C-25

ELEVATION CHANGES IN THE CITY OF LONG BEACH

NOVEMBER 2005 TO MAY 2006

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 May 2006. Changes in elevation that have occurred since the last two surveys, May 2005 and November 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 – November 2005 to May 2006 (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 0.027 feet (0.32 inches) occurred in the Civic Center area. The elevations of Alamitos Bay and Naples were unchanged during the period. 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, semi-regionally.

The Harbor District remained stable except for two areas. An elevation gain of up to 0.075 feet (0.90 inches) occurred throughout the eastern Harbor District, overlying Fault Blocks IV and V. A loss of 0.076 feet (0.91 inches) occurred in the middle of Pier S, overlying Fault Block III. 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 steamflood area around Henry Ford Avenue on Pier A and S. A loss of up to 0.076 feet (0.91 inches) was measured on Pier S, south of the Cerritos Channel. The steamflood, 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

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between the reservoirs. The DOP implemented increased water injection and production rates to hasten heat withdrawal and maintain reservoir pressure. Long Beach Gas and Oil (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 gain of 0.033 feet (0.40 inches) at Island White.

Elevation Change – November 2005 to November 2006 (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 0.088 feet (1.06 inches) occurred in the southern portion of the Civic Center area. During the previous 12 months the elevation of the Naples area increased by 0.036 feet (0.43 inches). 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, with minor elevation changes on several areas. The area overlying Fault Blocks IV and V, in the eastern portion of the Harbor District, increased in elevation. On Piers D and E elevations increased by 0.050 feet (0.60 inches). Elevation on Pier H increased by 0.076 feet (0.91 inches). These elevation changes were due to increased water injection.

The areas overlying Fault Blocks II and III, on Piers A, S, and T, continued to lose elevation through the 12-month period. Overlying Fault Block II, the one-year elevation loss of 0.148 feet (1.78 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 surrounding Henry Ford Ave. The one-year elevation loss overlying Fault Block III was 0.164 feet (1.97 inches) and centered on Pier S, south of the Cerritos Channel. 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 with the exception of a minor elevation loss of 0.020 feet (0.24 inches) on Island Chaffee.

Use of Global Positioning System (GPS)

This is the ninth 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 and PUMP 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 steamflood 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 Steamflood 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 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, 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 an 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 - 8)

The benchmarks 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 and sometimes years 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 waterflooding operations.

Bench Mark and Net Injection Graphs, Ocean Boulevard and the Offshore Drilling Islands (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.

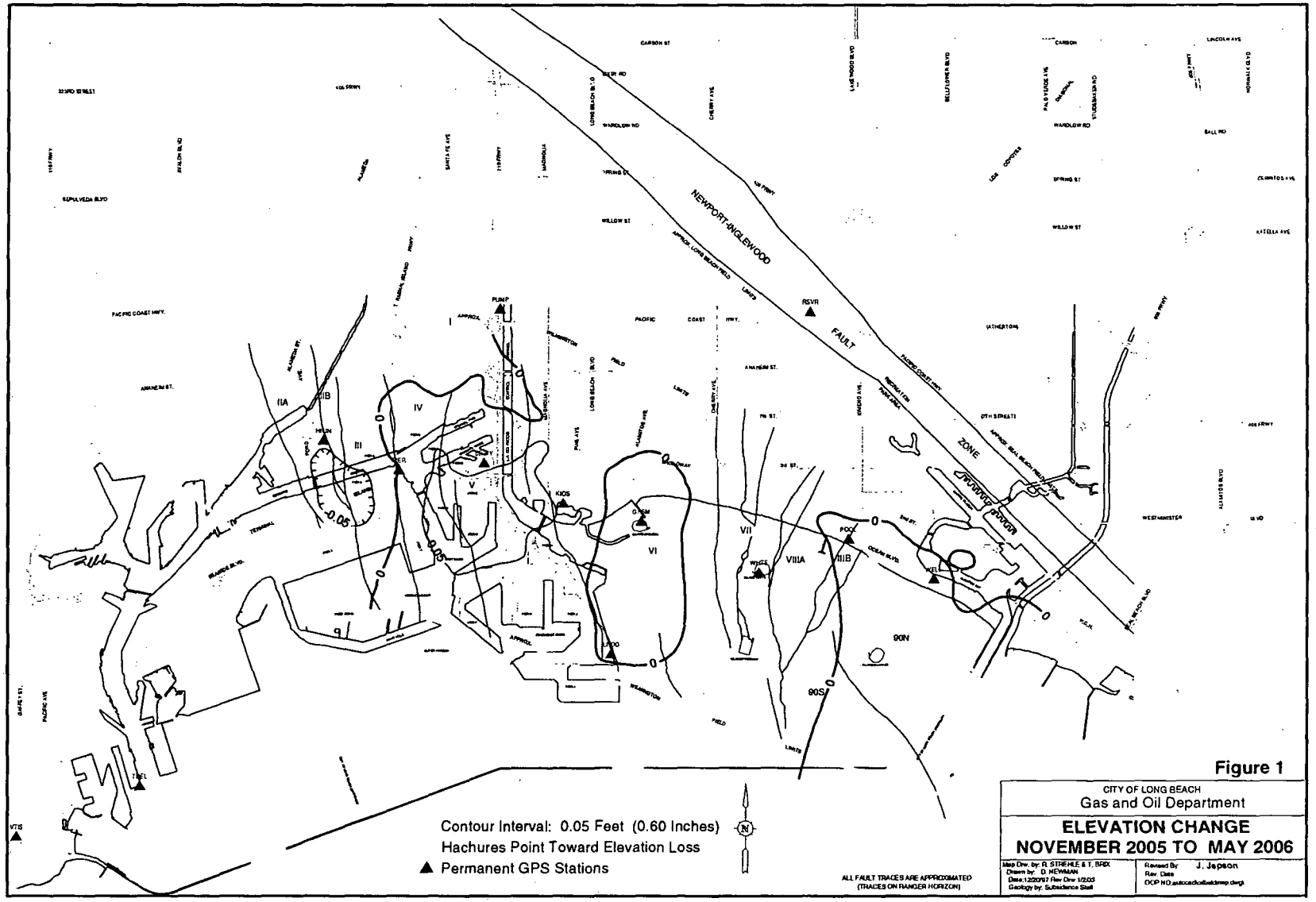


Figure 1

CITY OF LONG BEACH
Gas and Oil Department

ELEVATION CHANGE
NOVEMBER 2005 TO MAY 2006

Map Drw. by: R. STREHLE & T. BRIX
Drawn by: D. HEWMAN
Date:12/20/07 Rev Drw 1/2/08
Geology by: Subsidence Staff

Revised By: J. Jepson
Rev. Date
DCP NO.autocad\subsmap.dwg

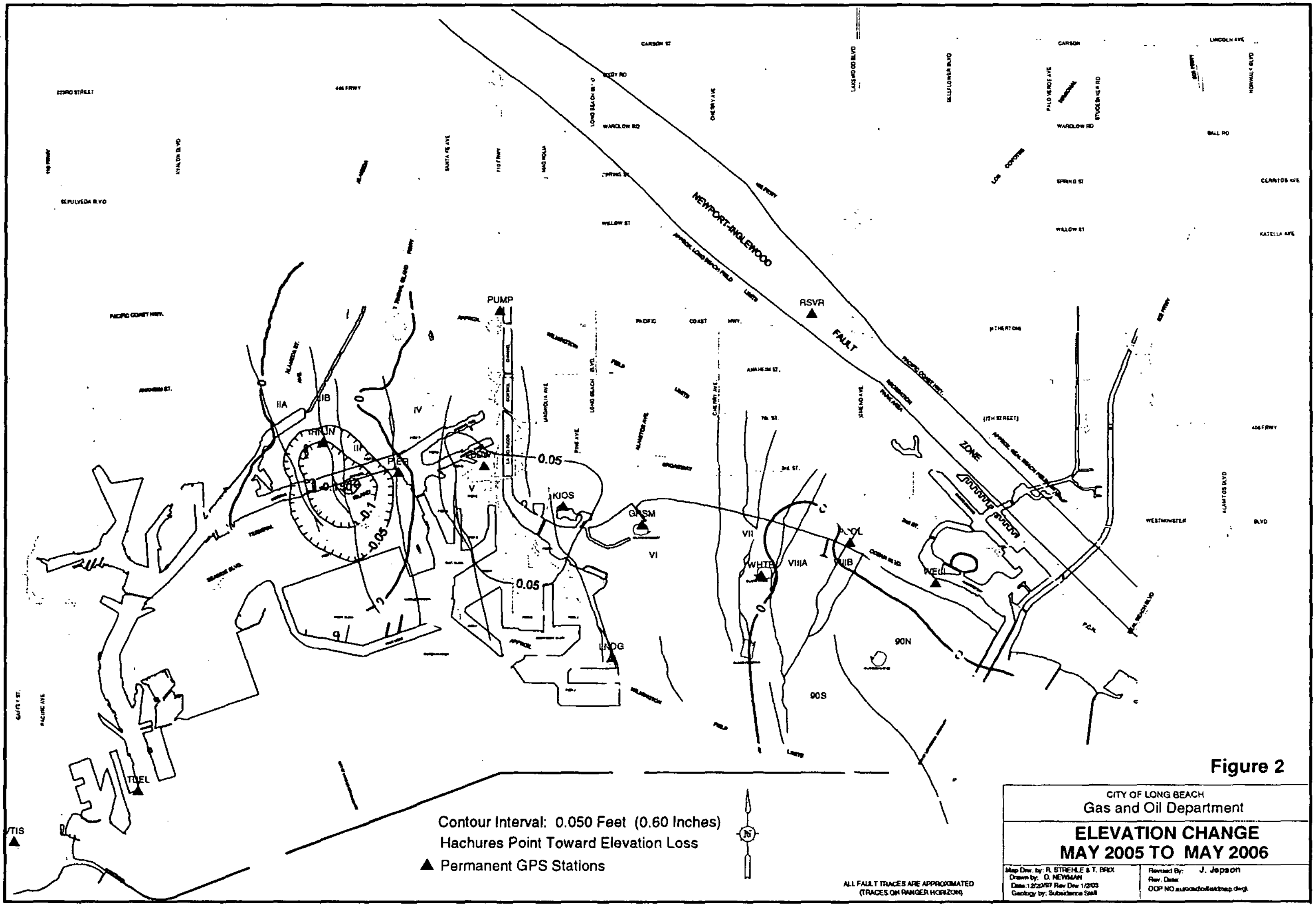


Figure 2

CITY OF LONG BEACH
Gas and Oil Department

ELEVATION CHANGE
MAY 2005 TO MAY 2006

Revised By: J. Jepson

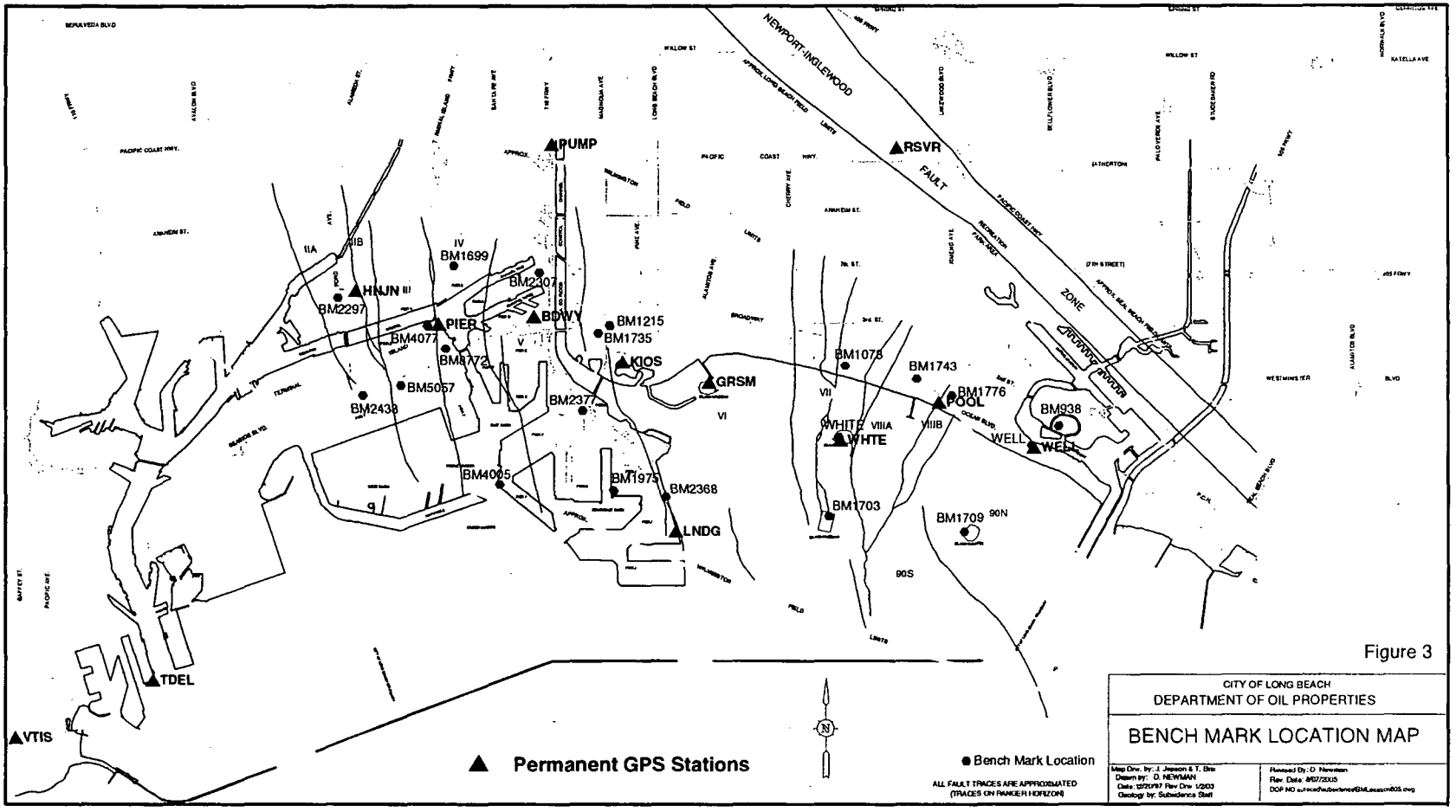


Figure 3

CITY OF LONG BEACH
DEPARTMENT OF OIL PROPERTIES

BENCH MARK LOCATION MAP

Map Drw. by: J. Jepson & T. Dix
Drawn by: D. NEWMAN
Date: 12/20/97 Rev Drw 1/2003
Geology by: Subsidence Staff

Revised By: D. Newman
Rev. Date: 4/07/2005
DOP NO subsidence\BMLocation805.dwg

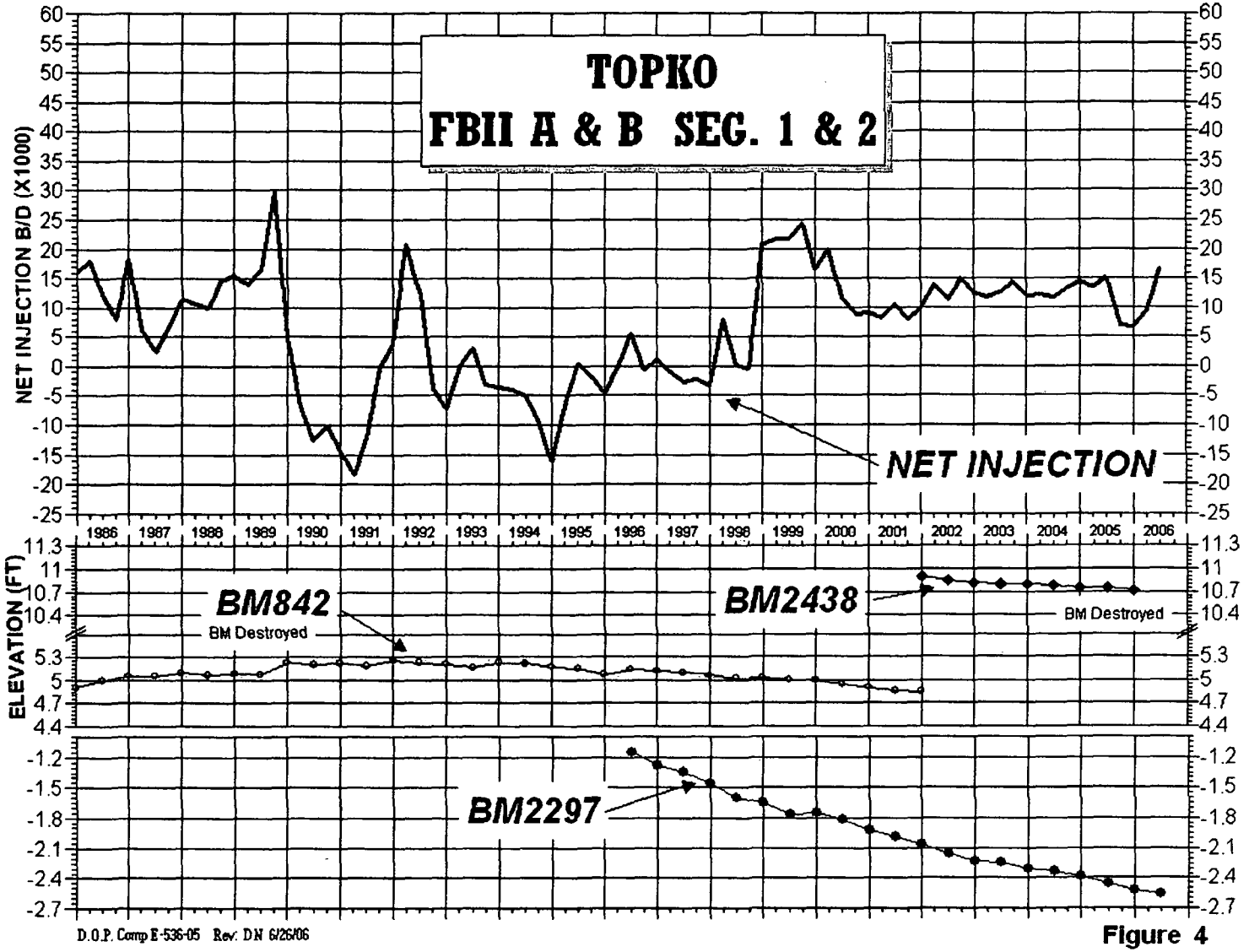
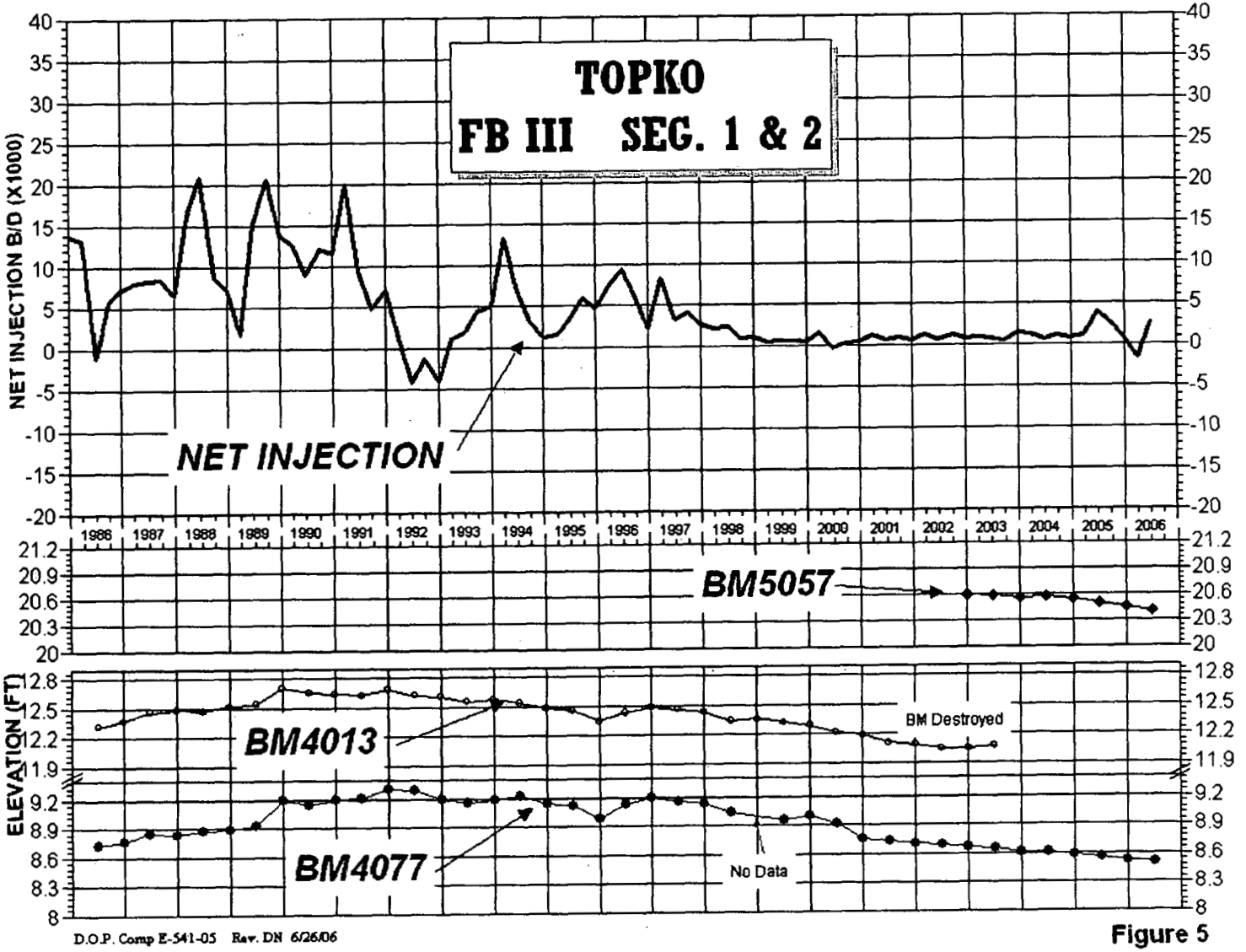

TOPKO
FBII A & B SEG. 1 & 2
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
BM842
BM Destroyed
BM2438
BM Destroyed
BM2297
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
D.O.P. Comp E-536-05 Rev: DN 6/26/06

Figure 4



D.O.P. Comp E-541-05 Rev. DN 6/26/06

Figure 5

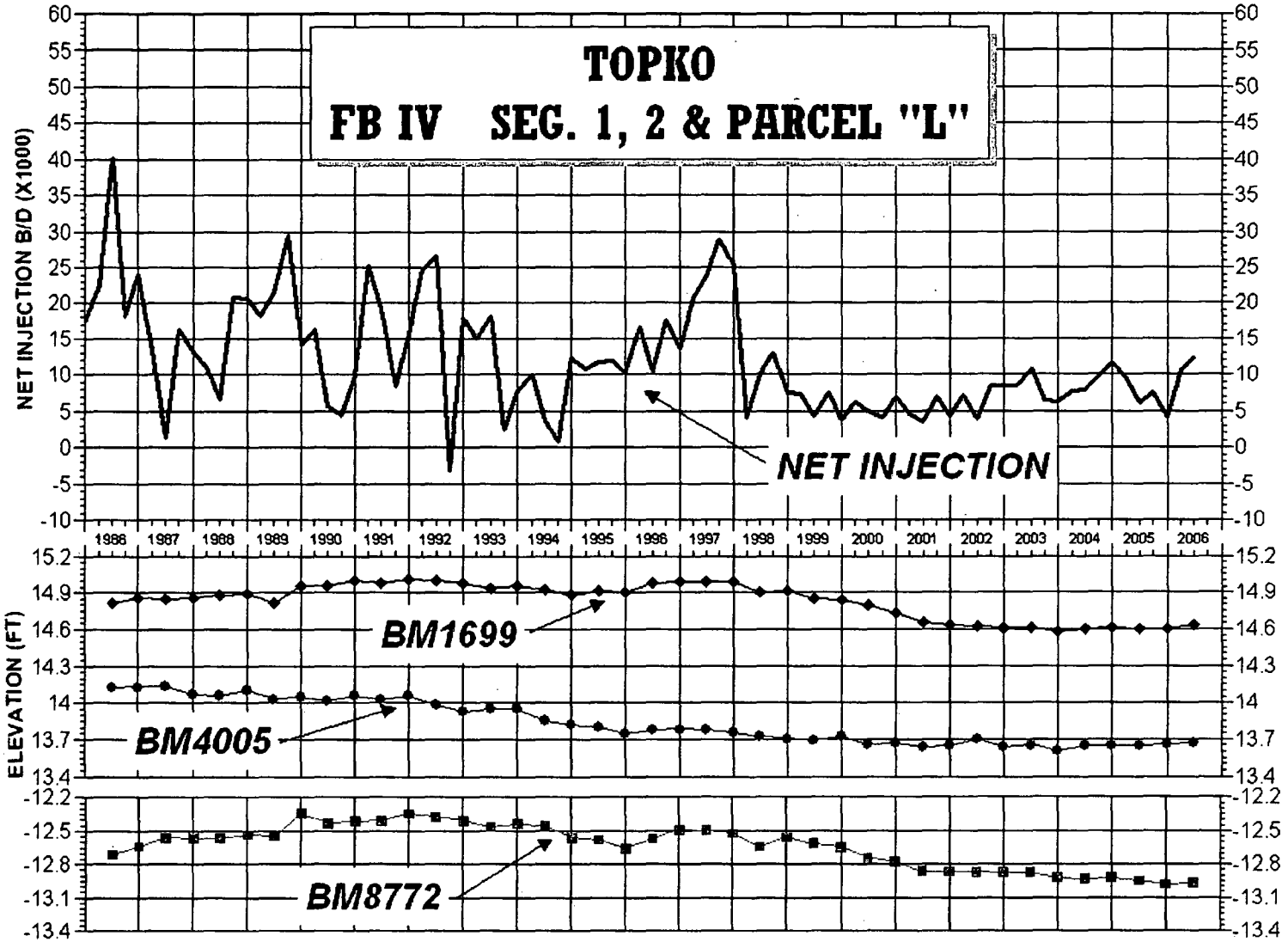

TOPKO
FB IV SEG. 1, 2 & PARCEL "L"
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
BM1699
BM4005
BM8772
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
D.O.P. Comp E-535-05 Rev: DN 6/26/06

Figure 6

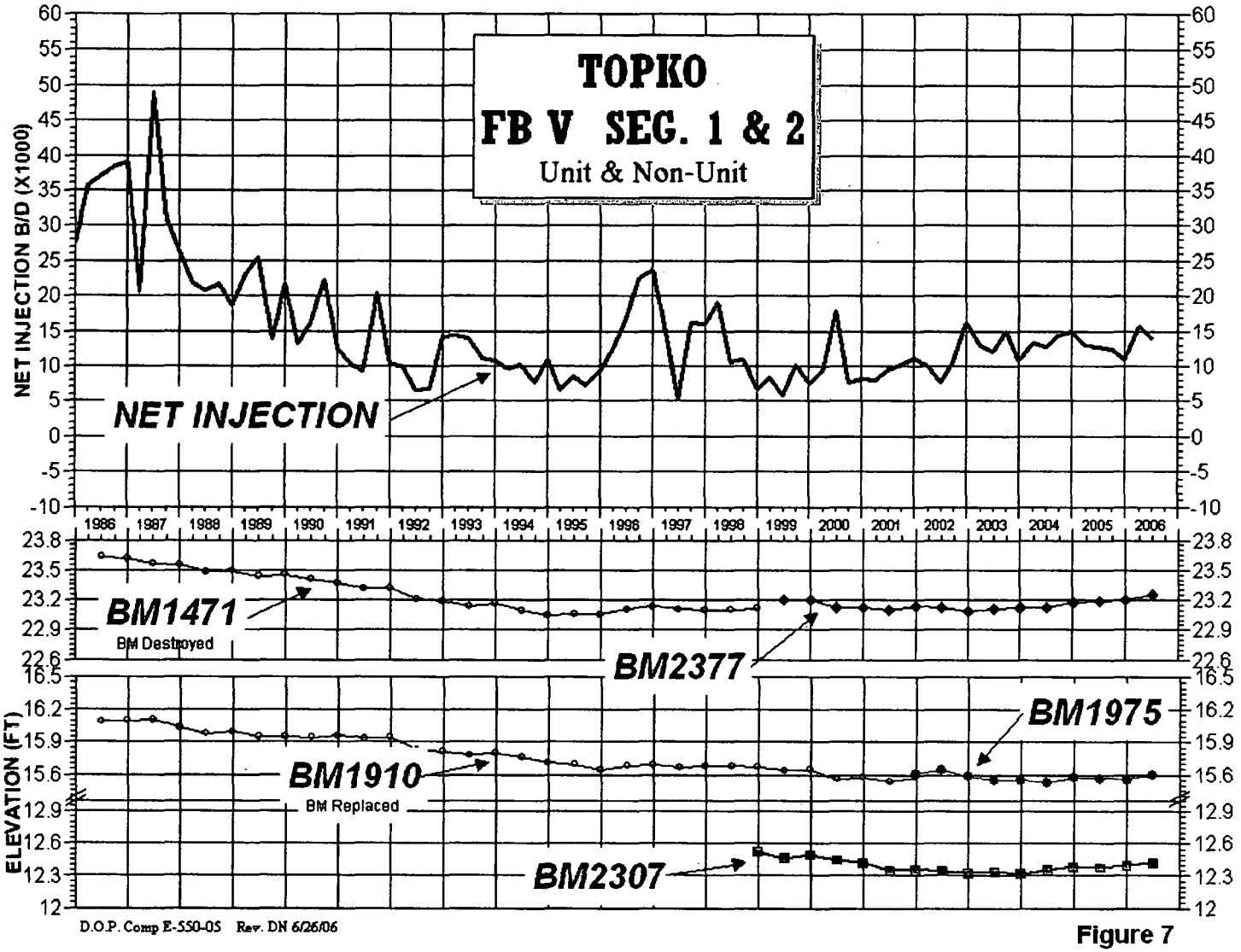
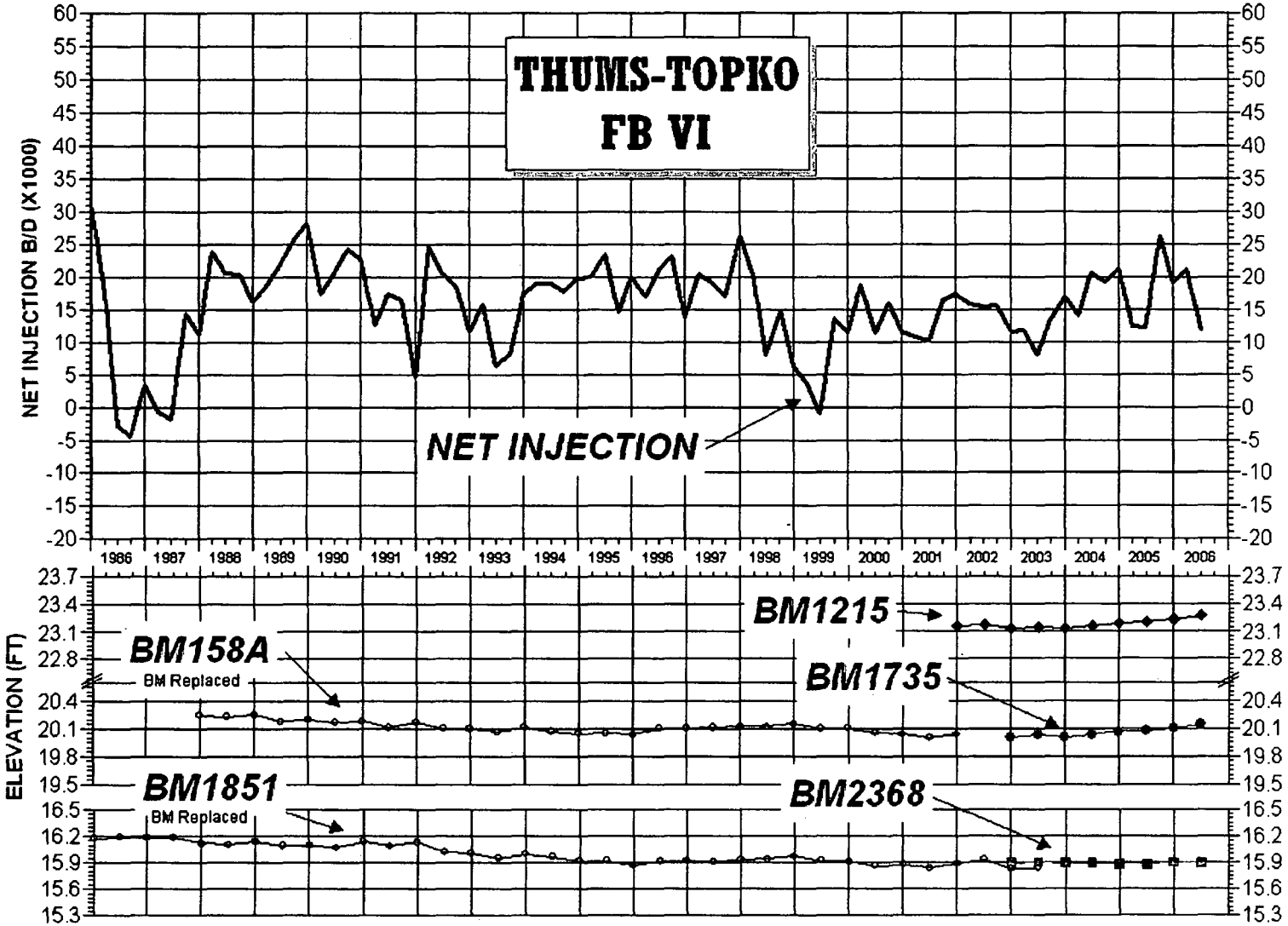
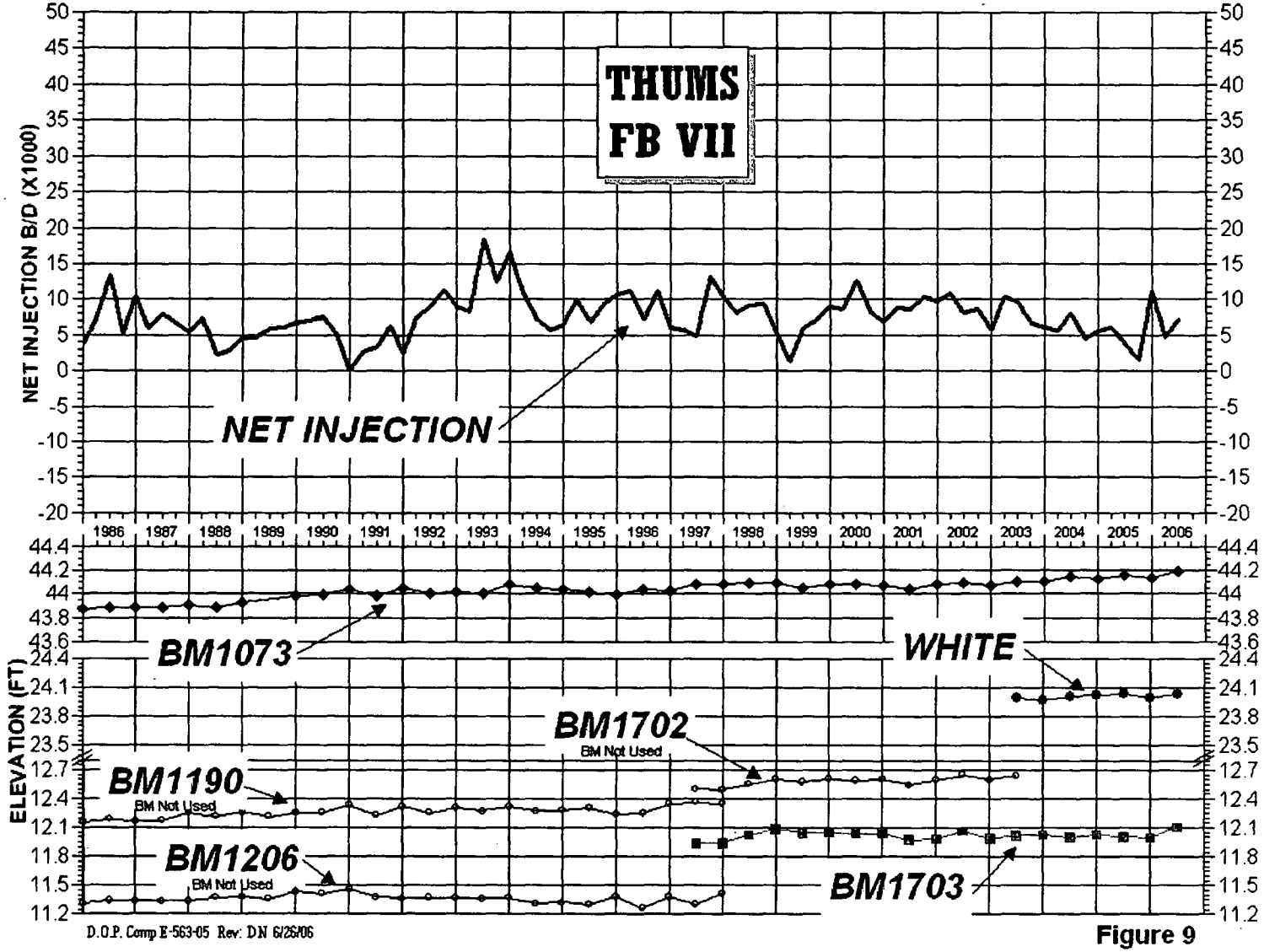

TOPKO
FB V SEG. 1 & 2
Unit & Non-Unit
NET INJECTION B/D (X1000)
NET INJECTION
BM1471
BM Destroyed
BM2377
BM1975
BM1910
BM Replaced
BM2307
ELEVATION (FT)
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
D.O.P. Comp E-550-05 Rev. DN 6/26/06

Figure 7



D.O.P. Comp E-562-05 Rev. DN 6/26/06

Figure 8


THUMS
FB VII
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
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WHITE
BM1702
BM Not Used
BM1190
BM Not Used
BM1206
BM Not Used
BM1703
D.O.P. Comp E-563-05 Rev: DN 6/26/06

Figure 9

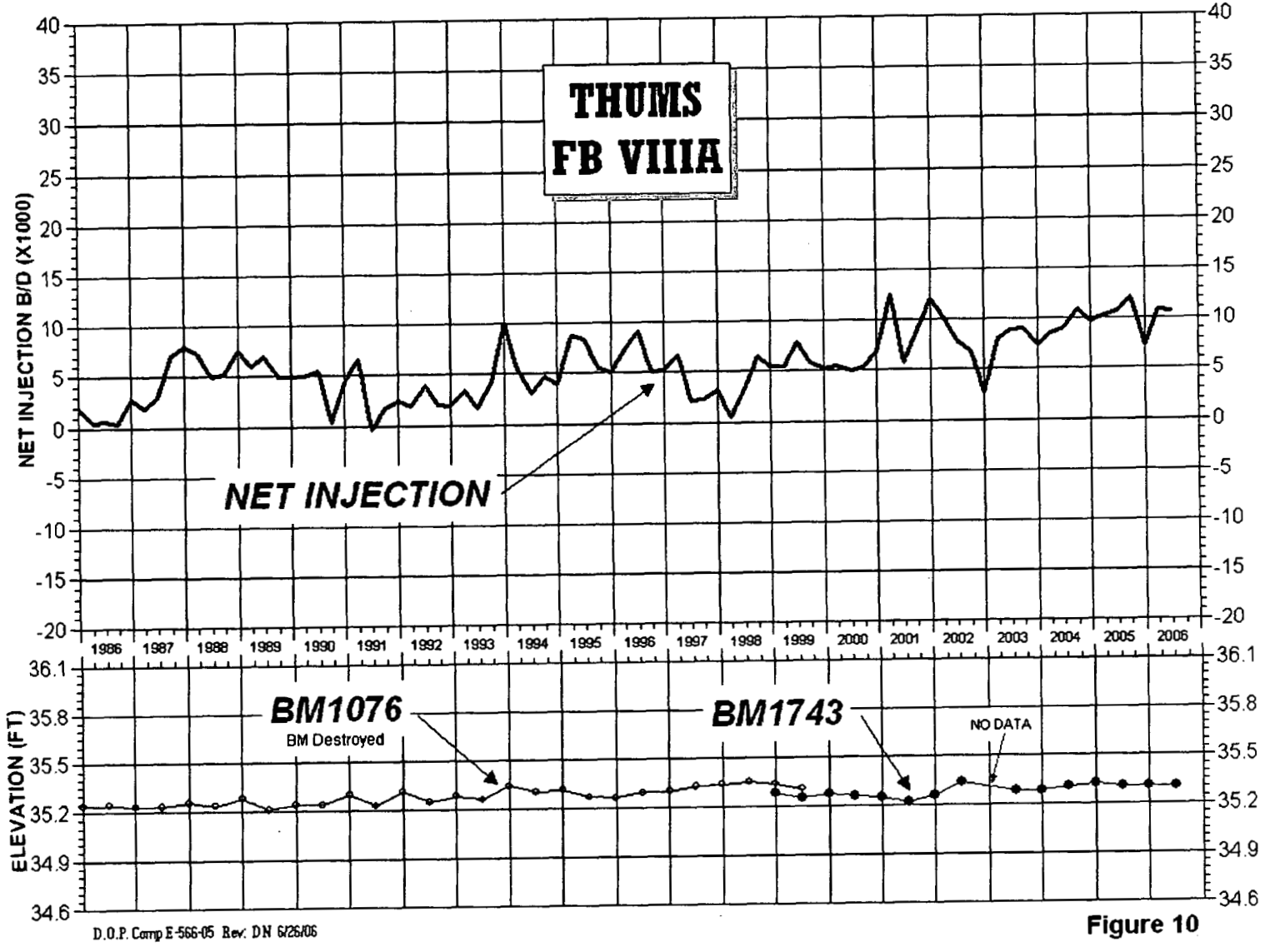
THUMS
FB VIIIA
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
BM1076
BM Destroyed
BM1743
NO DATA
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
D.O.P. Comp E-566-05 Rev. DN 6/26/06

Figure 10

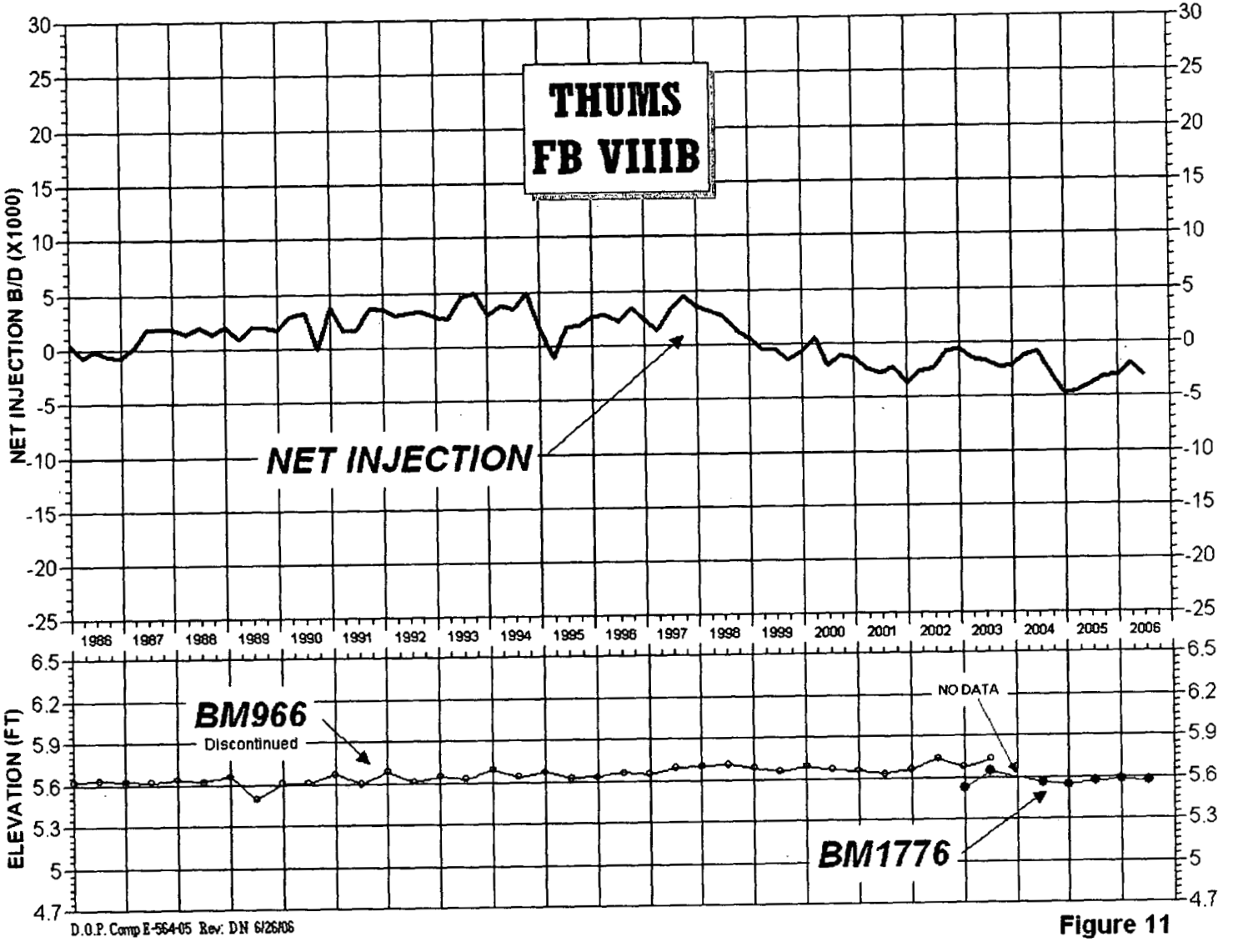
THUMS
FB VIIIB
NET INJECTION B/D (X1000)
NET INJECTION
ELEVATION (FT)
BM966
Discontinued
NO DATA
BM1776
1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006
D.O.P. Comp E-564-05 Rev: DN 6/26/06

Figure 11

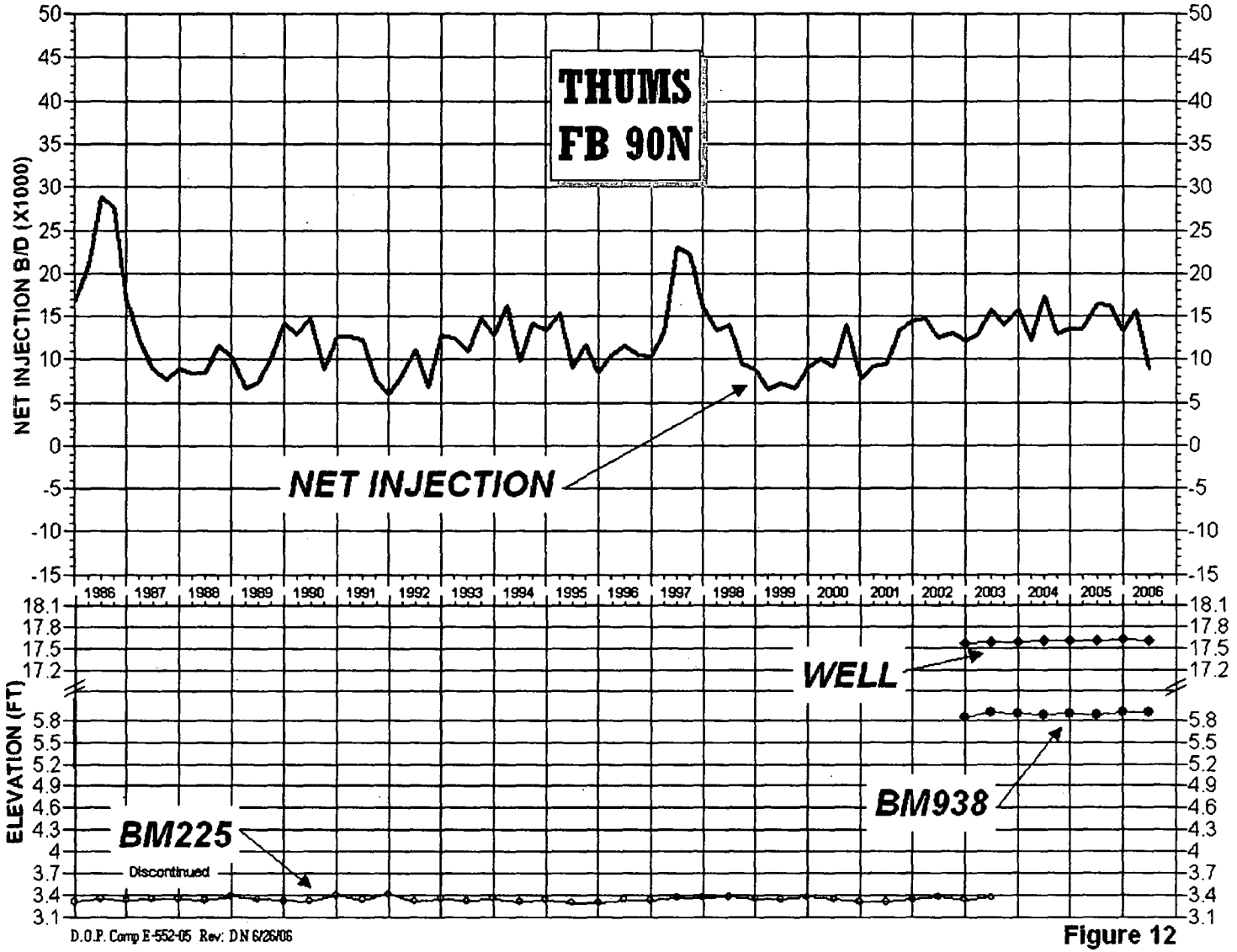
THUMS
FB 90N
NET INJECTION B/D (X1000)
NET INJECTION
WELL
BM938
BM225
Discontinued
ELEVATION (FT)
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
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Figure 12

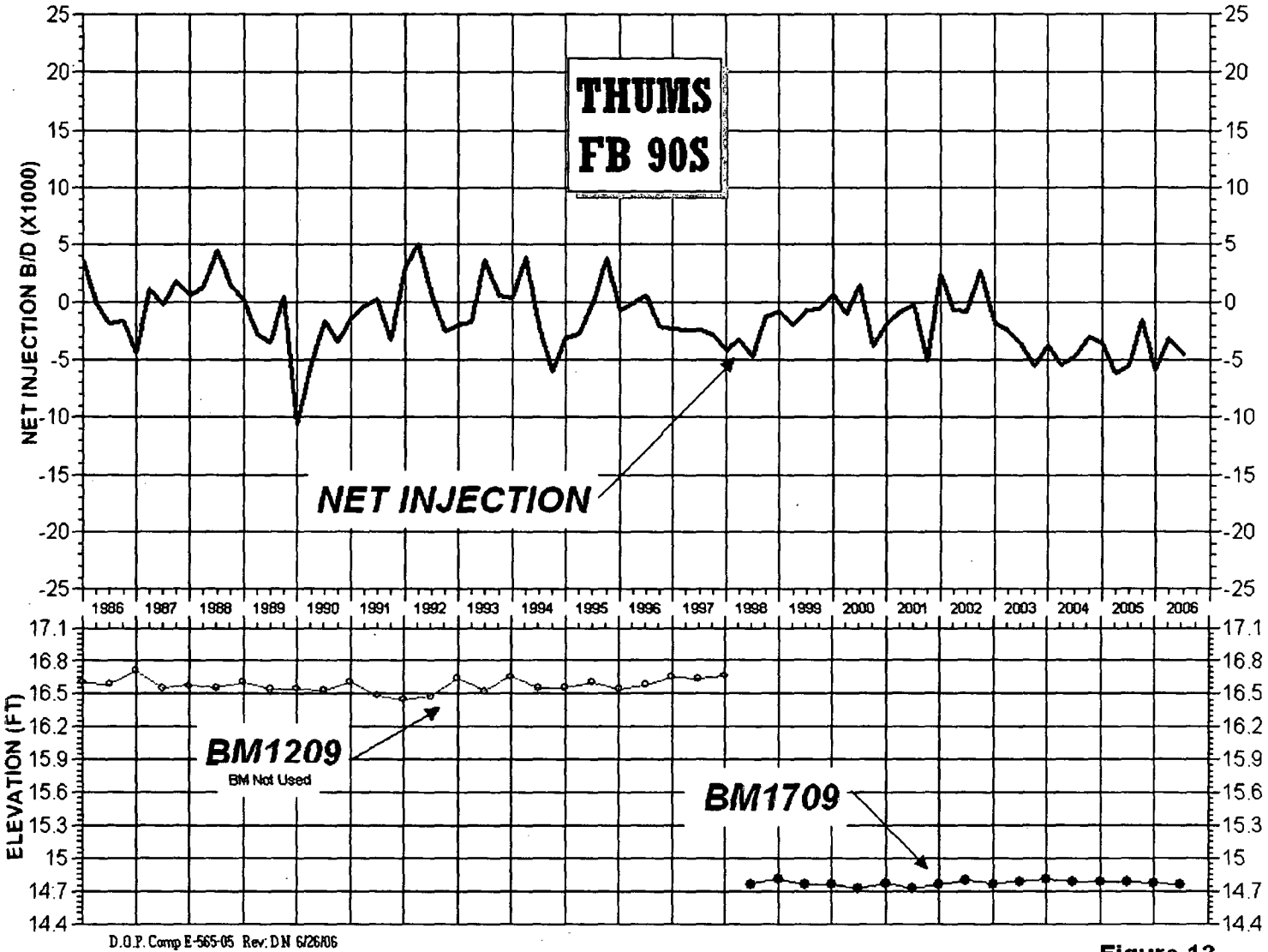
THUMS
FB 90S
NET INJECTION B/D (X1000)
NET INJECTION
BM1209
BM Not Used
BM1709
ELEVATION (FT)
D.O.P. Comp E-565-05 Rev: DN 6/26/06

Figure 13

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