

**ELEVATION CHANGES  
IN THE  
CITY OF LONG BEACH  
NOVEMBER 2004 TO May 2005**

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

## CONTENTS

		<u>Page</u>
I.	<b>SUBSIDENCE AND REBOUND SURVEY ANALYSIS</b>	
	Elevation Change – November 2004 to May 2005.....	3
	Elevation Change – May 2004 to May 2005 .....	4
	Use of Global Positioning System (GPS).....	4
II.	<b>APPENDIX</b>	
	Brief History of Long Beach Subsidence .....	6
	Survey Accuracy .....	7
	Elevation Change Map Construction .....	8
	Bench Mark and Net Injection Graphs, Harbor District .....	8
	Bench Mark and Net Injection Graphs, Ocean Boulevard and Offshore Drilling Islands .....	9
III.	<b>ELEVATION CHANGE MAPS</b>	<u>Figures</u>
	November 2004 to May 2005.....	1
	May 2004 to May 2005.....	2
	<b>BENCH MARK AND NET INJECTION GRAPHS</b>	
	Bench Mark Location Map .....	3
	Harbor District, Fault Blocks II-VI .....	4-8
	Coastal Areas and Offshore Drilling Islands, Fault Blocks VI through 90S .....	9-13

## **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 2005. Changes in elevation that occurred since the last two surveys, November 2004 and May 2004, 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 2004 to May 2005 (Figure 1)**

Elevations throughout the Civic Center, Central City, Alamitos Bay, and Naples areas were stable during the six-month period. A minor localized elevation increase of 0.048 feet (0.576 inches) occurred near the intersection of Alamitos Avenue and Third Street. Elevations in the City of Long Beach outside of the oil-impacted areas 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 “stable” or slightly “up” period.

The Harbor District remained stable except for three areas of minor elevation loss. A loss of 0.066 feet (0.79 inches) occurred along Ocean Boulevard, in the middle of Fault Block III. A localized elevation loss of up to 0.036 feet (0.432 inches) was measured at the southwest corner of Pier T. Across the channel to the east, Pier D lost of 0.040 feet (0.48 inches) of elevation. These elevation changes were due to the realignment of oil production and water injection facilities in the Harbor District.

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 Fault Block II. A loss of up to -0.082 feet (-0.984 inches) was measured along the Pier A wharf, to the south 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 were stable, having no significant elevation change during the 6-month period.

### **Elevation Change – May 2004 to May 2005 (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 elevation increase of up to 0.102 feet (1.22 inches) occurred near the intersection of Alamitos Avenue and Third Street. Geologically active zones outside the oil-impacted areas indicate the one-year period to have been a slightly positive elevation period.

The Harbor District experienced slight increases in elevations. A maximum increase of 0.066 feet (0.79 inches) occurred on Pier H. 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 -0.153 feet (-1.84 inches) was centered on the Henry Ford Ave, north 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. Loss of rebound from past over injection into Fault Block III could also be a cause.

Islands Grissom, Chaffee and Freeman had no elevation change while Island White experienced a slight gain of 0.025 feet (0.3 inches) during the 12-month period.

### **Use of Global Positioning System (GPS)**

This is the seventh 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 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-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 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. 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, 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 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.

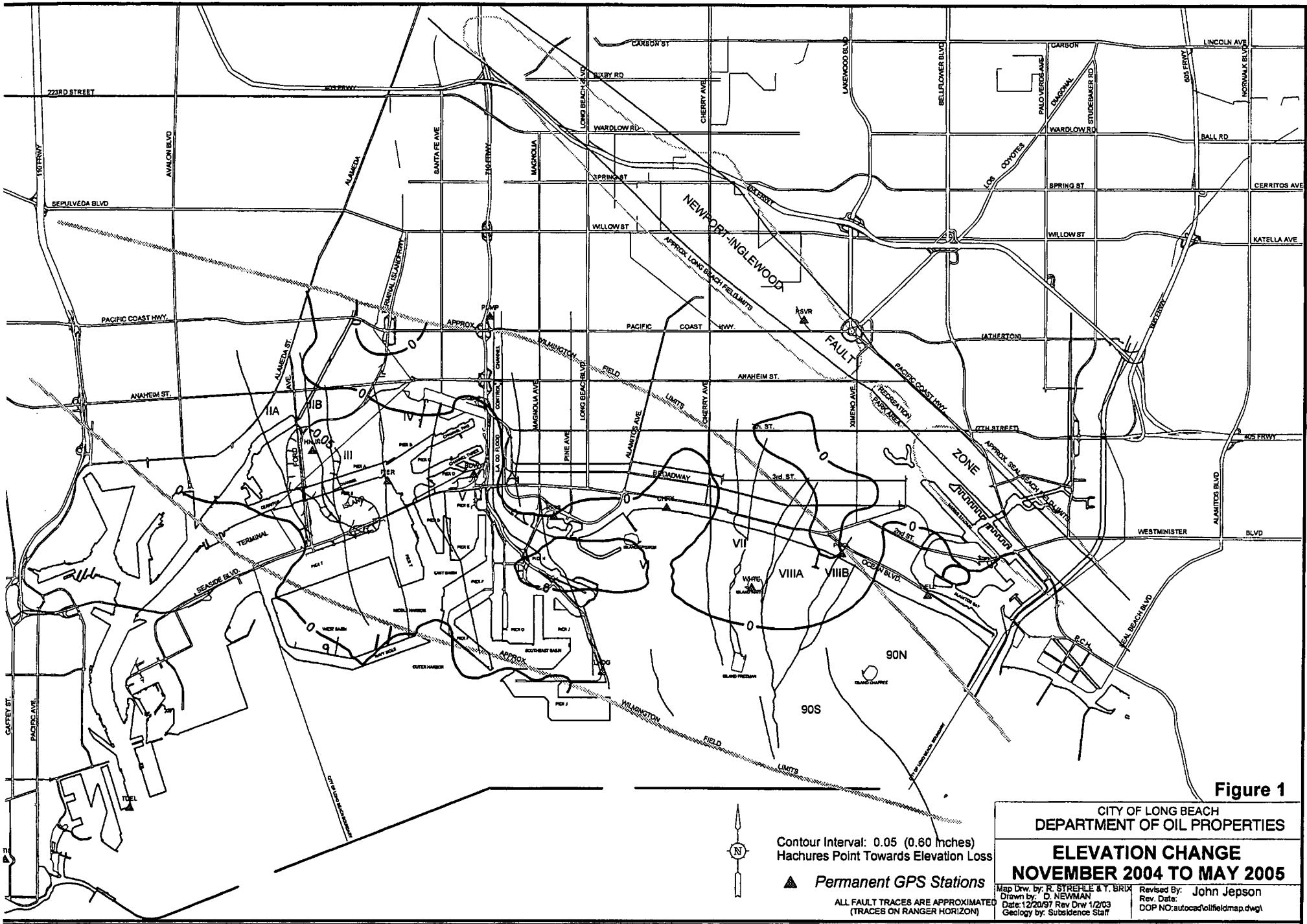
In general, these graphs show a good correlation between the net injection and elevation change. For example, an increase in net injection is usually followed by an increase in elevation. There tends to be a lag time of months between the net injection change and the subsequent elevation change. The 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 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.



**Figure 1**

CITY OF LONG BEACH  
DEPARTMENT OF OIL PROPERTIES

**ELEVATION CHANGE  
NOVEMBER 2004 TO MAY 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)

Map Drawn by: R. STREHLE & T. BRINK  
Drawn by: D. NEWMAN  
Date: 1/22/05 Rev: 1/2/03  
Geology by: Subsidence Staff

Revised By: John Jepson  
Rev. Date:  
DOP NO: autocad\oilfieldmap.dwg\1

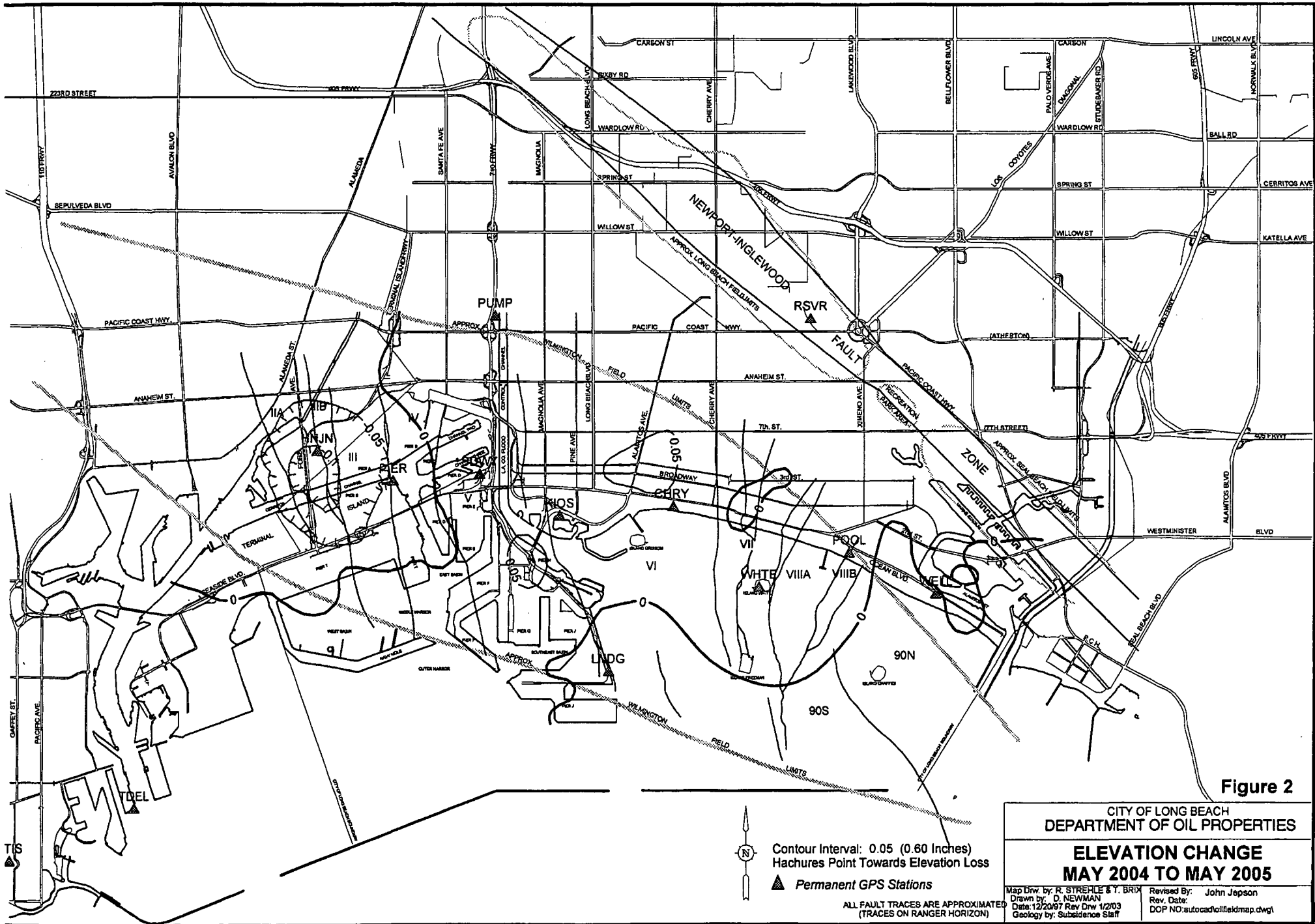


Figure 2

CITY OF LONG BEACH  
DEPARTMENT OF OIL PROPERTIES

**ELEVATION CHANGE  
MAY 2004 TO MAY 2005**

Map Drw. by: R. STREHLE & T. BRUX	Revised By: John Japson
Drawn by: D. NEWMAN	Rev. Date:
Date: 12/20/07 Rev Drw 1/2/03	DOP NO: autocad/oilfieldmap.dwg
Geology by: Subsidence Staff	

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

ALL FAULT TRACES ARE APPROXIMATED  
(TRACES ON RANGER HORIZON)

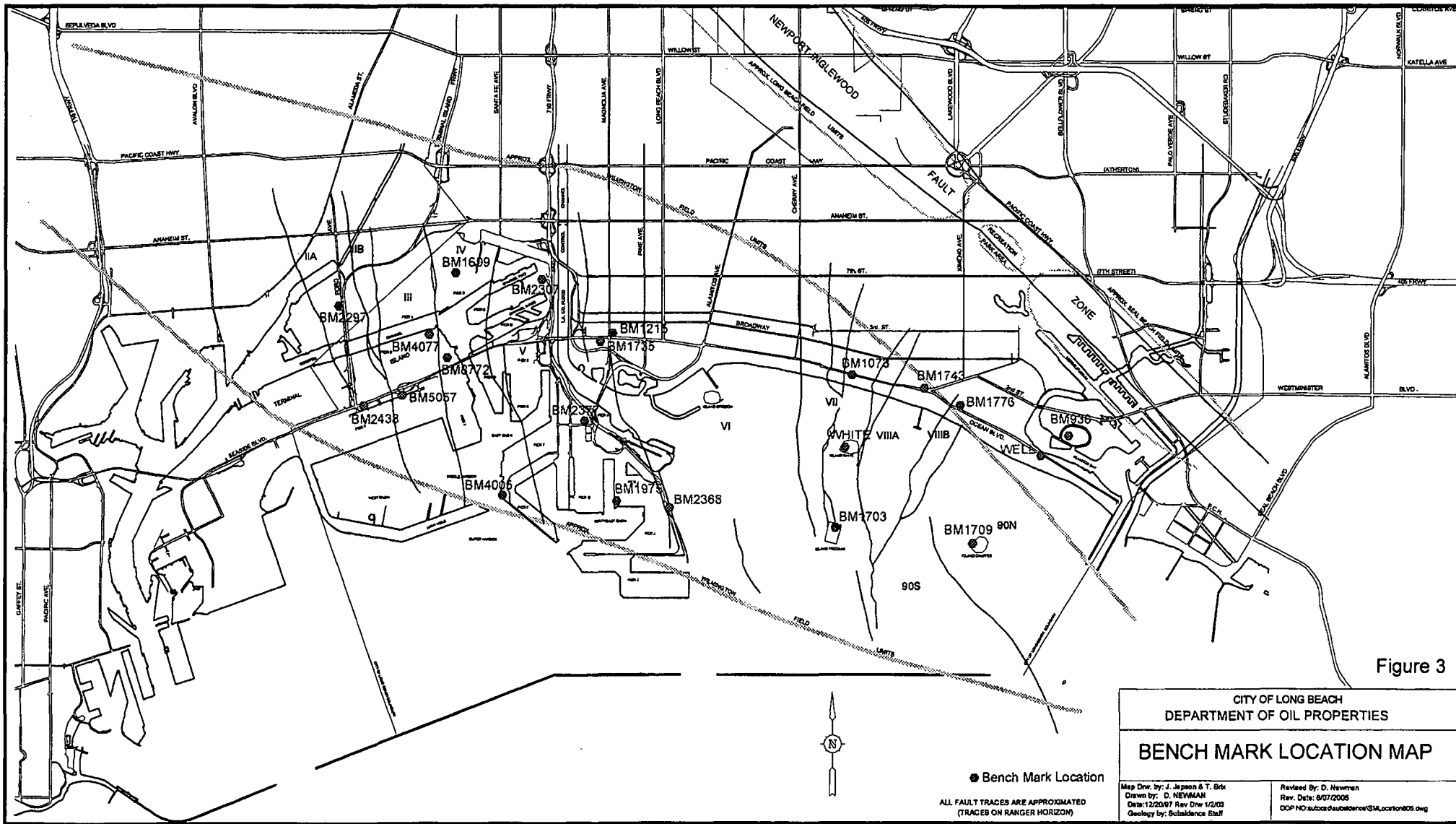


Figure 3

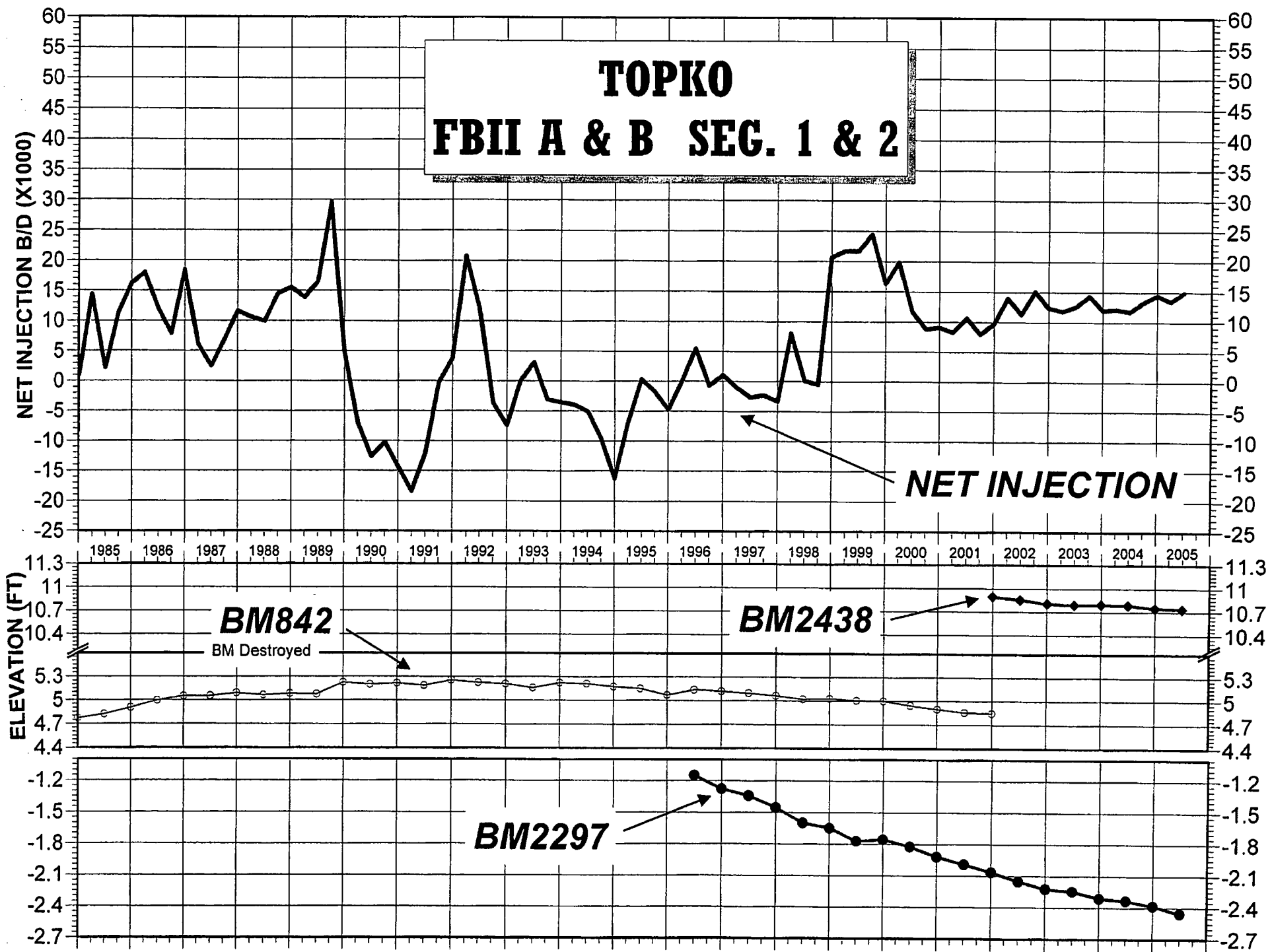
CITY OF LONG BEACH  
 DEPARTMENT OF OIL PROPERTIES

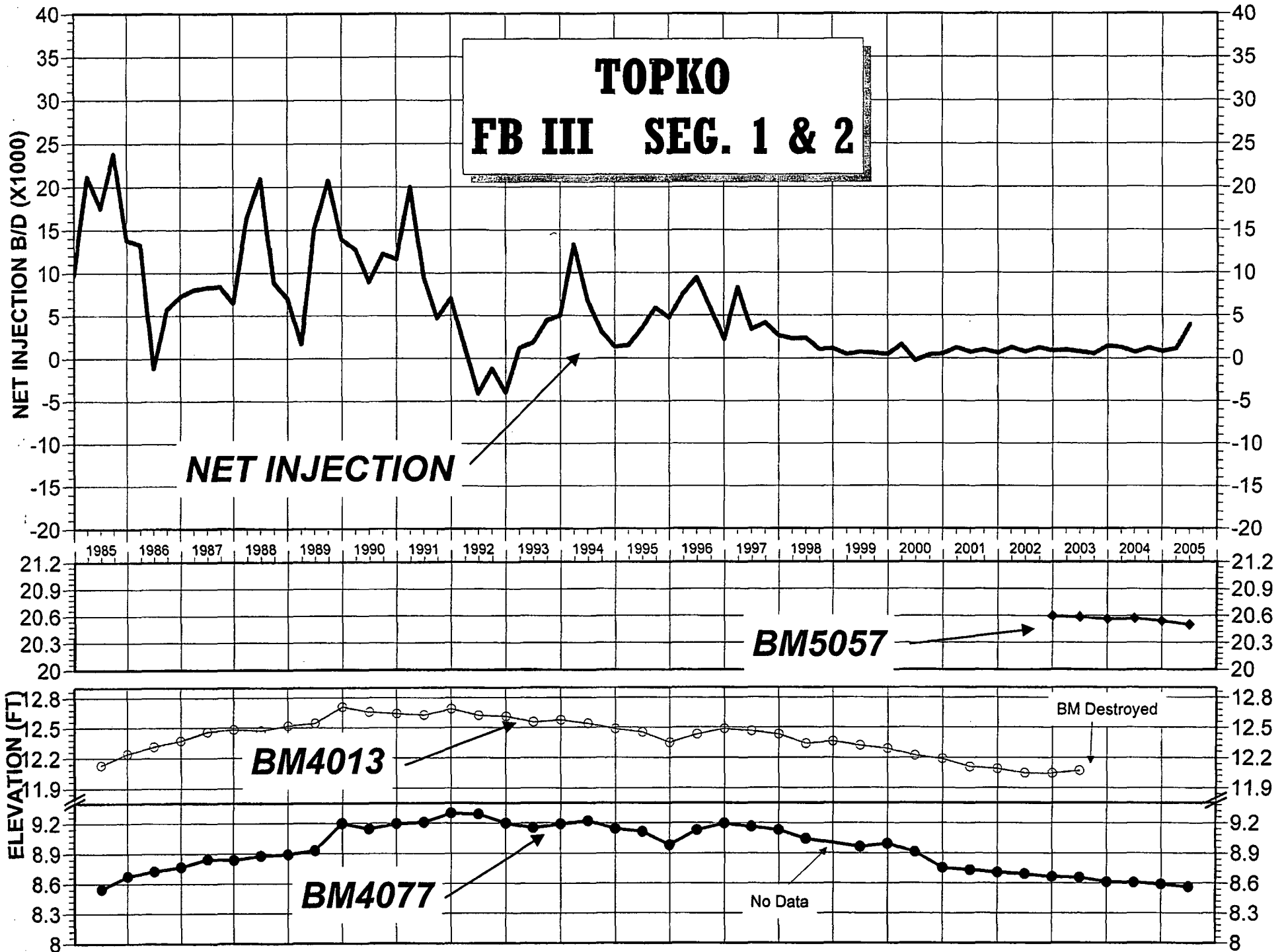
**BENCH MARK LOCATION MAP**

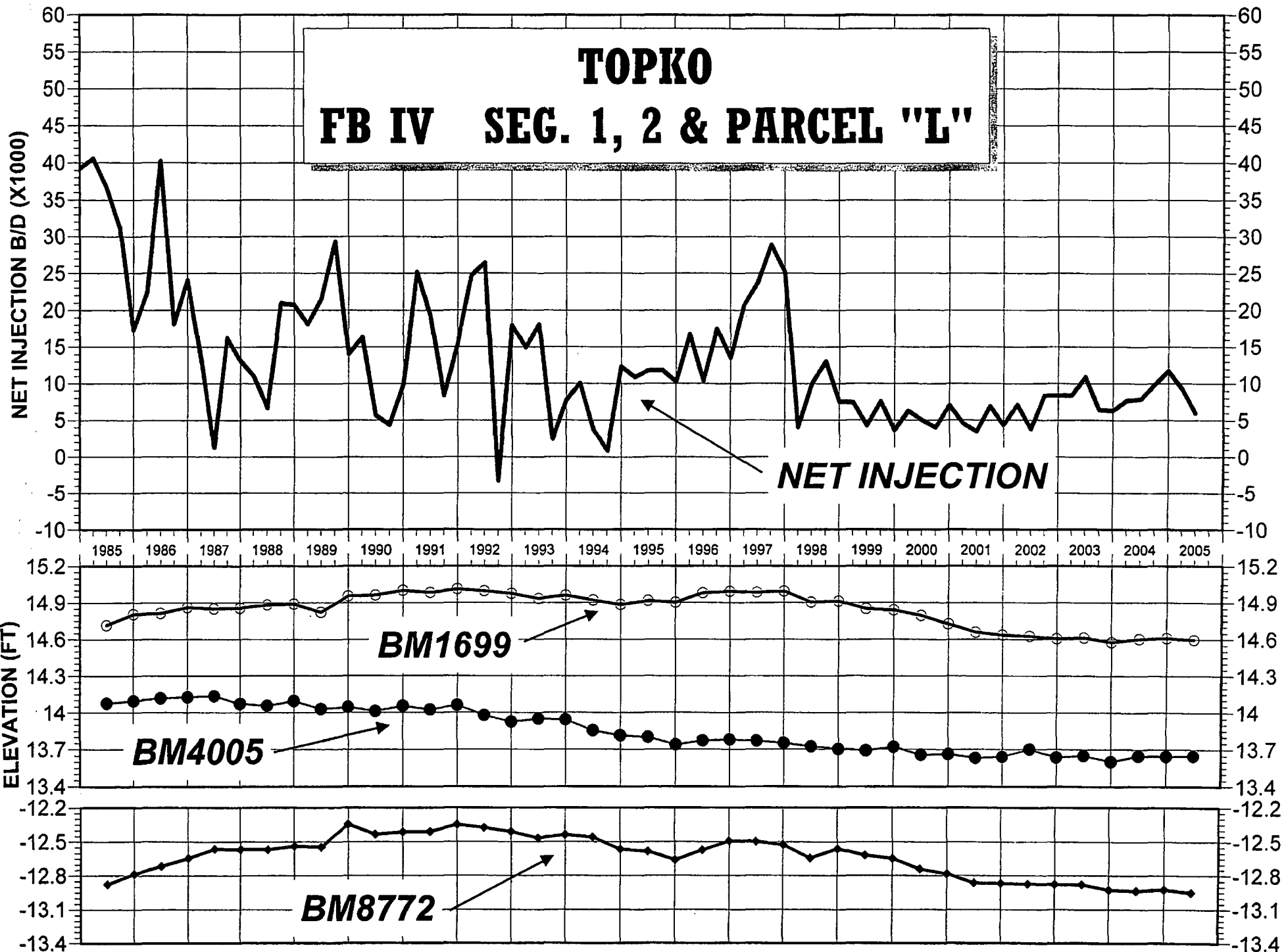
Map Dwn. by: J. Jipson & T. Brk  
 Drawn by: D. NEWMAN  
 Date: 12/20/97 Rev Dwn 1/2/03  
 Geology by: Schaldene Staff

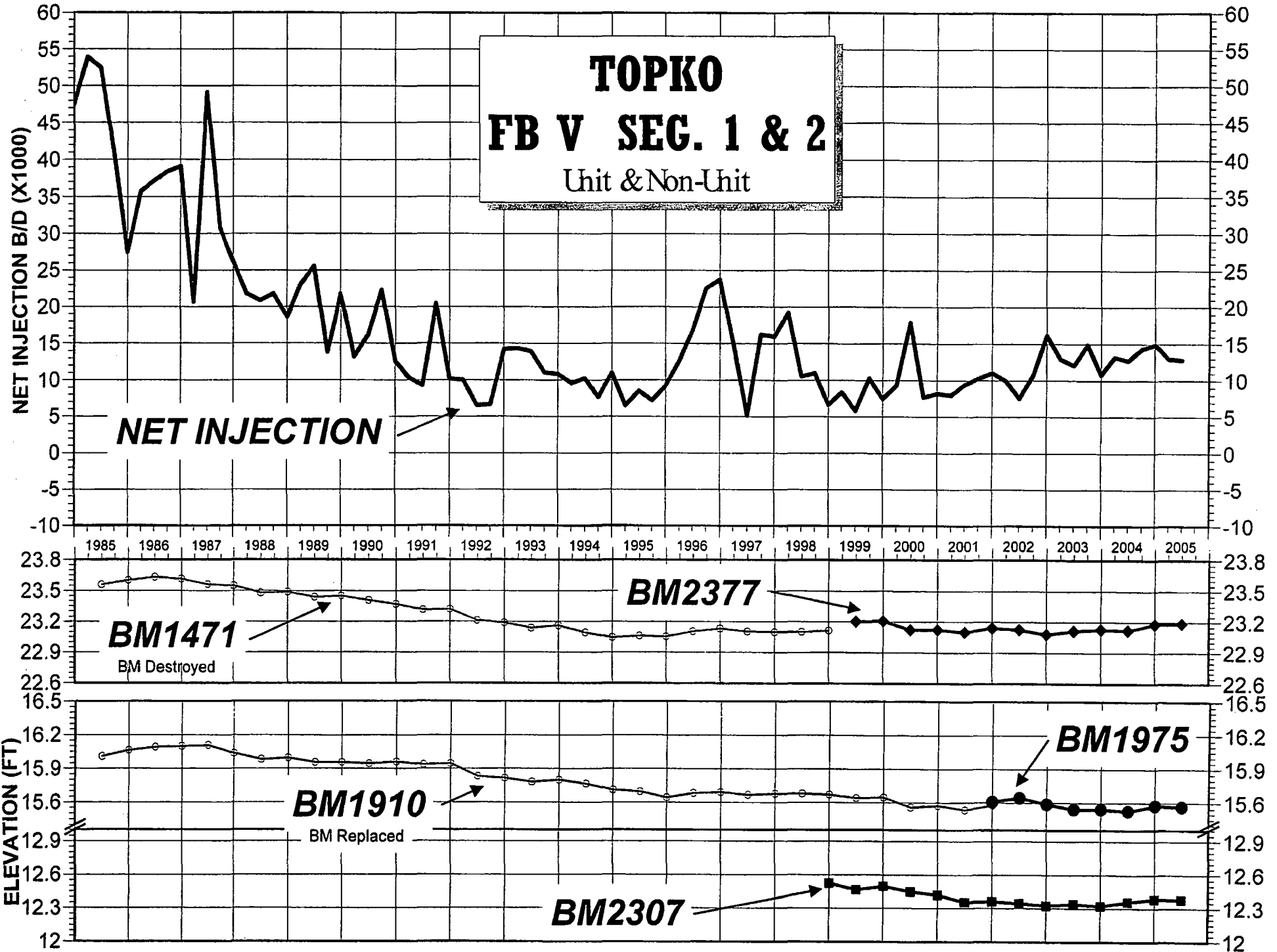
Revised by: D. Newman  
 Rev. Date: 8/07/2005  
 DOP NO: subordsubordnew\314\_location05.dwg

# TOPKO FBII A & B SEG. 1 & 2



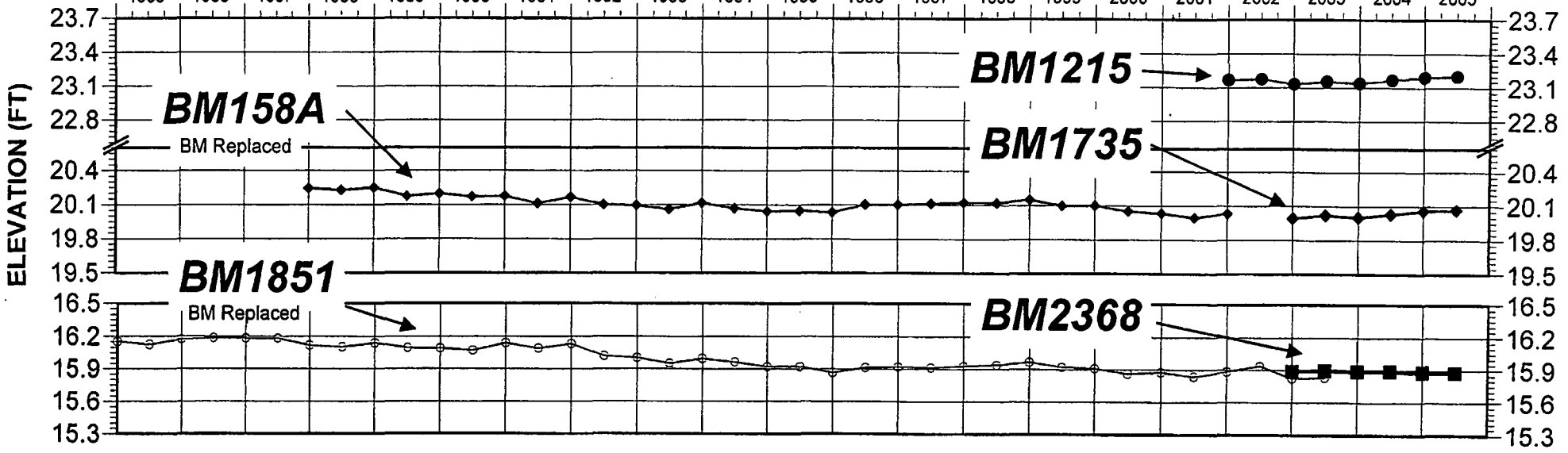
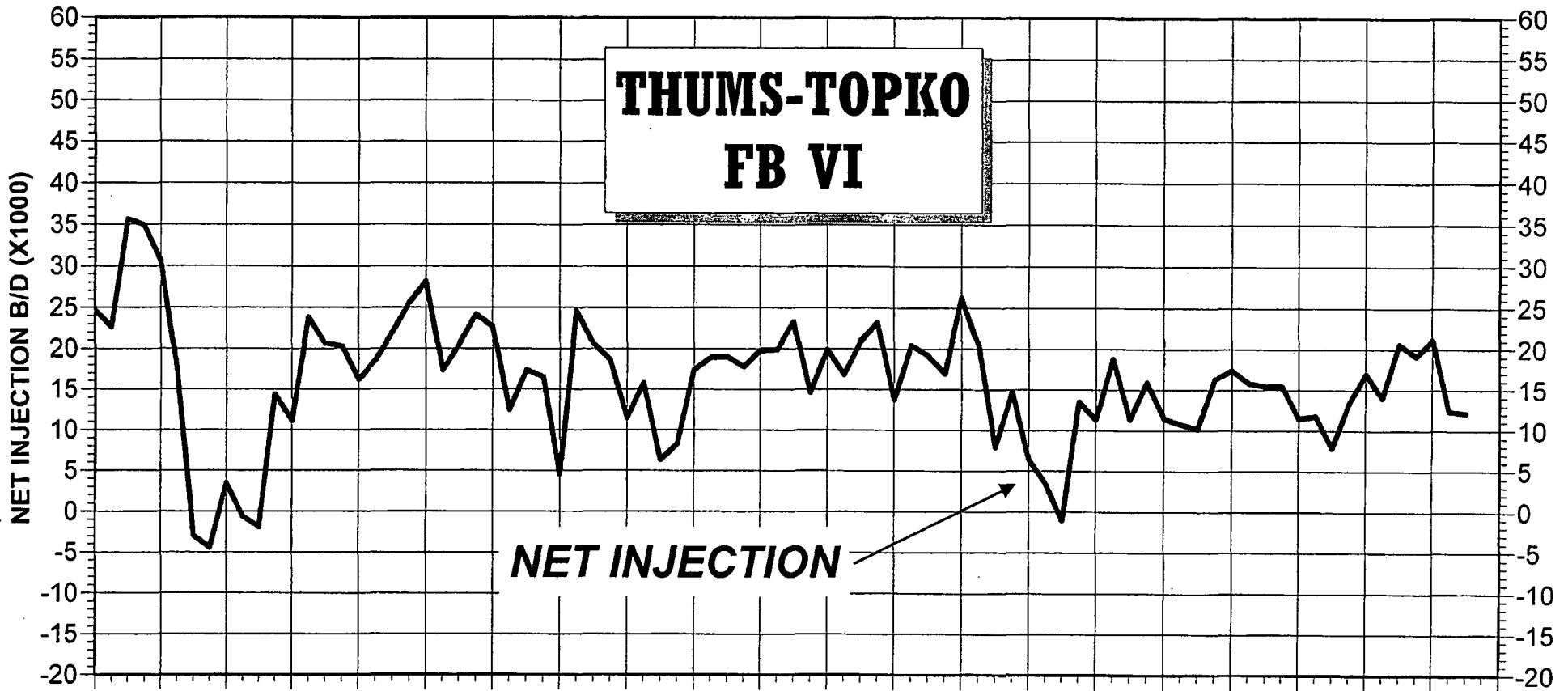








# THUMS-TOPKO FB VI



**Figure 8**

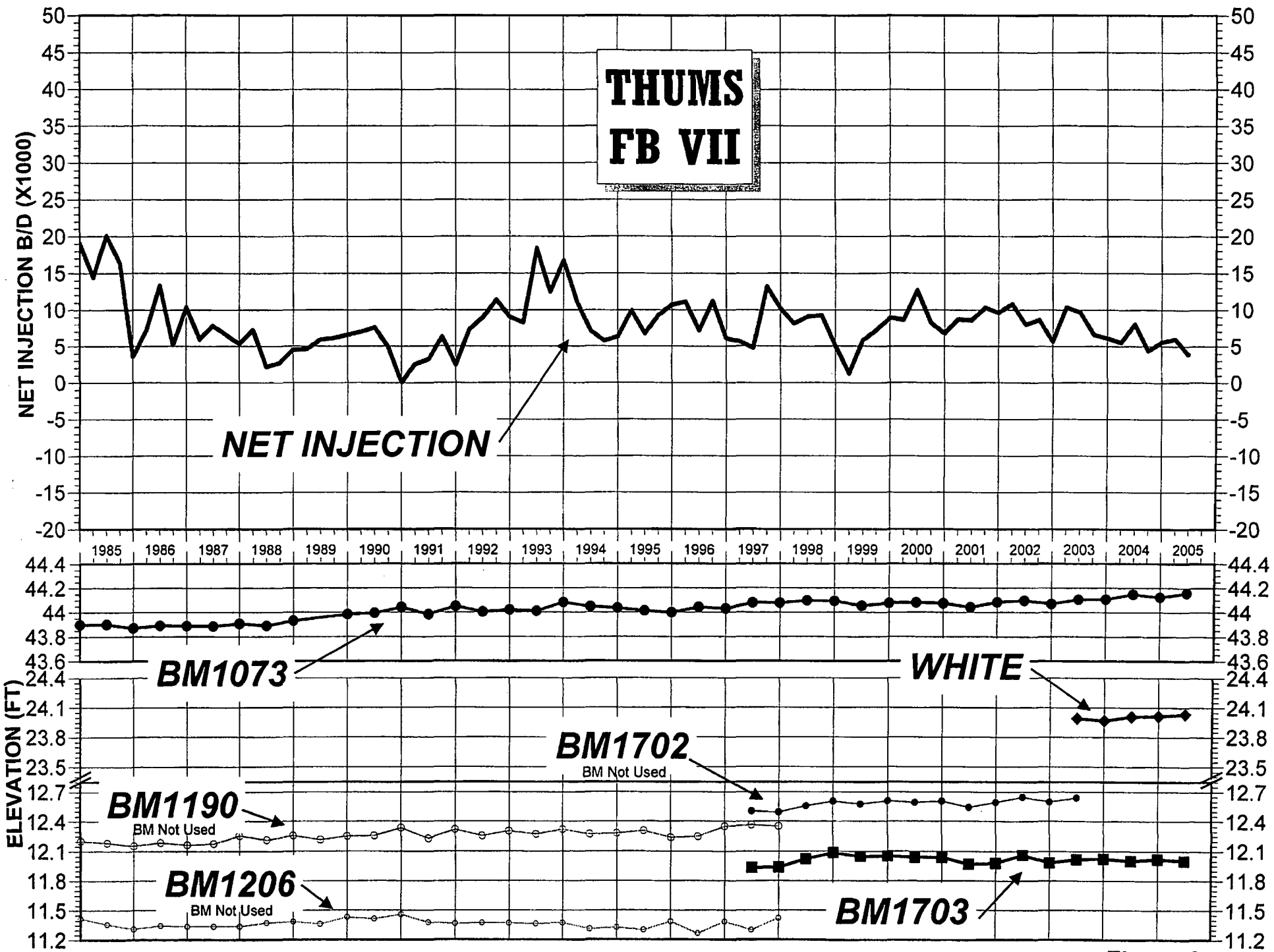
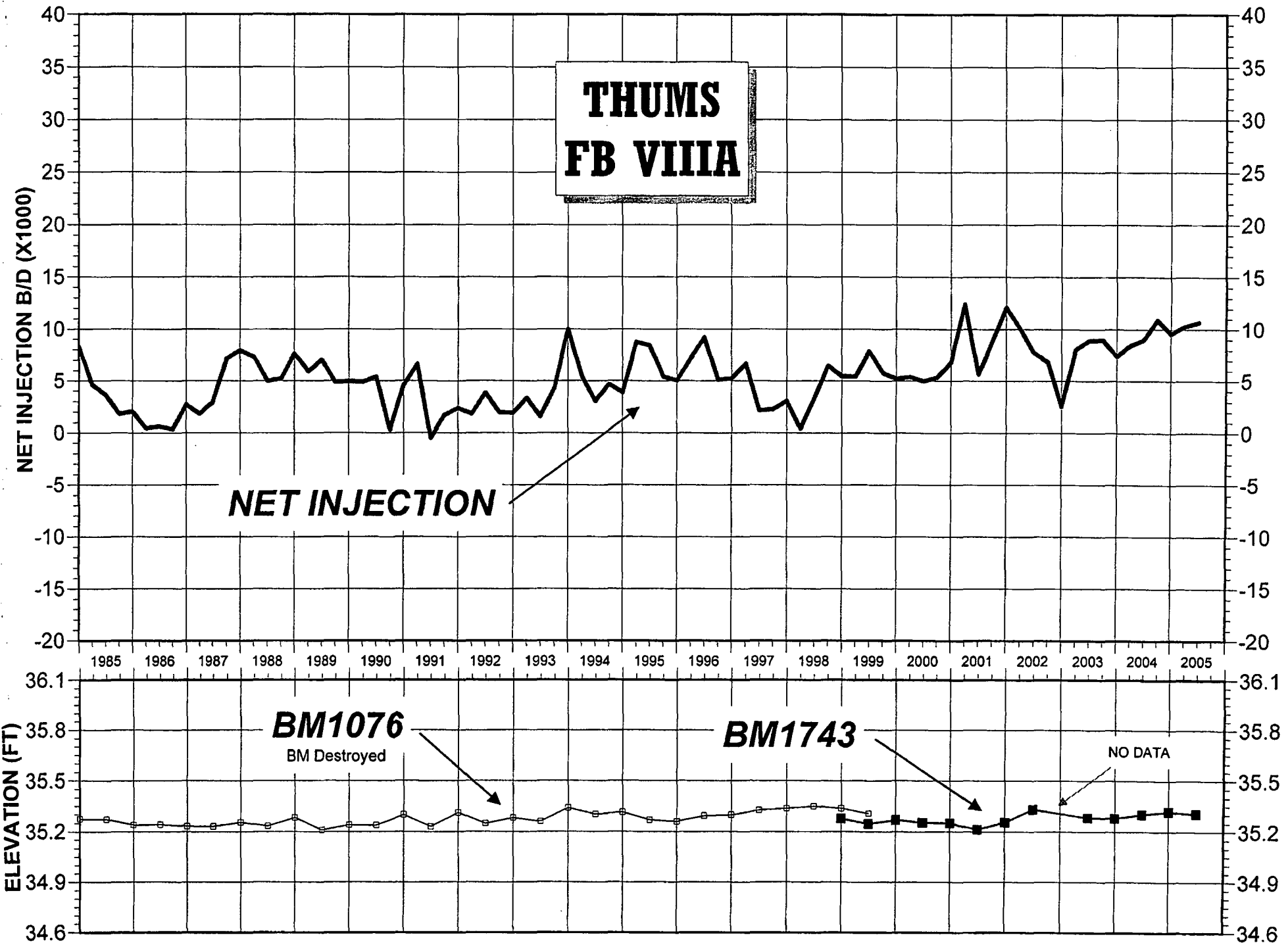
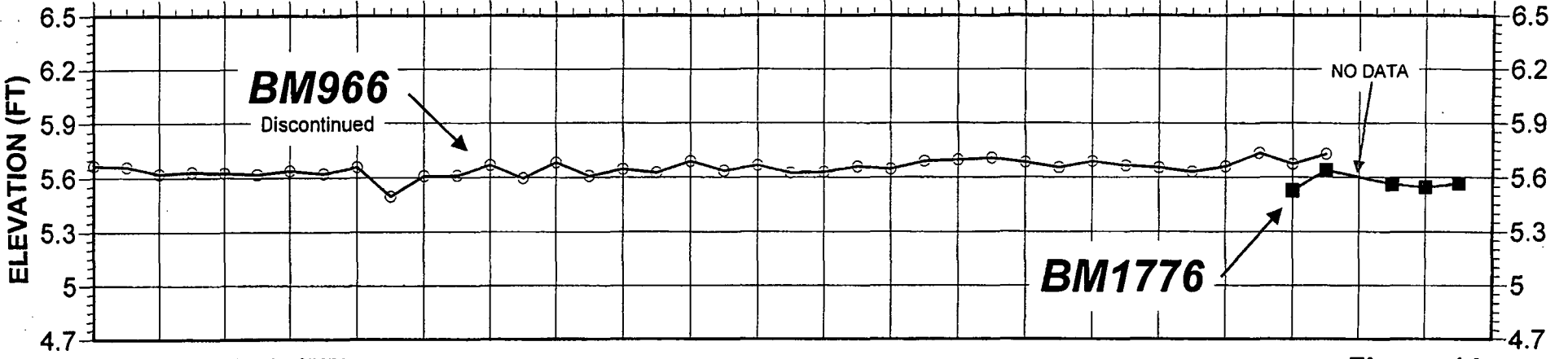
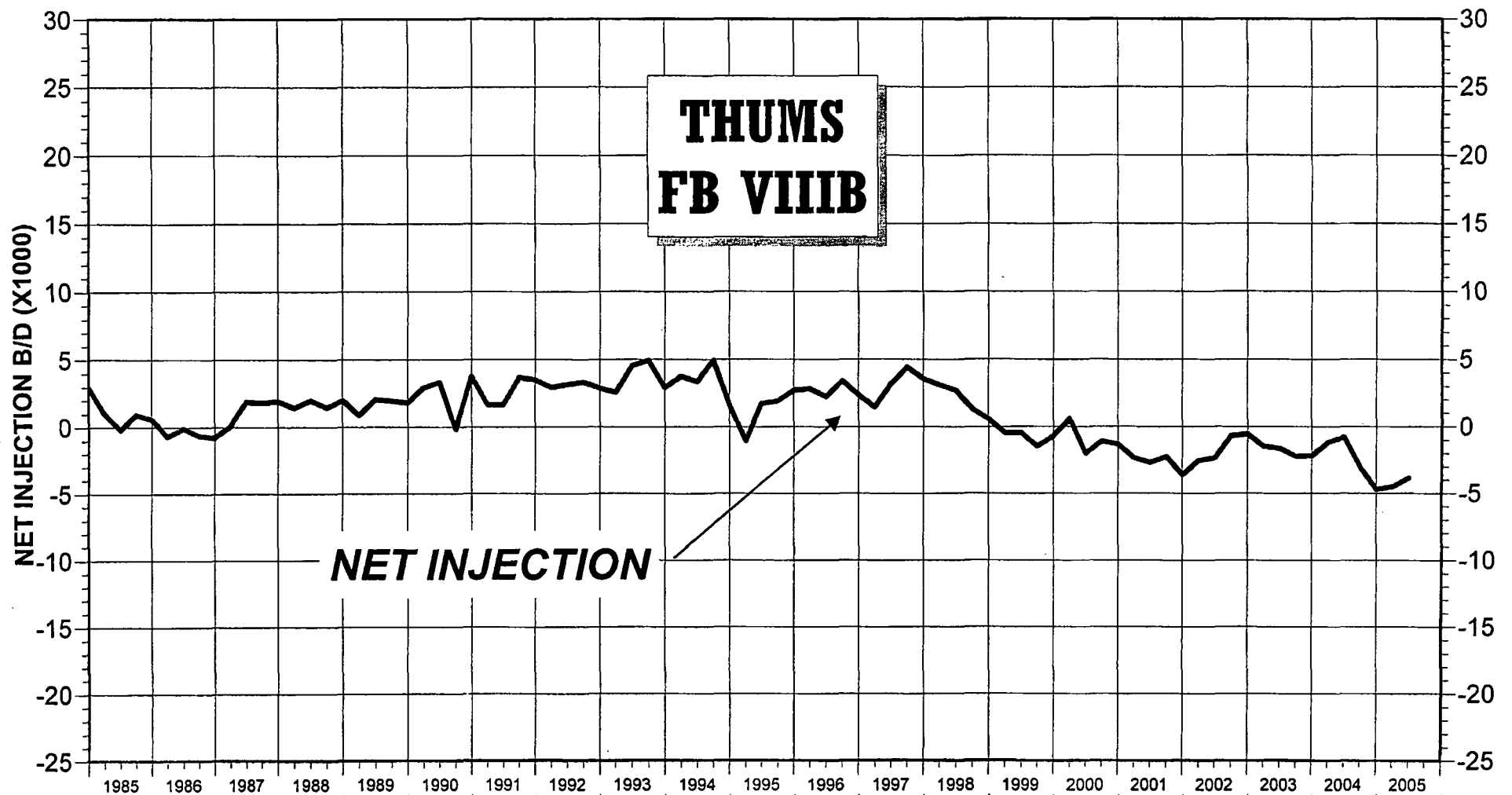
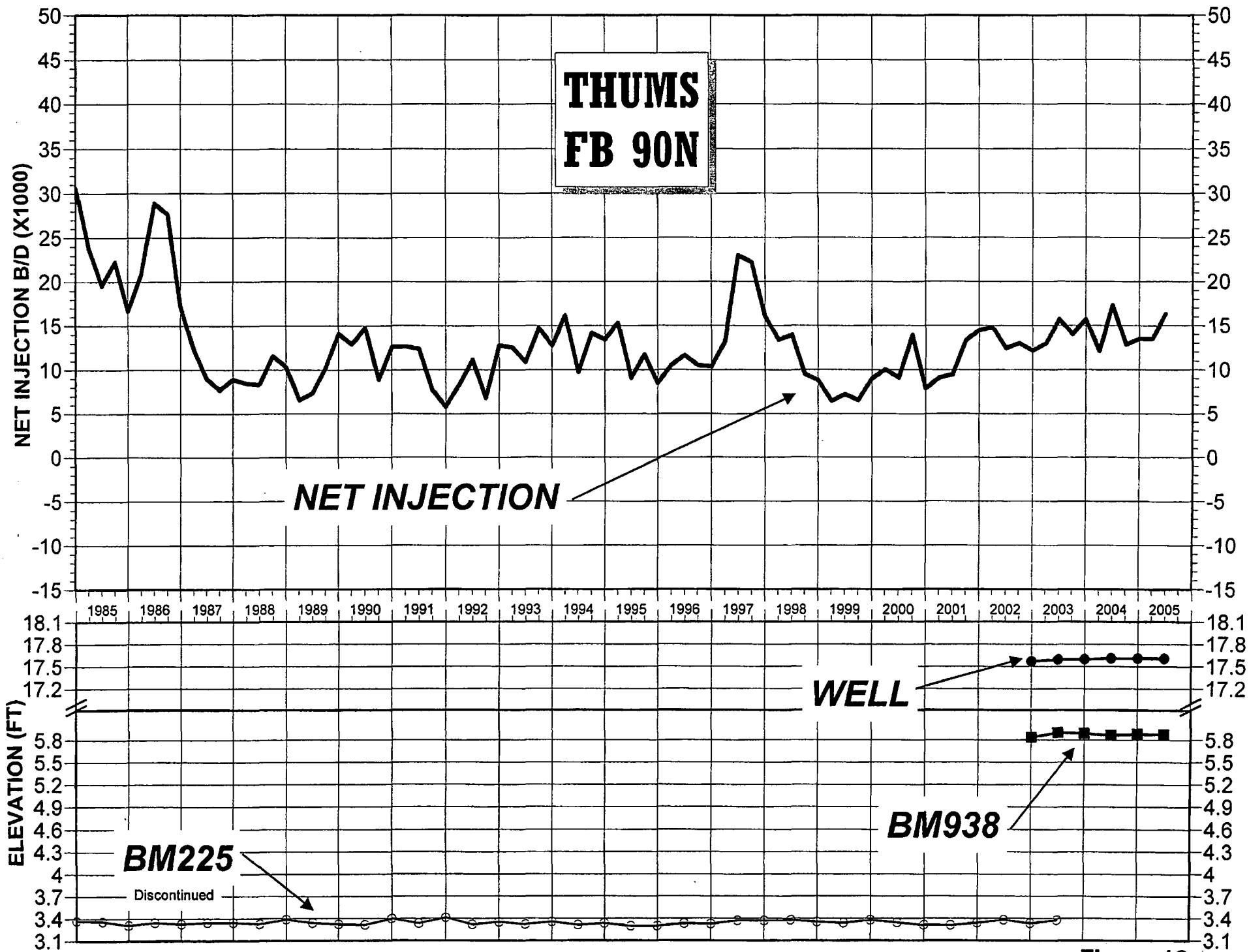


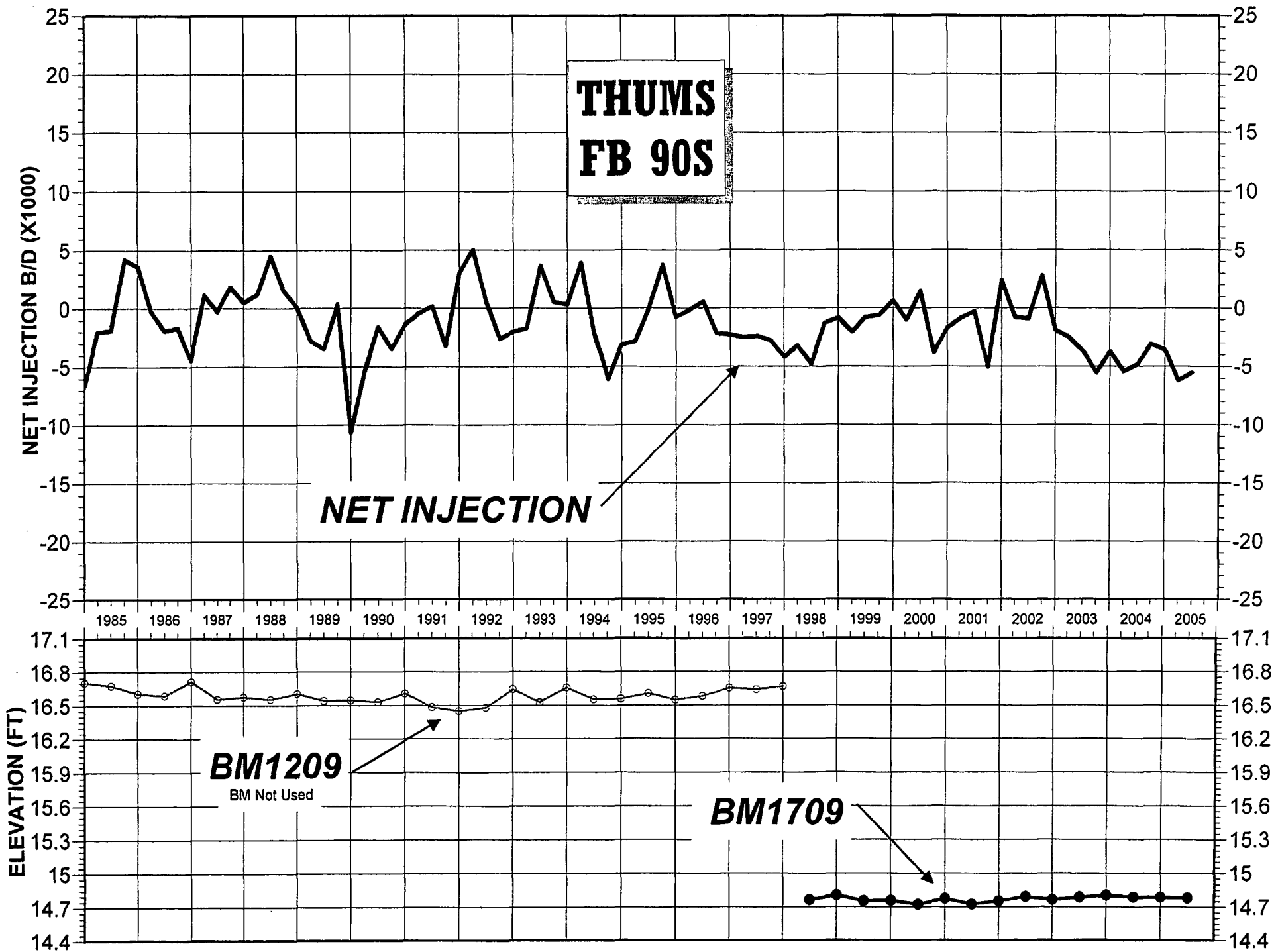
Figure 9





**Figure 11**





**Figure 13**