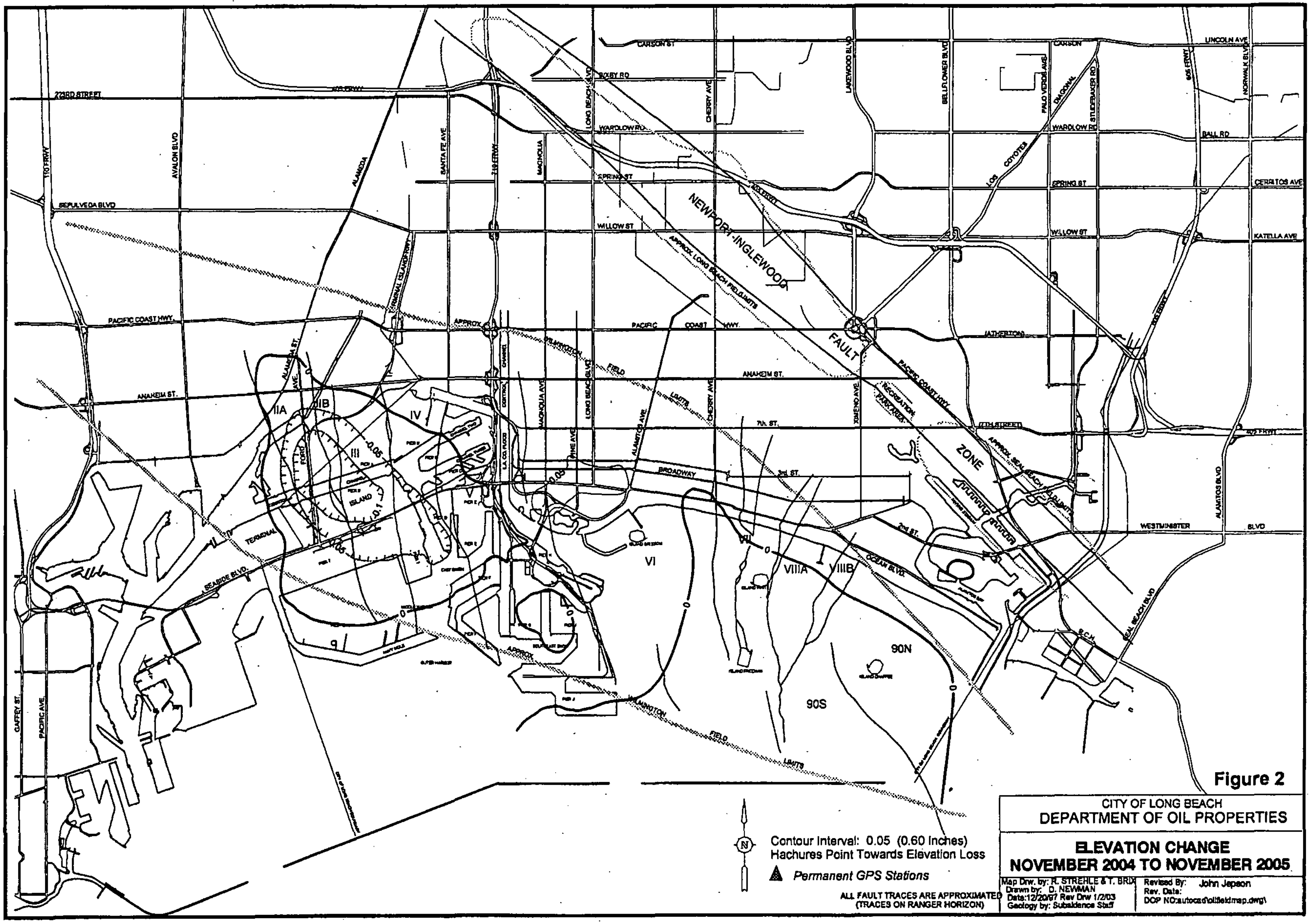


Figure 2

CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES

**ELEVATION CHANGE
NOVEMBER 2004 TO NOVEMBER 2005**

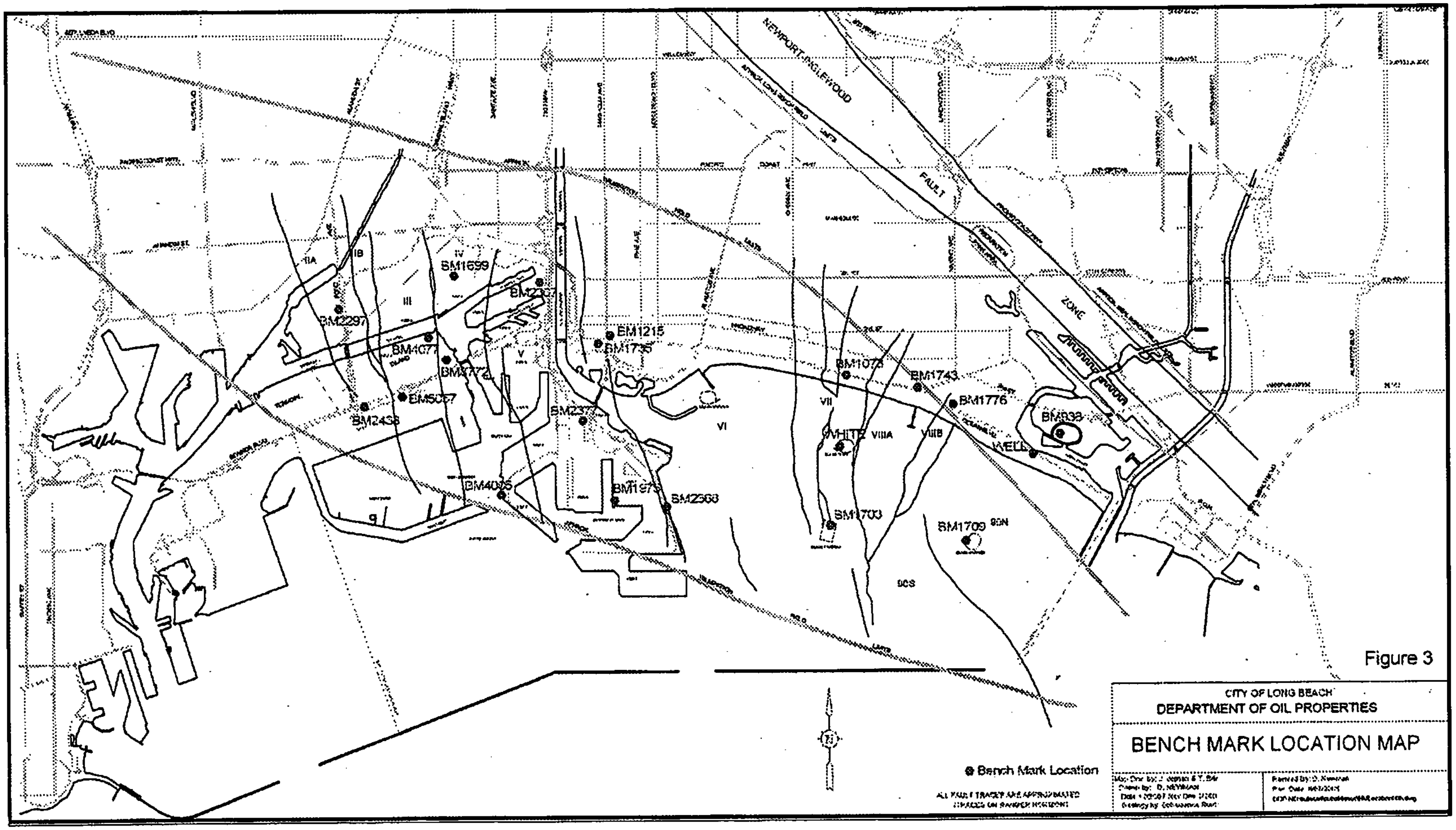
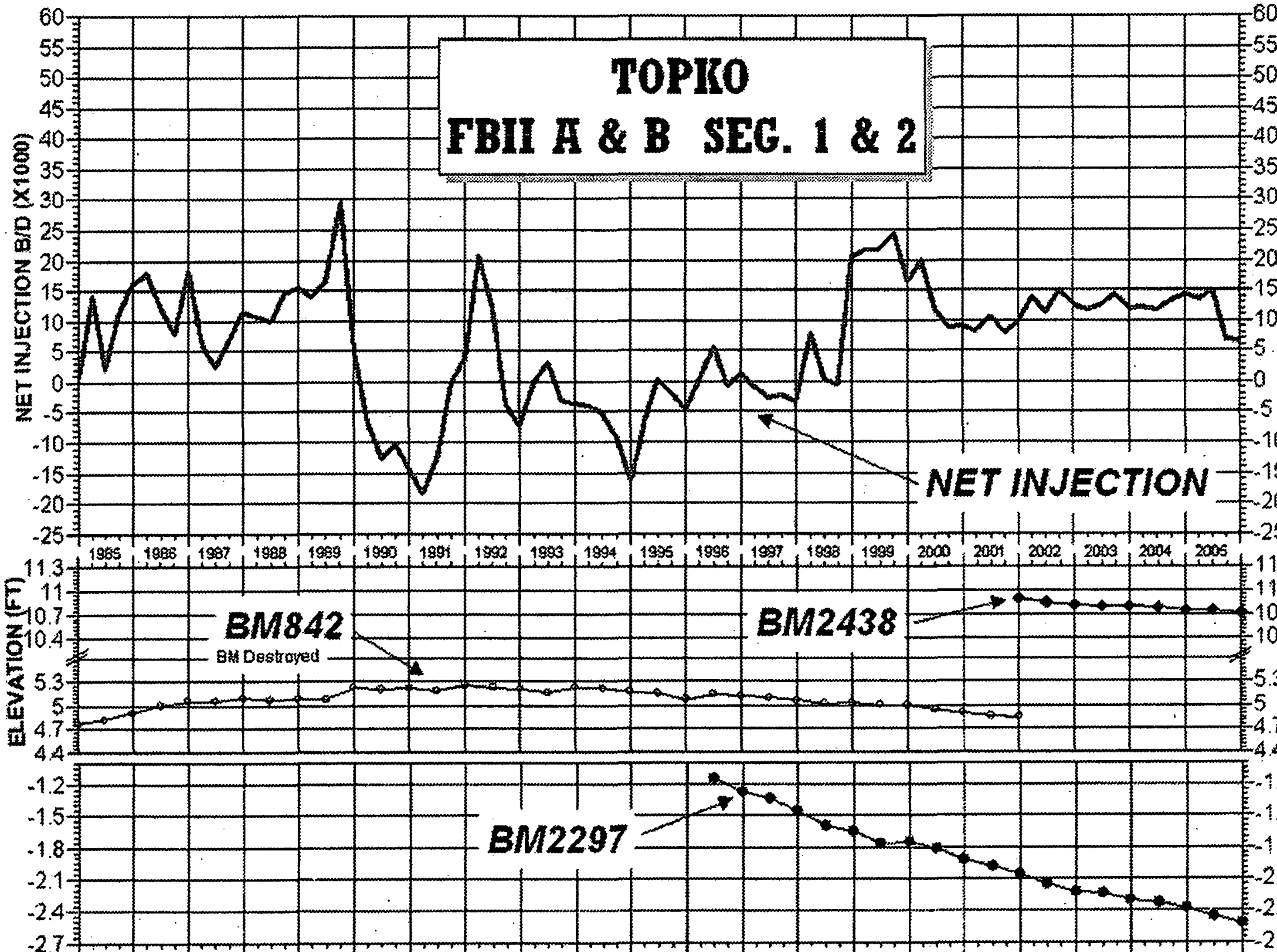


Figure 3

CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES

BENCH MARK LOCATION MAP



D.O.P. Comp E-536-05 Rev. DN 1/21/06

Figure 4

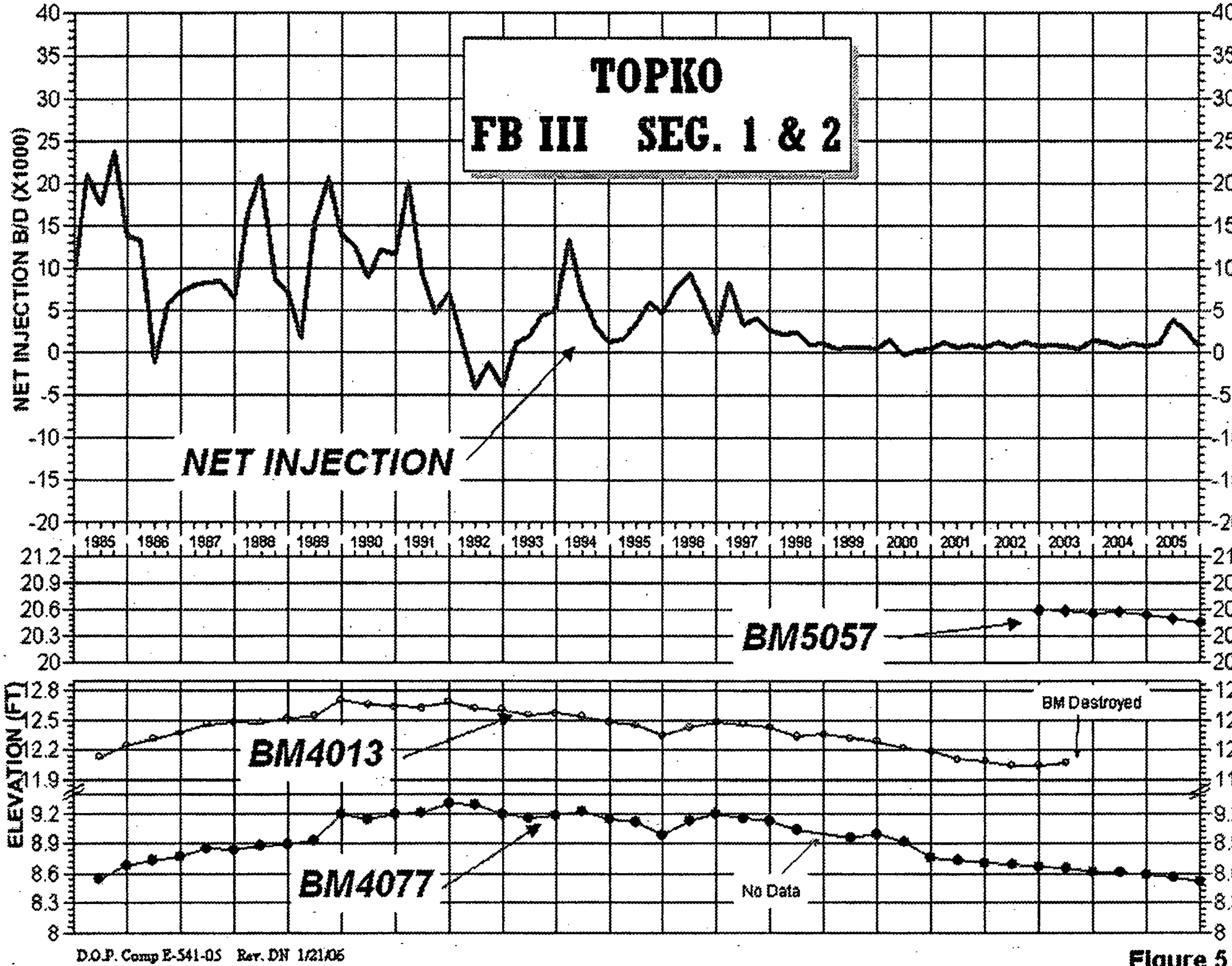
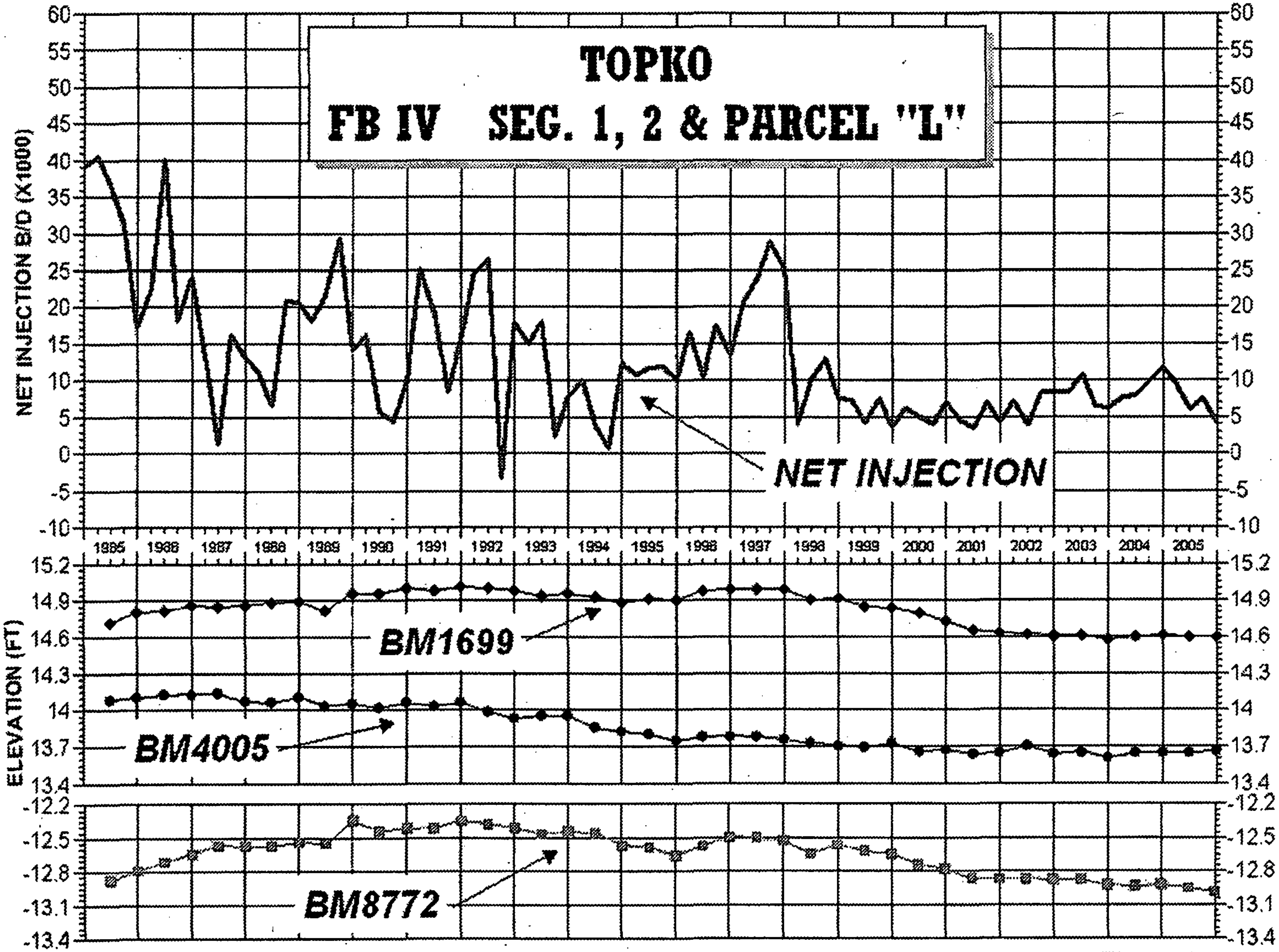

TOPKO
FB III SEG. 1 & 2
NET INJECTION B/D (X1000)
NET INJECTION
1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005
BM5057
ELEVATION (FT)
BM4013
BM Destroyed
BM4077
No Data
D.O.P. Comp E-541-05 Rev. DN 1/21/06

Figure 5



D.O.P. Comp E-535-05 Rev: DN 1/21/06

Figure 6

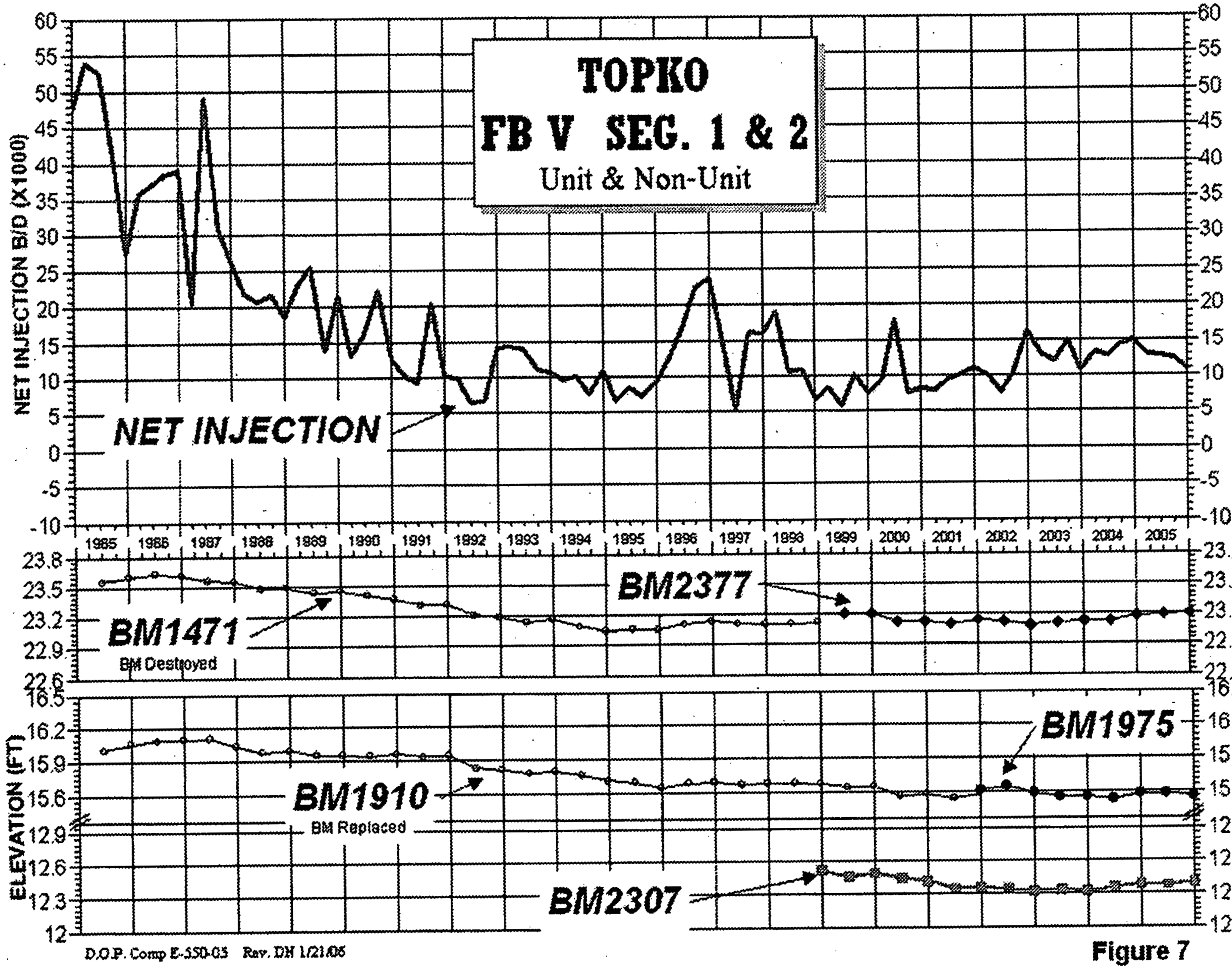
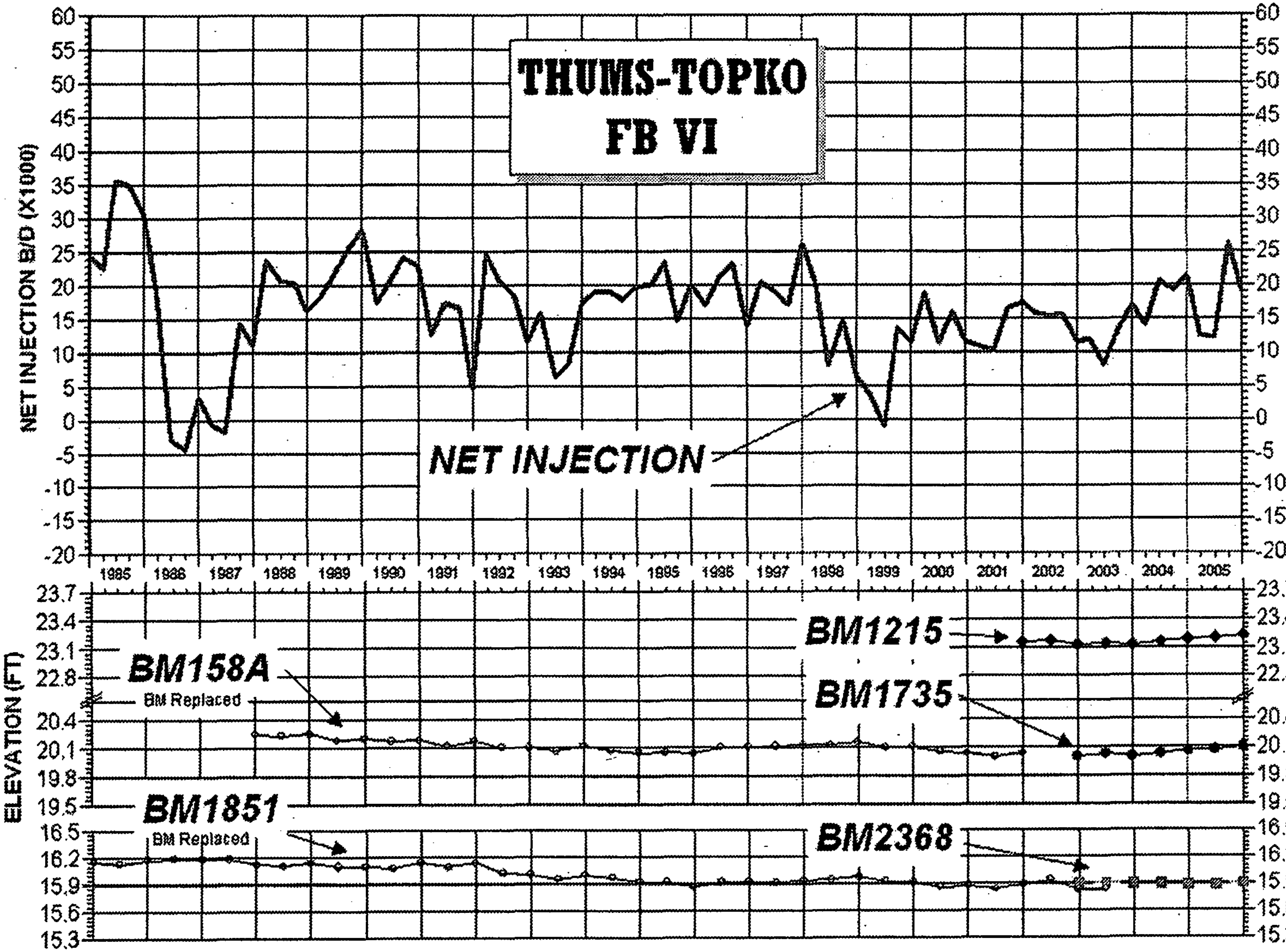
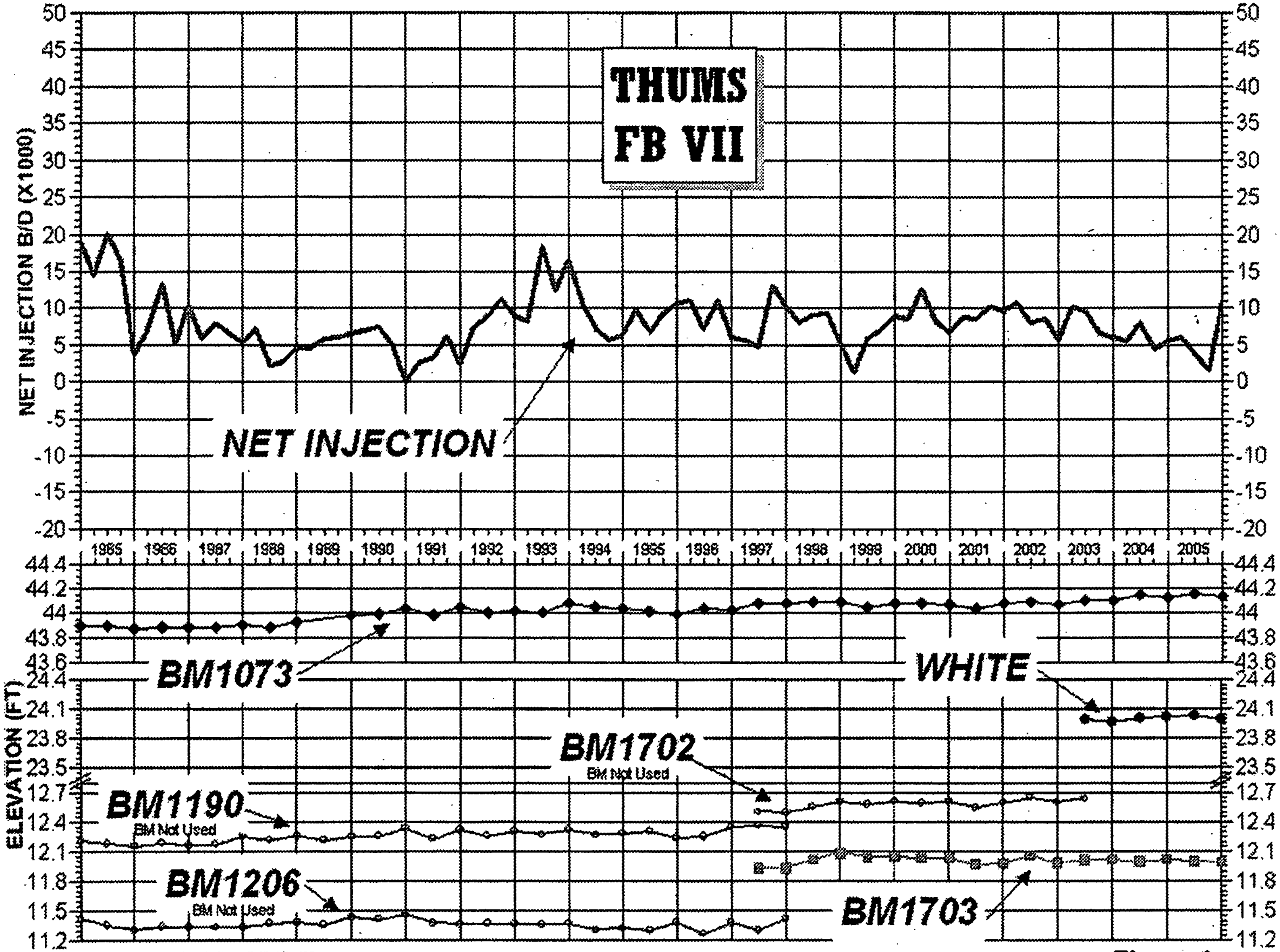

TOPKO
FB V SEG. 1 & 2
Unit & Non-Unit
NET INJECTION B/D (X1000)
NET INJECTION
BM2377
BM1471
BM Destroyed
BM1975
BM1910
BM Replaced
BM2307
ELEVATION (FT)
D.O.P. Comp E-550-05 Rev. DH 1/21/06

Figure 7



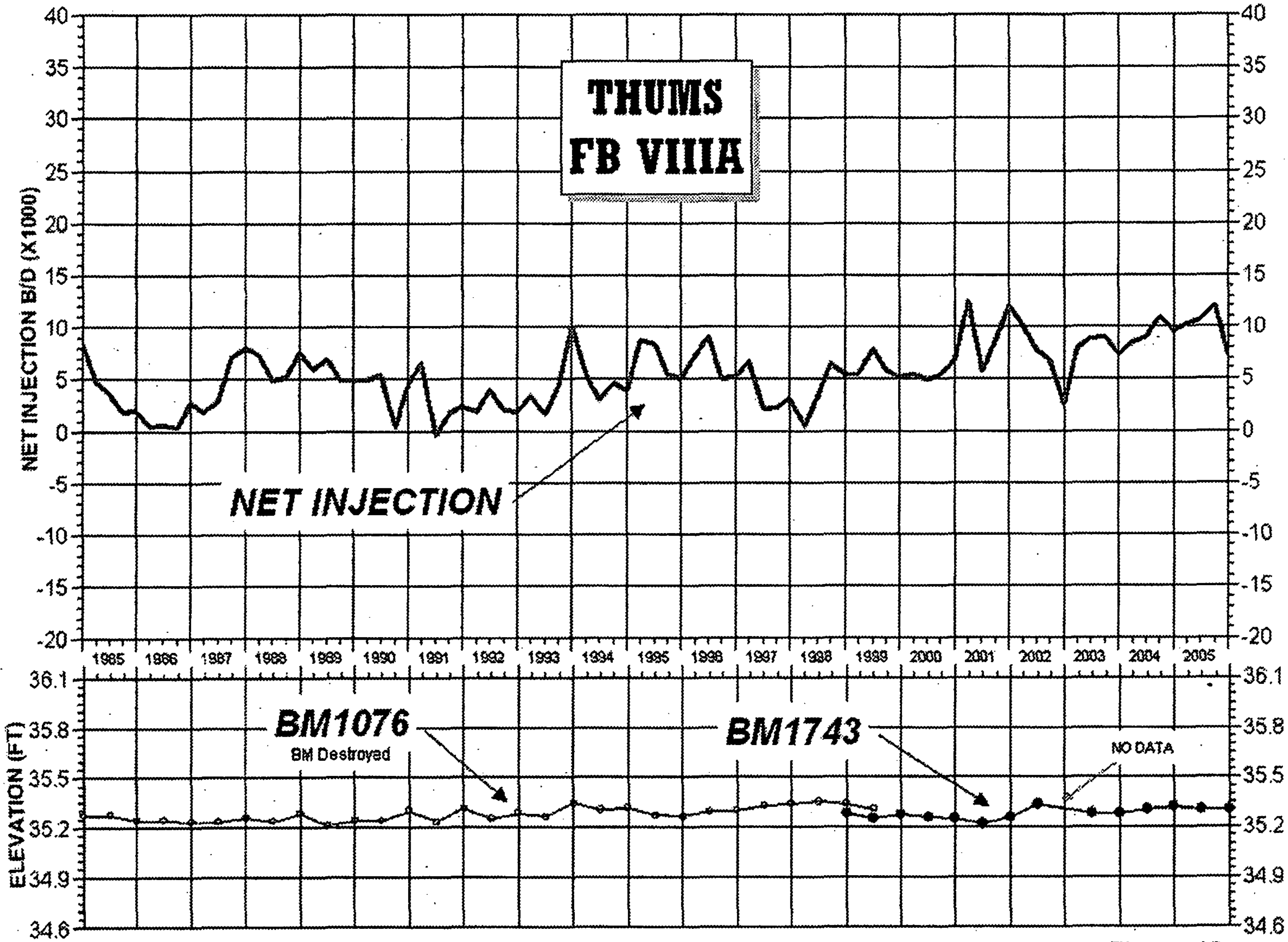
D.O.P. Comp E-562-05 Rev. DN 1/21/06

Figure 8



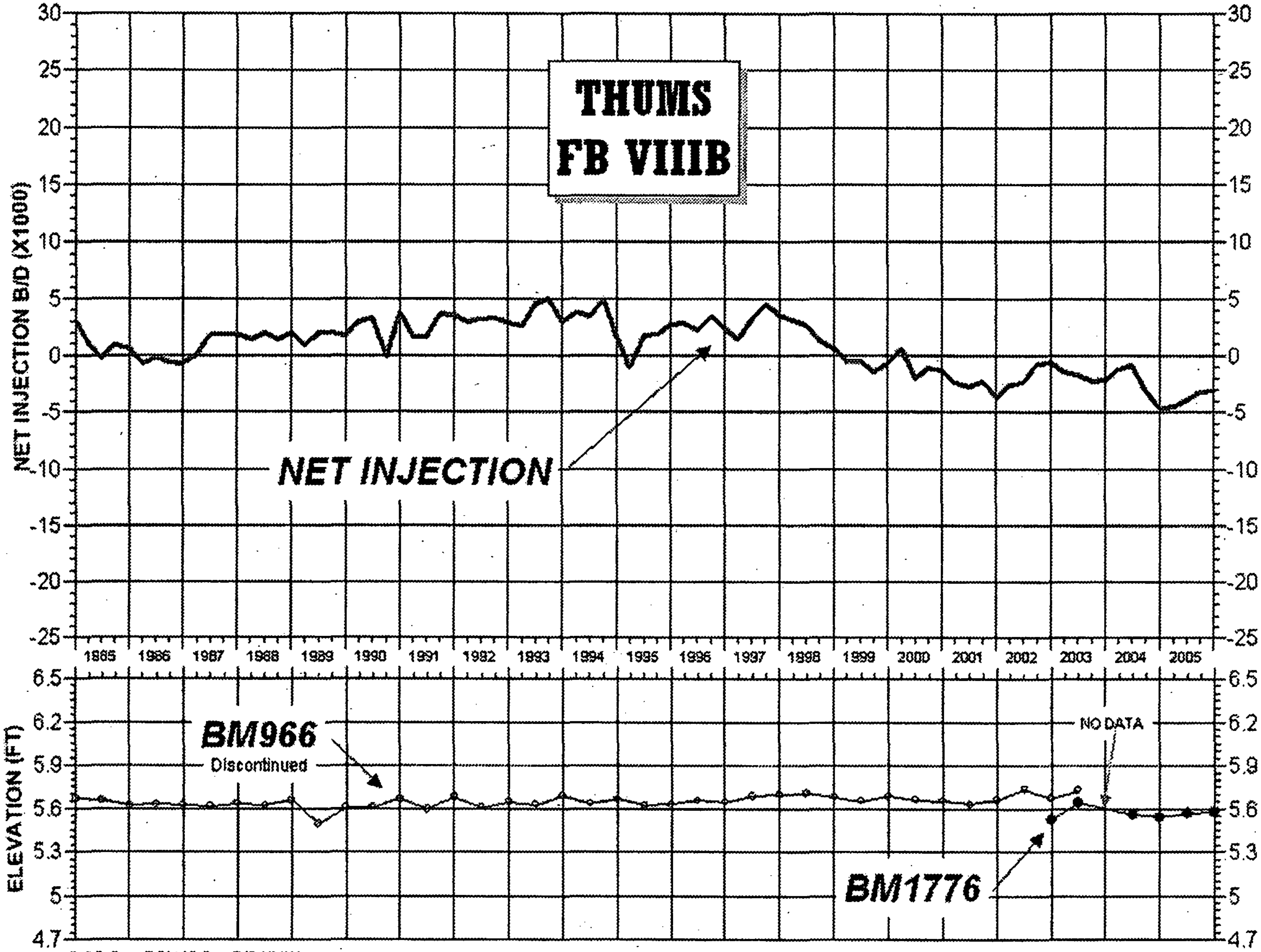
D.O.P. Comp E-563-05 Rev: DN 1/21/06

Figure 9



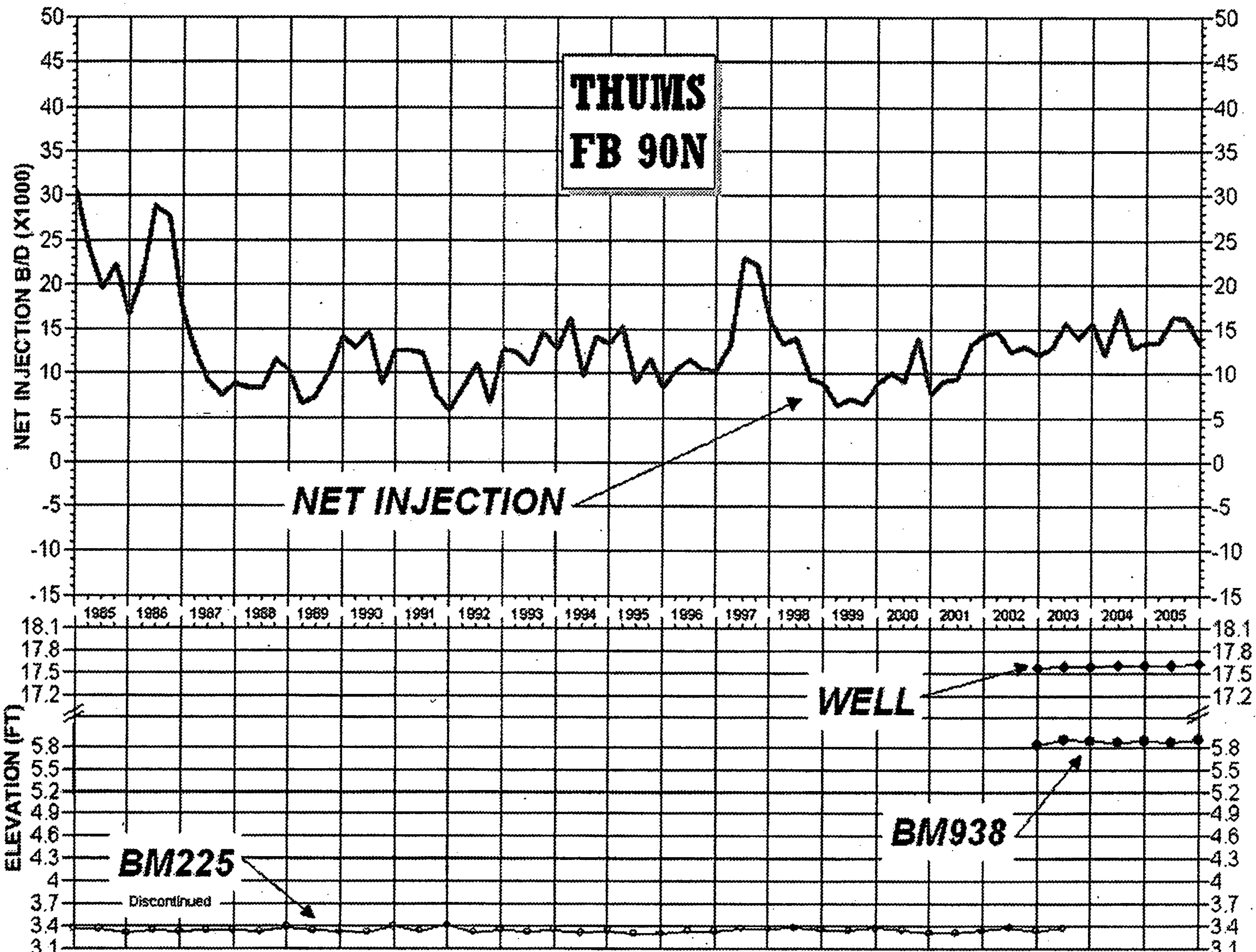
D.O.P. Comp E-566-05 Rev: DN 1/21/06

Figure 10



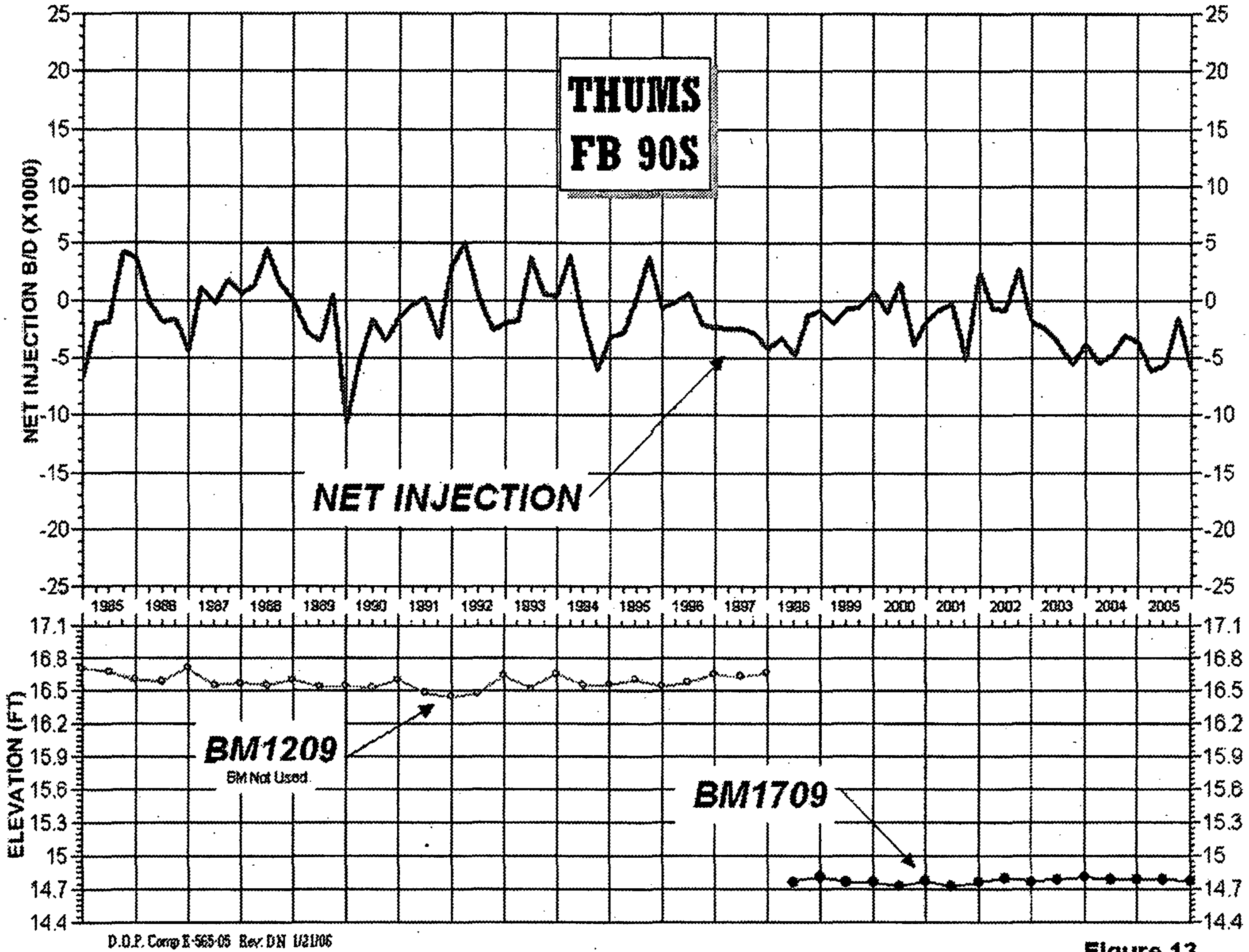
D.O.P. Comp E-564-05 Rev. DN 1/21/06

Figure 11



D.O.P. Comp E-552-06 Rev: DN 1/21/06

Figure 12



THUMS
FB 90S
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
BM1209
BM Not Used.
BM1709
D.O.P. Comp E-565-06 Rev. DN 1/21/06

Figure 13

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