Improved Waterflood and Adoption of Advanced Drilling and Completion Technology Pays Rich Dividend in Mumbai High North Field*

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Abstract

Mumbai High North Field, the northern part of major offshore oil field Mumbai High, was discovered in 1974. Multilayered carbonate reservoir NL-III is the main producer and has been on production since 1976. Water injection was commenced in the Field in 1984. Being on continuous production for last 34 years, the Field is in the mature stage of its producing life. The oil production rate from the Field was of the order of 130,000 bopd during 1982 to 1989. During early and mid-nineties the Field had entered a crucial decline phase and production level dropped to about 63,000 bopd by December, 1993 due to a rise in GOR, injection water break through and closure of some high GOR and high water cut wells. Various remedial measures such as installation of gas lift, water and gas shut off jobs and reopening of some wells showing reduced GOR resulted in improving the production level to around 78,000 bopd by December, 1999. Further implementation of redevelopment project of Mumbai High North Field initiated in 2000 resulted in improving production which reached the level of 100,000 bopd in June, 2005.

The unfortunate fire accident at MHN process platform on July 27, 2005 caused major disruption of offshore production systems of Mumbai High Field. Restoring the oil production without having a new process platform within a short period became a major challenging task. The systematic actions taken in the field restored the production level to 80% within six months. Focused waterflood management keeping layer specific requirements and successful implementation of NA1 layer development scheme helped in further improving oil production to the level of 92,000 bopd (restoring 92% oil production) in September, 2007.The oil production is currently being maintained at around 80,000 bopd. This paper highlights the integrated Asset approach in reviving and improving oil production from the Field after the MHN accident. The adoptions of new techniques and technologies have further added in a rejuvenation campaign of the Field. With the implementation of the current development plan and improved waterflood strategy, oil production is likely to be enhanced further which well help in achieving oil recovery to 33% from main reservoir of the Field.

Introduction

Mumbai High Field is the largest offshore oilfield of India located about 160 km west-northwest of Mumbai City in the Arabian sea at a water depth of about 80 m. The Field has an aerial spread of about 1200 sq km. The multilayered carbonate reservoir L-III is the main producer and has been on production since 1976. The northern and southern sectors are divided by an east-west impermeable shale channel. The Field has been developed through various field development schemes drawn and implemented at various stages. Water injection initially through peripheral row of injectors was initiated in 1984 in North Field after a brief phase of natural depletion. Injection was later augmented through central and up dip row of injectors. During the mid- and late eighties oil production level of around 5.5 MMTPA (Figure 1) had been maintained from Mumbai High North Field. With a rise in water-cut and gas-oil ratio the production level dropped significantly by the middle of the nineties.

In order to control the declining trend and to improve the reservoir performance of Mumbai High North Field, a comprehensive review was carried out through integrated analysis by multi-disciplinary teams. Pilots were conducted to assess the potential of by-passed oil areas and to examine the feasibility of oil drainage from the considerable area below the gas-cap. A redevelopment plan aimed at better reservoir drainage through additional wells was drawn considering techno-economically viable options. A continuously improving learning curve has helped to overcome setbacks and hunt for better alternatives resulting in assimilation of effectively applicable technology.

The improved understanding of reservoir complexity through use of new generation tools, integration of geo-scientific data, refined reservoir simulation and 3D visualization have provided a higher degree of confidence to assess the potential reserves of bypassed oil. Poor producers were analysed for a cost effective option of side-tracking for better reservoir drainage. Advanced techniques in drilling, mud systems, logging and well completion were used for improve productivity from new wells. A noticeable turn-around in field performance was already visible. Various measures taken under the redevelopment projects also exhibit the improved reservoir health. The Field GOR level, which had increased to over 500 v/v in the early nineties, is consistently coming down and presently the GOR is around 254 v/v. Water-cut has been stable at around 60% during the last eight years (Figure 2). These measures taken in the Field led to further enhancing the oil production rate to the level of 100,000 bopd in June, 2005.

A major accident took place at BHN Process Platform in July, 2005. The process platform was completely destroyed in a fire without any physical remains above sea level. There was significant damage to the process platform NNF and moderate damage to the well-cum-process-platform NNA and gas-compressor-cum-water injection platform-MNW. The accident resulted in total loss of oil and gas production from Mumbai North Field. The multi-disciplinary team of Asset systematically devised and executed revival plans for restoring Mumbai High North Field production. The Revival plans envisaged resumption of production by surface facility modifications, diversion of fluid lines, creation of fluid handling capacity at the NNA platform, enhancing water injection to match voidage created , execution of NA1 development plan and a further redevelopment plan of the Field.

Mumbai High North Production Revival Milestones

The accident had incapacitated key production systems of Mumbai High North. Multiple actions were consolidated and put in place to recommence the production. A brief recount of activities is given below:

Resumption of NNQO Production

Prior to the accident, from the NNQO platform, oil production of 68,000 bopd was being dispatched to trunk line through the main oil line pumps of the MHN platform. High pressure gas was fed directly to the main gas trunk-line. Restoration of NNQO production could be accomplished through hooking up oil export facilities of NNQO to a new MUT line with modifications of NNQO platform's oil pumping facility. The work was completed within 30 days by the dedicated efforts of in-house teams, engineering consultants and offshore contractors.

Diversion of Well Platforms of BHN to NNQO and NMH South

Another priority task was to divert the maximum number of well platforms connected with the ill-fated BHN complex to nearby process platforms through the existing network of subsea lines with some modifications at surface. BHN's four well platforms NNV, NNJ, NNC and NN11 were diverted to NNQO after surface modifications at well platforms, interconnecting pipelines and converting the water injection lines to gas injection lines. This exercise led to a production gain of about 14,000 bopd. Figures 3A and 3B show the schematic of field diversions.

Re-Commissioning of NNA Platform

The re-commissioning of NNA, an old well cum process platform of the BHN complex, involved modifications for crude processing and evacuation through SBM-tanker mode. The processing facilities of NNA, which were not operative recently, were made operational by installing a Process Control room at the rig Sagar Samrat and connecting the same to NNA through a bridge. In this manner, the revival of production from four well platforms, NNA, NNB, NN5 and NNU was completed by December, 2005 and oil from NNA was dispatched to a tanker moored at NNA SBM. The re-commissioning of NNA platform added oil production to the tune of 8000 bopd.

Diversion of NN1 and NN2 platforms to NNQO

NN1 and NN2 well platforms were connected to NNQO using pipelines which were going to the BHN platform. The partly damaged underwater pipelines were located and repaired. In this way, production from two platforms (NN1 and NN2) were diverted to NNQO after underwater hook-up of the existing NNQG- NNF gas lift line with NN1-BHN well fluid line. The wells of NN2 platform started flowing through NN1 platform to NNQO. The production gain from this diversion was 3500 bopd.

Revival of NN9 Platform

The revival of these platforms were difficult due to the remote location of platform and non-availability of suitable pipeline hookups for diverting the well fluid line. In this set of activities, the sub-sea tie-in of BHN pipelines was involved. NN9 platform was put on production through NNQO by sub-sea tie-in of BHN-NNV and BHN-NN9 lines. The well fluid was taken to NNQO through NNV.

Revival of NMNW Platform

NMNW, the new process platform commissioned in 2004, was bridge connected to BHN. MNW had certain structural damage due to the severing of the bridge. The water injection plant of NMNW was commissioned in May-June, 2005. NMNW facilitated water injection and gas compression. The gas compressor was receiving gas from erstwhile BHN platform. Newly constructed MUT pipeline was also originating from NMNW. Due to the fire accident the gas input to MNW was cut off. NMNW revival scheme was designed to recondition the platform for power generation and water injection. Gas compression was required to arrest the gas flaring of NNA. By restoring NMNW gas compression, 1.9 MM m^3/d gas was fed to the gas lift grid and sales. These aforesaid actions taken in the field restored the production level to 80,000 bopd within six months.

NA1 Development Plan Implementation

Based on the success of horizontal wells in the periphery area of NMHN, a development scheme for NA1 reservoir was conceived with 19 new development wells through three light-weight bridge connected platforms NN2, NNEA and NNHA and six clamp-on wells from existing NNU and NN1 platforms. All the inputs of the scheme are in place and the project has been completed successfully. With the implementation of this scheme, oil production has reached to the level of 92,000 bopd by September, 2007 (Figure 4).

Improved Waterflood Performance of Main Reservoir

Water injection rate in NL-III reservoir was around 310,000 bwpd in August, 2002. Due to leakage in some of the pipelines, water injection was suspended in some of the injectors and the injection came down to around 180,000 bwpd. Injection was further affected due to conversion of some of the lines to gas injection after the BHN accident and the voidage replacement ratio (VRR) remained at around 60-70%. Since August, 2006 efforts were made to improve the water injection scenario through laying of new pipelines and opening of closed injectors. Water injection was redistributed in needy reservoir layers through profile modifications, stimulation of injectors, conversion of new injectors and regulation of water injection to control breakthrough in nearby producers. With all these efforts the injection level has improved to around 315,000 bwpd and VRR around 98% (Figure 5). A bubble map of current water injection in MHN L-III is shown in (Figure 6) which indicates the distribution of water injection rates throughout the Field. The distribution pattern of injection water which initially started with peripheral injection wells, got significantly modified to balance the withdrawal rate from individual layers in different part of the Field.

Productivity Enhancement - Horizontal Wells

Marked improvement in productivity has been achieved in the low permeability west flank area by resorting to horizontal wells. A similar enhancement has been achieved in case of low permeability lower zones in the crestal part of the reservoir.

Use of horizontal wells and multi-laterals has led to economic development of thin layers, particularly in the fringe area with sweet zones as low as 3 m thick. Horizontal well placement in these complex geometry reservoir layers is being carried out with the help of fine scale geological earth modeling and geosteering with logging-while-drilling tools. Wells with drain hole length up to 1100 m horizontal sections have been drilled in the thin oil column. The horizontal wells completed in thin layers have offered the advantage of accelerated production with less drawdown and delayed water production. The average production from the horizontal wells is about 2 to 3 times higher than the average productivity of the conventional wells in the same layers (Figure 7) realizing early oil gain.

Improved Well Production -Multi Laterals

In the structurally high eastern part of the Field, a major portion of the L-III reservoir is gas bearing and the lower layers hold significant untapped oil saturations. The conventional wells in this area had problems of poor primary cementation in the shale section and across the pay zone. The wells completed produced with high gas cut due to channeling, cusping and coning affecting the well productivity. Low pay thicknesses of the layers with deteriorating petro-physical characteristics deterred the initial development of this sector and contributed to the overall lower recovery factor. Encouraged by the primary success of horizontal wells in thin upper layers in the peripheral areas, the technology has been extended to oil bearing lower sub-layers beneath the gas-cap. A number of horizontal wells have been successfully placed in these zones using LWD-Geosteering. Wells recently completed in the eastern part of Field have produced with better initial oil rates with normal GOR. Multi-lateral drilling in multi-layers recently attempted to address two and more layers through dual completions in some of the wells has given encouraging results. Multi-lateral completions using swell packers and dual completions is providing better management of reservoir layers separately. The completion sketch of a specific well is presented in (Figure 8).

Redevelopment Phase-II

With the objective of the production enhancement and further improvement in recovery from the Field, Mumbai High North Redevelopment Phase-II is conceived. The development plan envisages integrated development of NL-III, NL-II and NL-I reservoirs of MH North. The envisaged inputs are drilling of 52 wells from five new platforms, 21 wells from existing free slots and 3 wells from clamp-on with 38 side-track wells The cumulative oil production works out to 206.91 MMt and incremental oil gain with respect to Base variant is 18.555 MMt. Oil recovery is 31.7% (Figure 9). The oil recovery of L-III reservoir is likely to be 33%.

Conclusions

● The inherent strength of the Asset was fully exploited for production revival and as a result, the production was restored 85% within two months of the BHN fire accident.

● Successful implementation of NA1 layer development in the field has further accelerated the production to the current level of 92,000 bopd within two years despite offsetting the natural decline and fluid handling constraint in the Field.

● The Focused layer wise management of water injection commensurate to withdrawal has helped in controlling water cut, reducing GOR and maintaining base production from the Field.

● Hi-tech horizontal and multi-lateral infill drilling with new generation tools and improved mud system with new completion techniques has helped in improved productivity of wells.

● Adoption of the evolving technologies is expected to continue to provide leverage for further boosting of production and improvement of recovery from the field during proposed implementation of phase-2 redevelopment scheme.

Acknowledgement

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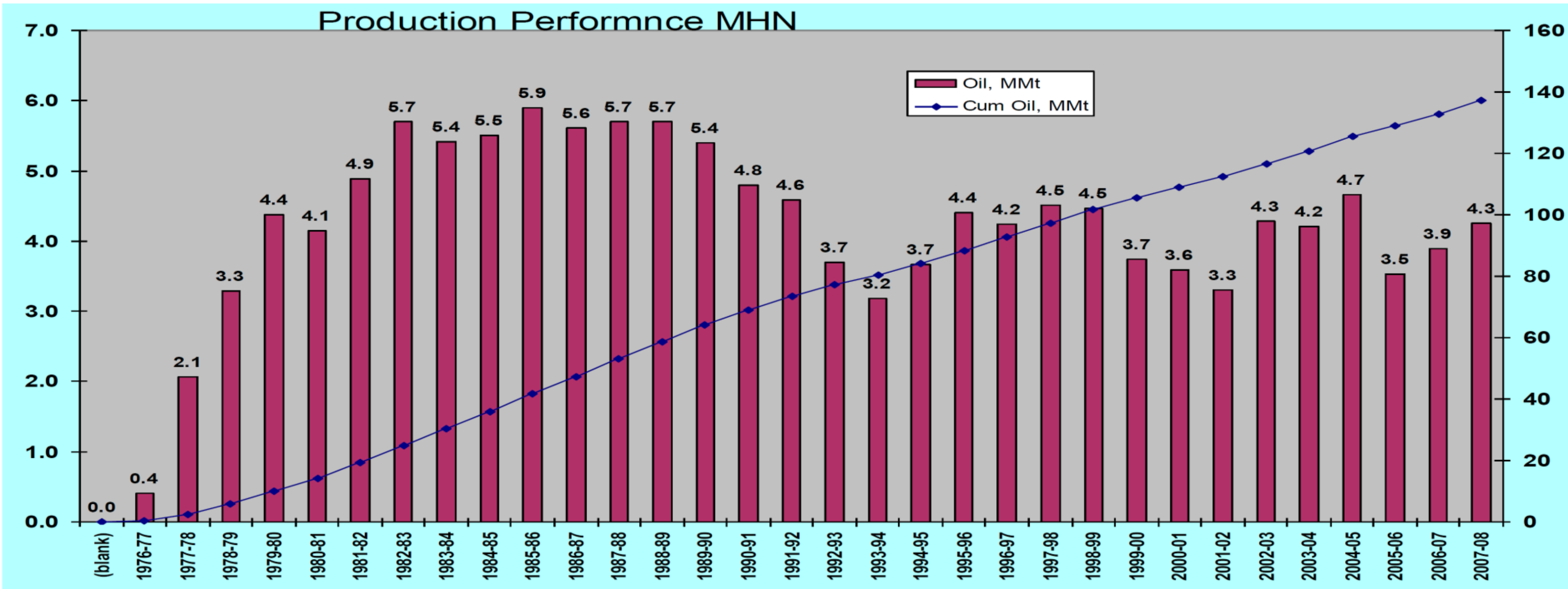


Figure 1. Production performance of Numbai High North Field.

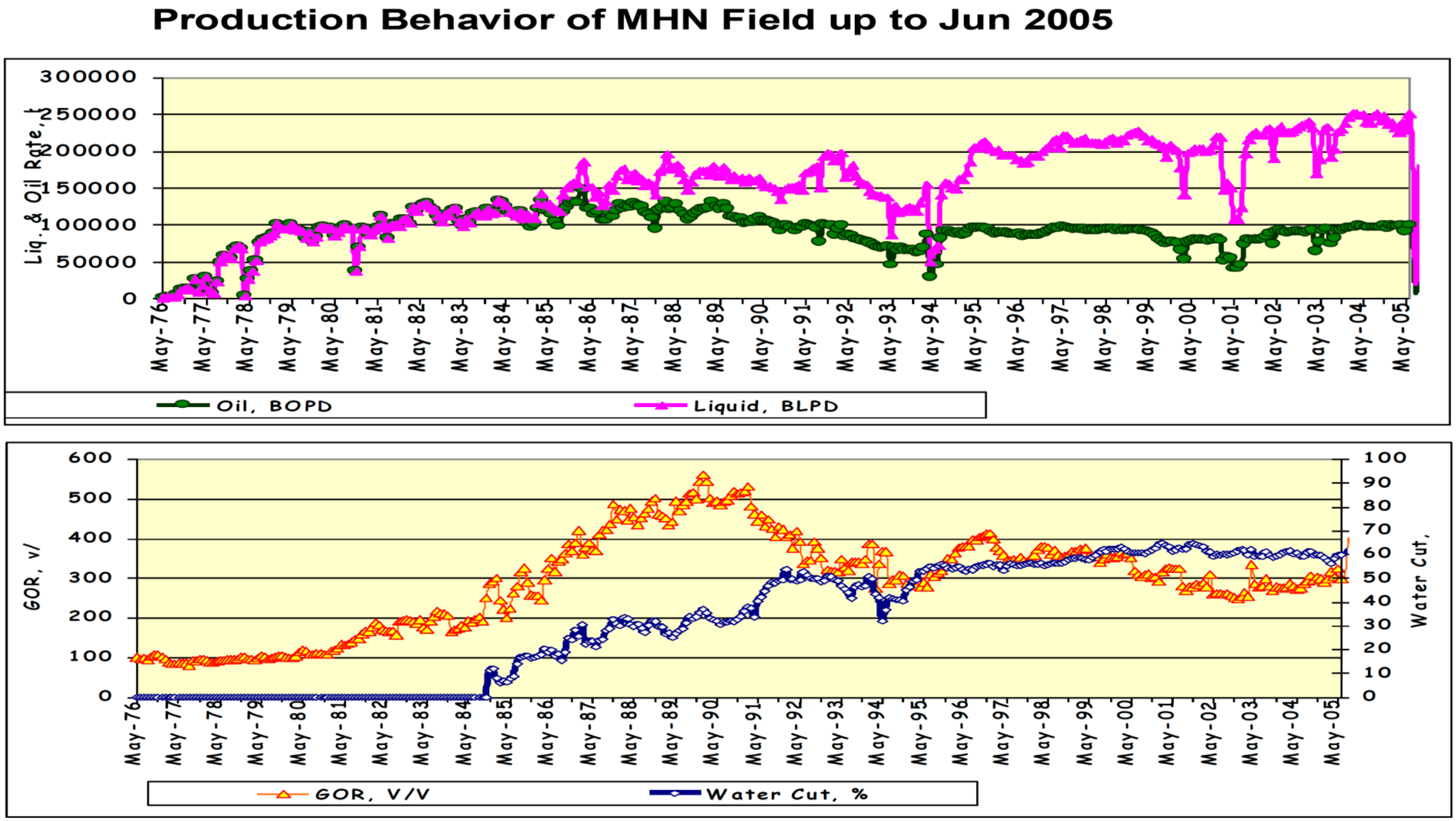


Figure 2. Production behavior of Mumbai High North Field to June 2005.

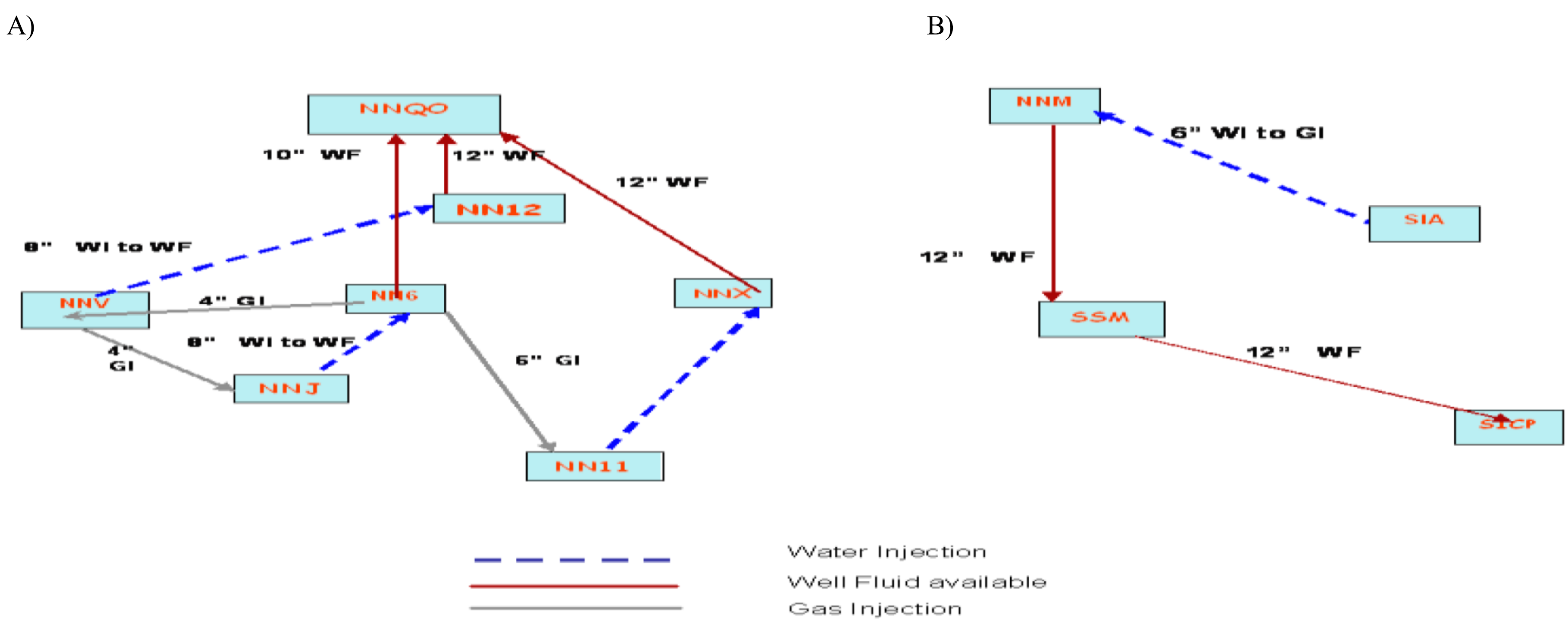
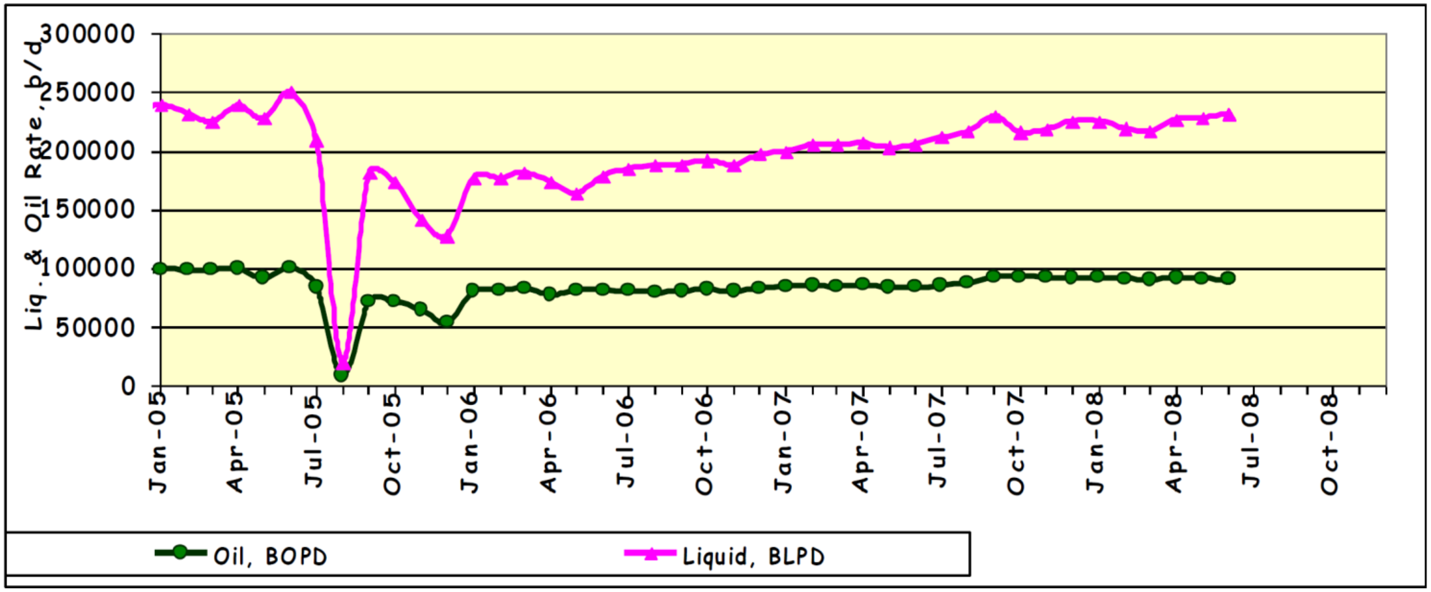


Figure 3. A) Diversion of well platforms to NNQO. B) Diversion of NNM to SICP.



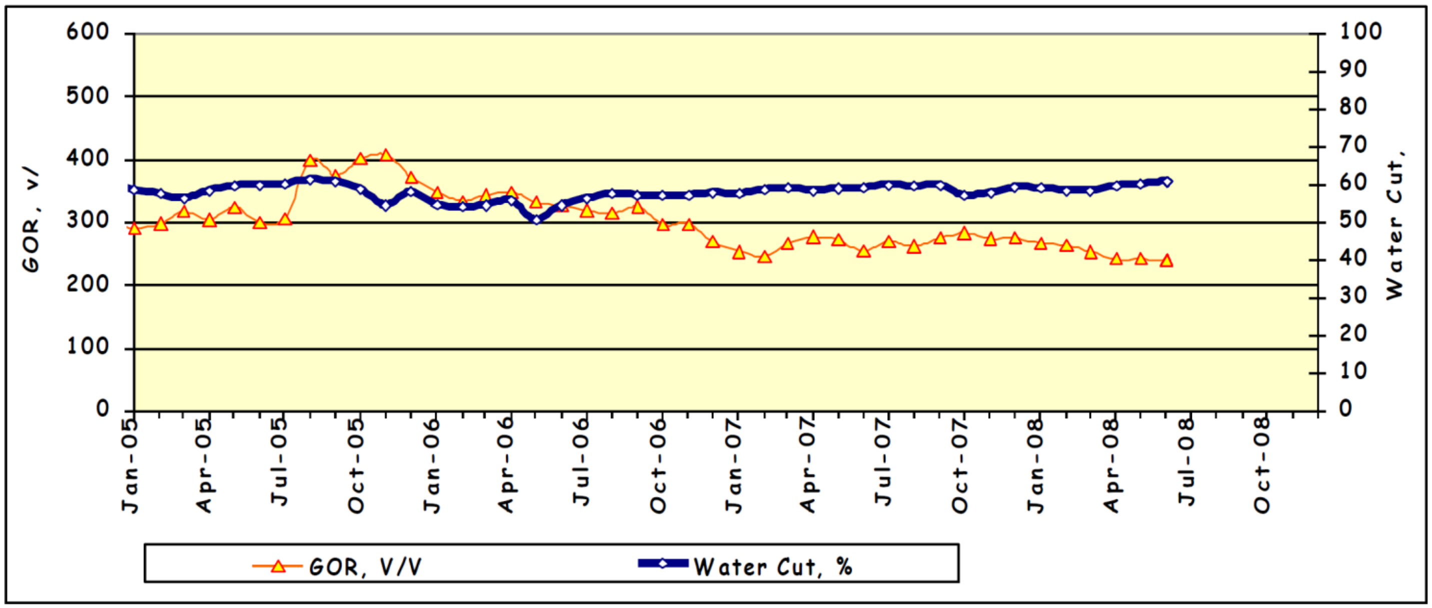


Figure 4. Production behavior of Mumbai High North Field after June 2005.

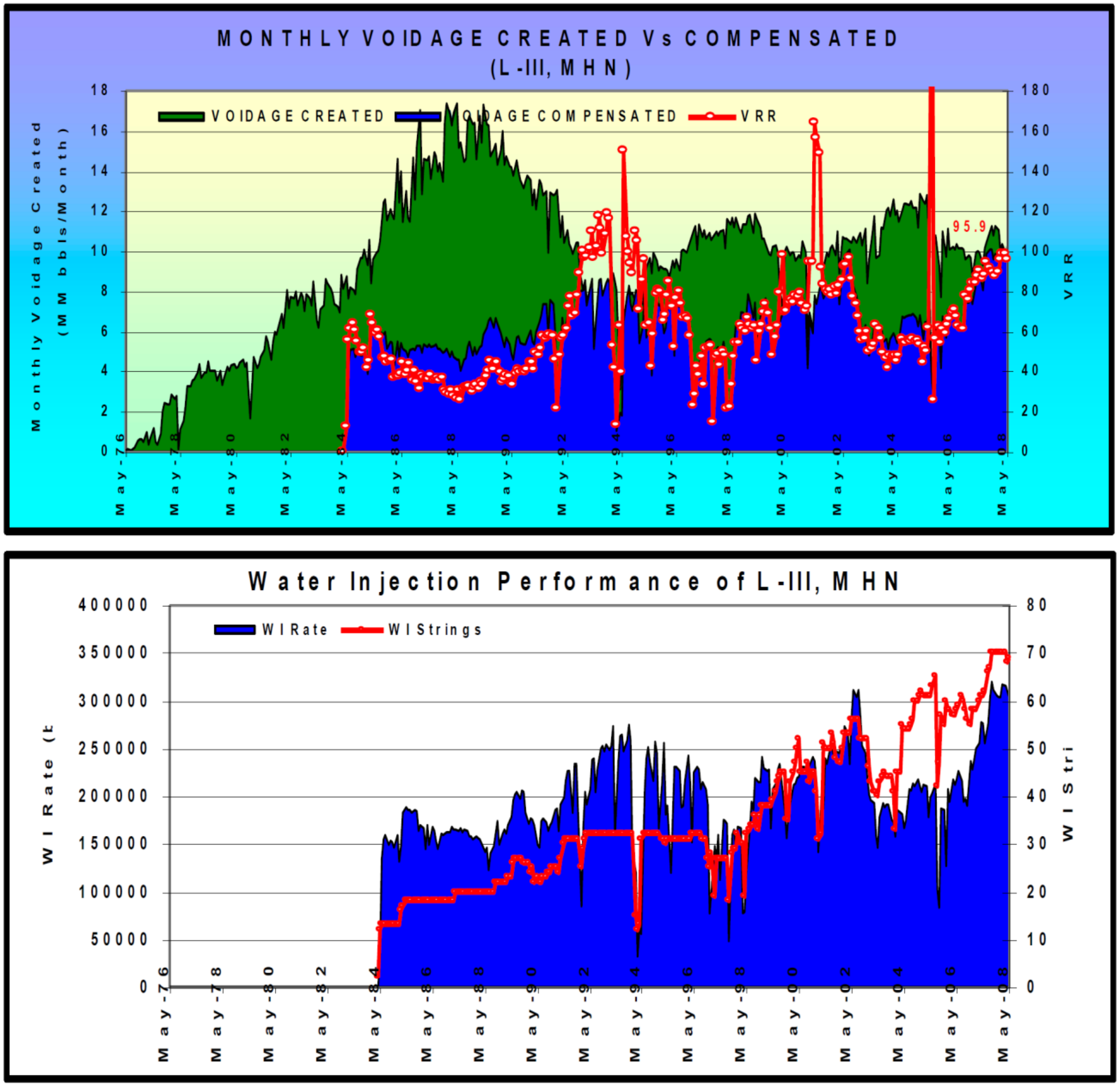


Figure 5. Water injection performance of Mumbai High North Field.

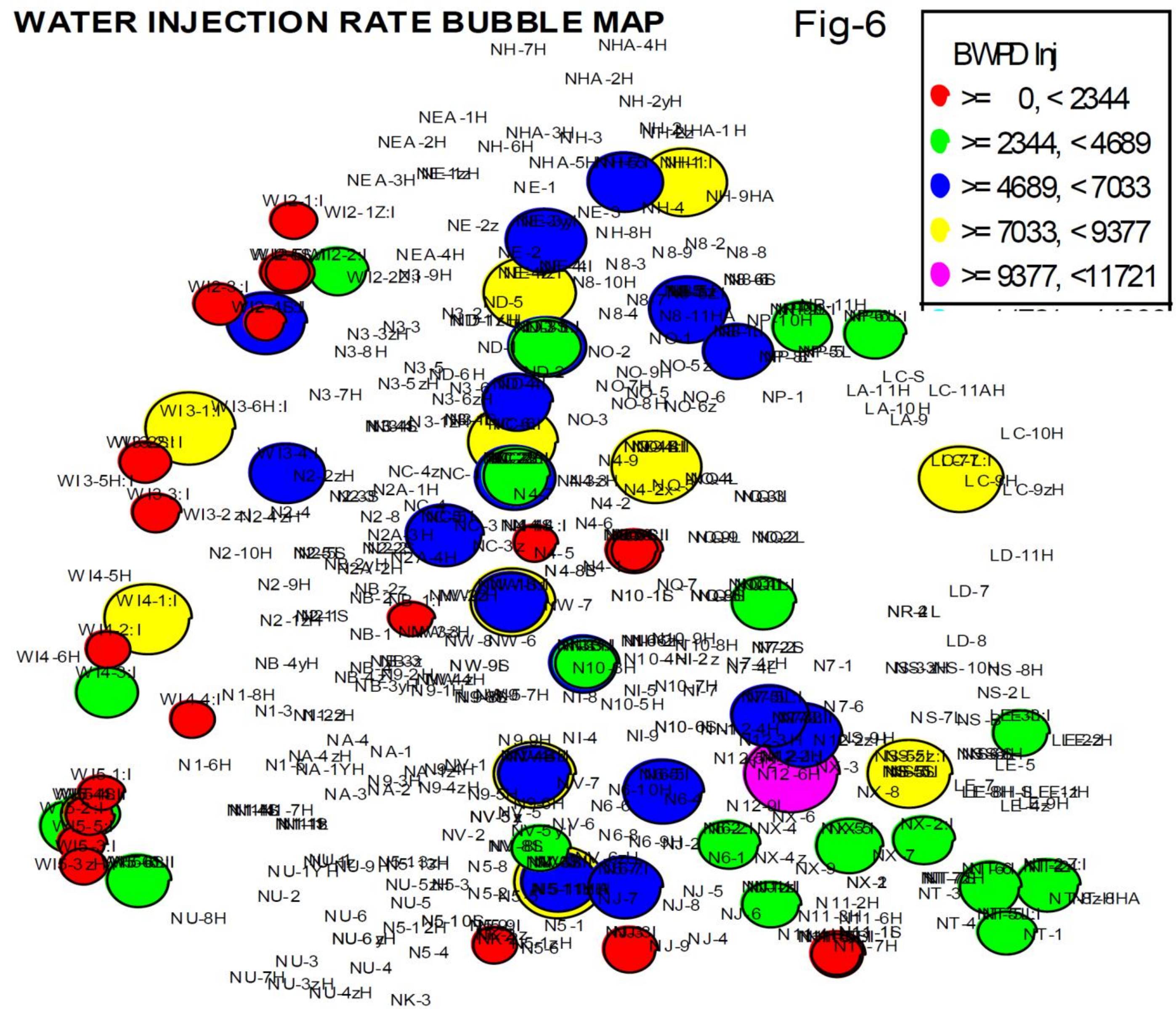


Figure 6. Water injection rate bubble map.

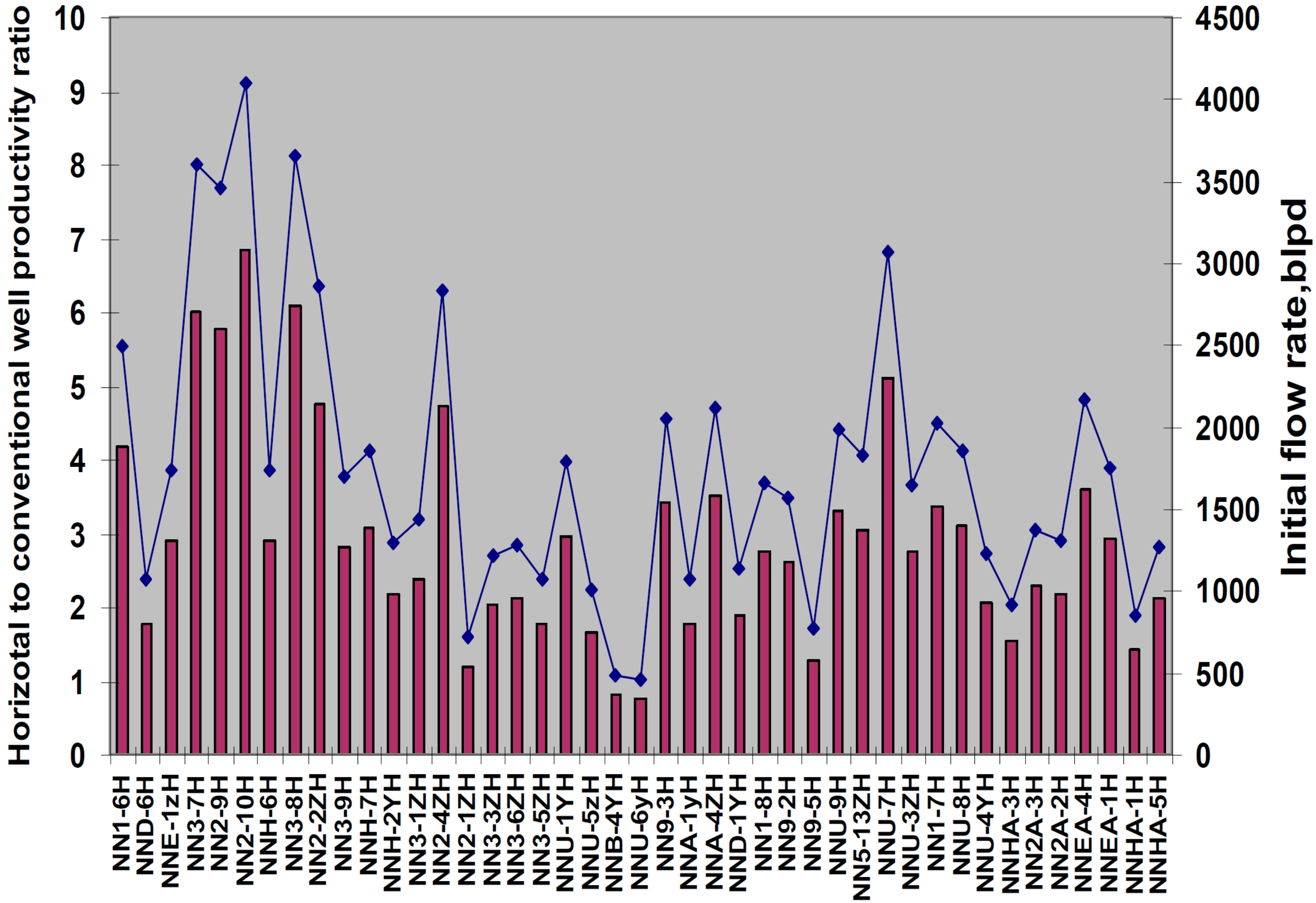
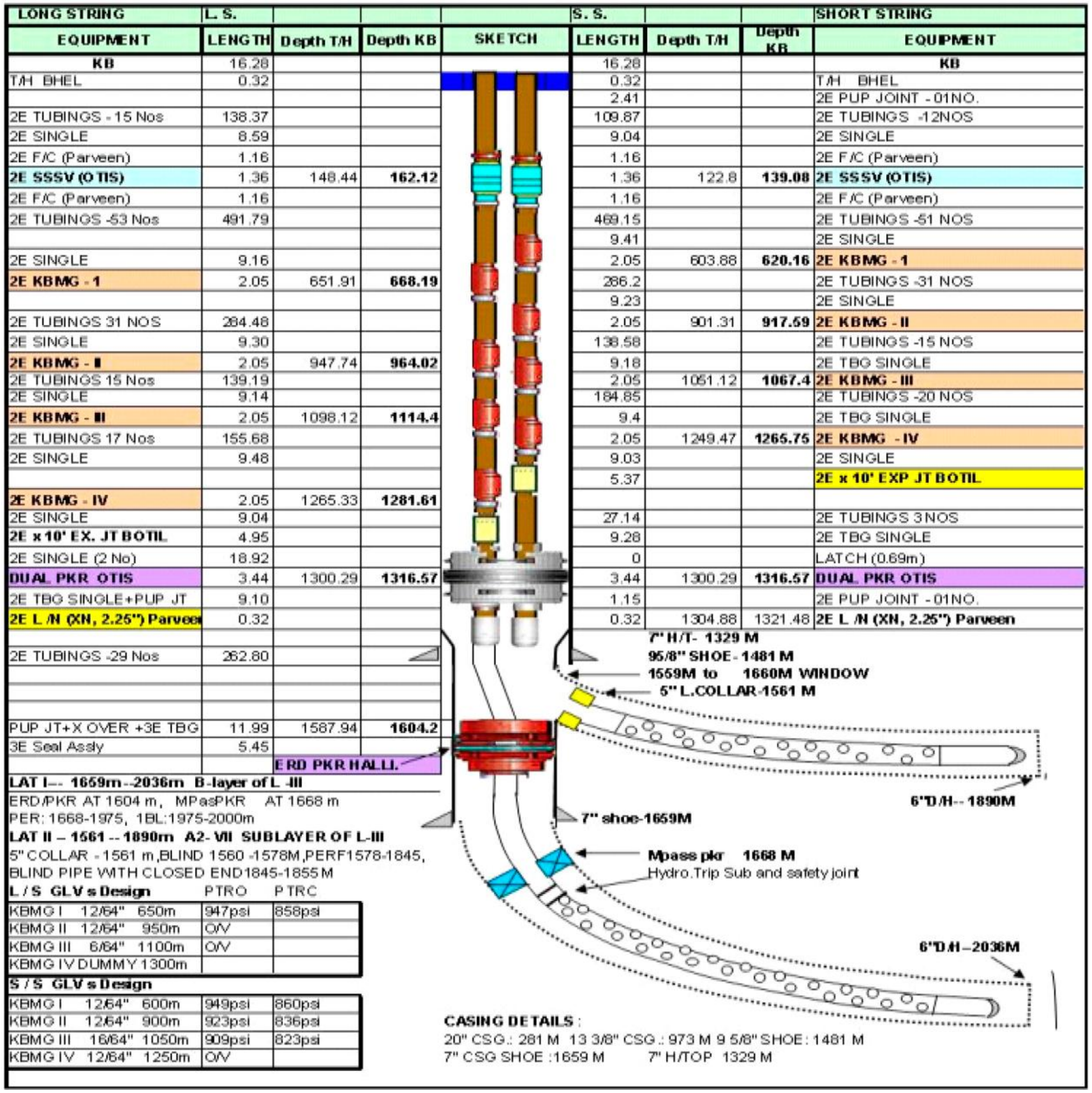


Figure 7. Productivity of horizontal to conventional wells for NA1 layer.



LONG STRING EQUIPMENT	L. S. LENGTH	Depth T/H	Depth KB	S. S. LENGTH	Depth T/H	Depth KB	SHORT STRING EQUIPMENT
KB	16.28			16.28			KB
T/H BHEL	0.32			0.32			T/H BHEL
				2.41			2E PUP JOINT - 01NO.
2E TUBINGS - 15 Nos	138.37			109.87			2E TUBINGS -12NOS
2E SINGLE	8.59			9.04			2E SINGLE
2E F/C (Parveen)	1.16			1.16			2E F/C (Parveen)
2E SSSV (OTIS)	1.36	148.44	**162.12**	1.36	122.8	**139.08**	**2E SSSV (OTIS)**
2E F/C (Parveen)	1.16			1.16			2E F/C (Parveen)
2E TUBINGS -53 Nos	491.79			469.15			2E TUBINGS -51 NOS
				9.41			2E SINGLE
2E SINGLE	9.16			2.05	603.88	**620.16**	**2E KBMG - 1**
2E KBMG - 1	2.05	651.91	**668.19**	286.2			2E TUBINGS -31 NOS
				9.23			2E SINGLE
2E TUBINGS 31 NOS	284.48			2.05	901.31	**917.59**	**2E KBMG - II**
2E SINGLE	9.30			138.58			2E TUBINGS -15 NOS
2E KBMG - II	2.05	947.74	**964.02**	9.18			2E TBG SINGLE
2E TUBINGS 15 Nos	139.19			2.05	1051.12	**1067.4**	**2E KBMG - III**
2E SINGLE	9.14			184.85			2E TUBINGS -20 NOS
2E KBMG - III	2.05	1098.12	**1114.4**	9.4			2E TBG SINGLE
2E TUBINGS 17 Nos	155.68			2.05	1249.47	**1265.75**	**2E KBMG - IV**
2E SINGLE	9.48			9.03			2E SINGLE
				5.37			**2E x 10' EXP JT BOTIL**
2E KBMG - IV	2.05	1265.33	**1281.61**				
2E SINGLE	9.04			27.14			2E TUBINGS 3 NOS
2E x 10' EX. JT BOTIL	4.95			9.28			2E TBG SINGLE
2E SINGLE (2 No)	18.92			0			LATCH (0.69m)
DUAL PKR OTIS	3.44	1300.29	**1316.57**	3.44	1300.29	**1316.57**	**DUAL PKR OTIS**
2E TBG SINGLE+PUP JT	9.10			1.15			2E PUP JOINT - 01NO.
2E L /N (XN, 2.25") Parveen	0.32			0.32	1304.88	1321.48	**2E L /N (XN, 2.25") Parveen**
2E TUBINGS -29 Nos	262.80						
PUP JT+X OVER +3E TBG	11.99	1587.94	**1604.2**				
3E Seal Assly	5.45						
		ERD PKR HALLI.					

LAT I--- 1659m--2036m B-layer of L -III
ERD/PKR AT 1604 m, MPasPKR AT 1668 m
PER: 1668-1975, 1BL:1975-2000m
LAT II – 1561 -- 1890m A2- VII SUBLAYER OF L-III
5" COLLAR - 1561 m, BLIND 1560 -1578M, PERF1578-1845, BLIND PIPE WITH CLOSED END1845-1855M

L / S GLV s Design	PTRO	PTRC
KBMG I 12/64" 650m	947psi	858psi
KBMG II 12/64" 950m	O/V	
KBMG III 6/64" 1100m	O/V	
KBMG IV DUMMY 1300m		

S / S GLV s Design		
KBMG I 12/64" 600m	949psi	860psi
KBMG II 12/64" 900m	923psi	836psi
KBMG III 16/64" 1050m	909psi	823psi
KBMG IV 12/64" 1250m	O/V	

CASING DETAILS :
20" CSG.: 281 M 13 3/8" CSG.: 973 M 9 5/8" SHOE: 1481 M
7" CSG SHOE :1659 M 7" H/TOP 1329 M

Figure 8. Multilateral completion of well NN-11H.

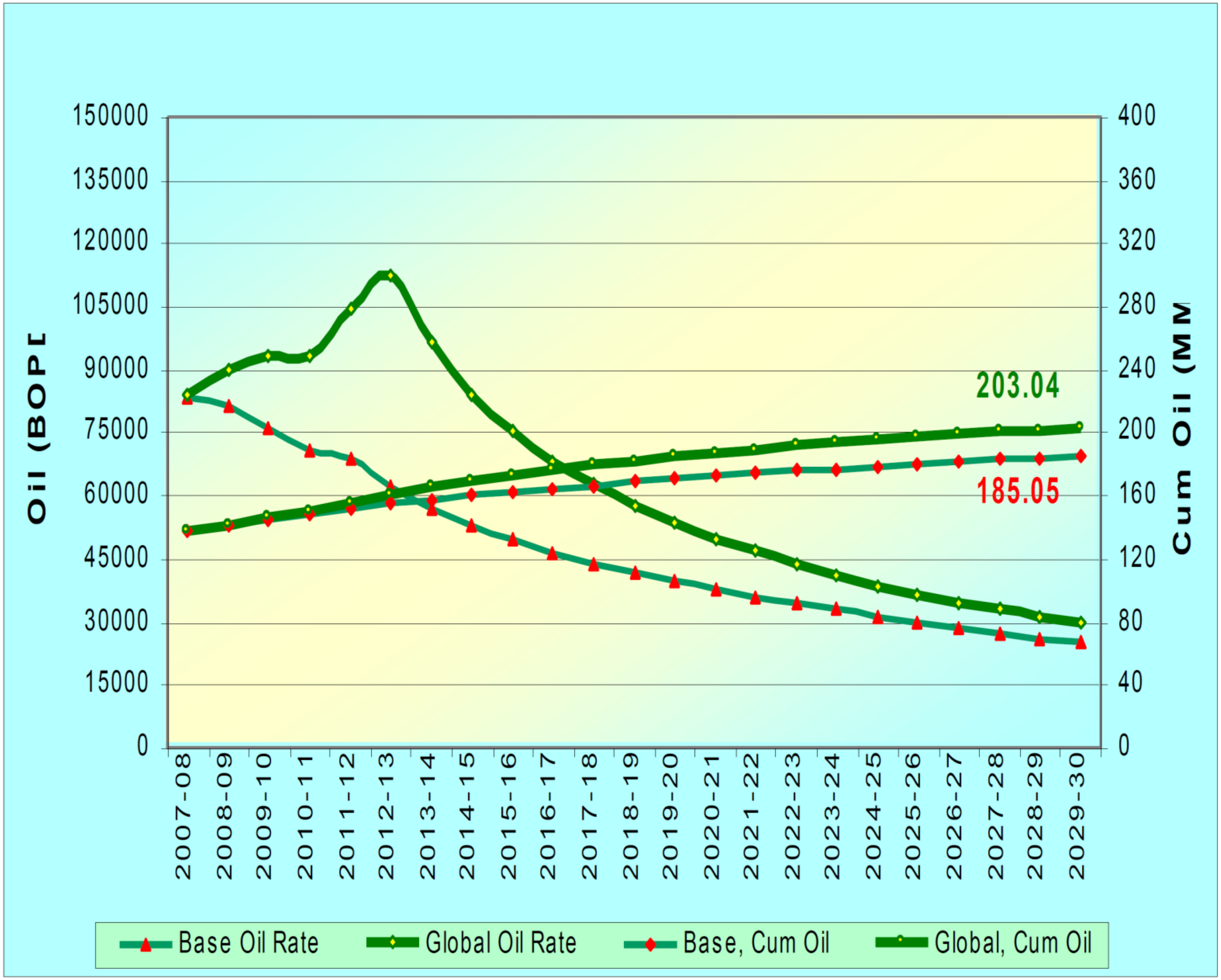


Figure 9. Production Profile (Base vs. Incremental), FR Phase-II.