Report of the Comptroller and Auditor General of India on Water Injection Operations in Western Offshore, ONGC

Union Government
Ministry of Petroleum & Natural Gas
No. 19 of 2021
(Compliance Audit)

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Contents

Preface

The Compliance Audi Report on 'Water Injection Operations in Western Offshore, ONGC' has been prepared under the provisions of Section 19-A of the Comptroller and Auditor General's (Duties, Powers and Conditions of Service) Act, 1971 for submission to the Government. The Audit has been carried out in line with the Regulations on Audit and Accounts, 2007 (revised in August 2020) and Compliance Audit Guidelines of the Comptroller and Auditor General of India.

The Audit covered the period from 2014-15 to 2018-19. The Report is based on the scrutiny of documents pertaining to the Oil and Natural Gas Corporation Limited. The Audit was conducted to get an assurance whether adequate water (quantity and quality) were injected into the reservoir, and if not, the reasons thereof. Audit revealed deficient planning resulting in lesser than sufficient injection into the reservoir, delay in revamping/ maintenance of critical equipment as per the adopted norms leading to equipment failure and affecting the quality and quantity of water injected. Against intended level of 100 *per cent* voidage compensation through water injection, as of March 2019, the company could achieve a cumulative voidage compensation of 54.43 *per cent,* 42 *per cent* and 78.8 *per cent* in Mumbai High, Neelam and Heera fields respectively. The insufficient injection was one of the reasons for not achieving the production envisaged in the redevelopment schemes of these fields.

Audit wishes to acknowledge the co-operation and assistance extended by the officers and staff of Ministry of Petroleum and Natural Gas, Government of India and ONGC for this Compliance Audit. Audit also places on record the cooperation extended by University of Petroleum Energy and Studies, the Consultant, during the course of field Audit and finalization of Audit Report.

Executive summary and recommendations

Oil and Natural Gas Corporation Limited (ONGC) is contributing around 70 *per cent* of domestic production of crude oil in the country. Mumbai High, Neelam and Heera fields of western offshore contribute around 59 *per cent* of this production. These fields have been operating from 1976 and 1984 respectively and therefore these mature fields are susceptible to decline in production. Water injection is a method for reservoir health management and increasing crude oil recovery from the reservoir.

A Compliance Audit was conducted to review performance of water injection operations in western offshore of ONGC for the period 2014-15 to 2018-19 with the following objectives to assess whether:

1. the requirement of water injection planned in the annual water injection build-up plan was commensurate with requirement envisaged in field development schemes/ feasibility reports approved by the management and planned quantity was injected into the reservoir,
2. requisite water injection equipment were made available to inject required quantity of water into reservoir,
3. desired quality of water was injected into the reservoir and
4. water injection facilities were maintained through corrosion monitoring, pigging of water injection lines, workover of injectors, stimulation of injection wells and backwash of injectors.

Results in Brief

There was inadequate water injection with less than one voidage replacement ratio and cumulative voidage compensation (as of March 2019) was only 54.43 *per cent* in Mumbai High, 78.8 *per cent* in Heera and 42 *per cent* in Neelam fields. Water injection in the field was affected due to ageing of injection infrastructure, frequent pipeline leakages due to poor quality of injection water, non-implementation of feasibility report inputs and to some extent, production from high gas-oil ratio wells. This led to drop in reservoir pressure sharply and impacted crude oil production. Even by the estimate of the company at the request of Audit, this deficient water injection impacted loss of production of crude worth ₹7,802.50 crore for ONGC and revenue loss of ₹3,474.29 crore to the Government of India by way of statutory levies during the audit period. This loss cannot be considered as deferred production but a permanent loss of oil. Further, even for exploitation of a part of this oil deficit, additional investment is required and this needs review from the point of economical oil recovery.

Audit findings

Planning and implementation of requirement of water injection

The annual plans for water injection were lower than the requirement as provided in the re-development schemes by 5 to 46 *per cent* during 2014-15 to 2018-19. The annual plan is prepared under resources constraints and instead of overcoming the constraints, they were accepted as reality and planned accordingly. Even the reduced annual targets were not achieved.

(Para 3.2 and 3.3)

Water injection quantity was measured regularly at water injection platform end. With multiple leakages in injection lines noticed during 2014-15 to 2018-19, injection quantity measured and reported at water injection platform end was not the correct measure of quantity injected into the reservoir.

(Para 3.5)

The company commenced water injection six to eight years after commencement of field production in Mumbai High, Neelam and Heera. Cumulative voidage compensation as on 1 April 2019 was only 54.43 *per cent,* 42 *per cent* and 78.8 *per cent* in Mumbai High, Neelam and Heera fields respectively.

(Para 3.6)

With reference to Audit findings on Planning and implementation of requirement of water injection, Audit recommends that:

1. ***Annual planning for water injection should emanate from the field development schemes. The company may devise a comprehensive catch-up plan to compensate the excess voidage created.***
2. ***Quantity of water injected has to be measured at unmanned platform end for better and timely monitoring. Integration of SCADA with the online meters may be considered in all platforms.***

Water injection surface facilities and equipment

Chemical dosing pumps which were required to maintain desired quality to avoid corrosion of water injection equipment, clogging of wellbore and indirectly affecting crude oil production were not considered as essential equipment.

(Para 4.3)

The equipment replacement policy adopted by the company was not adhered to and failure of equipment was attributed to delay in overhauling and replacement/ revamping along with deficiency in maintenance.

(Para 4.4)

System availability (availability of equipment for un-interrupted flow of production) of critical equipment was below the adopted target of 100 *per cent*. Instances were noticed where system availability of the equipment were shown as 100 *per cent* when the equipment failed to meet the field requirement or equipment was shown available when it was sent on repairs. Absence of data in ERP system, lack of proper mapping and maintaining important equipment details outside the ERP indicated that the company did not use the Plant Maintenance module of SAP-ERP effectively to obtain the intended benefits.

(Para 4.5, 4.6, 4.7 and 4.8)

There were delays in initiating revamping/ replacement process because of improper planning. Original Equipment Manufacturer (OEM) recommended norms/ maintenance practices were not followed leading to equipment deterioration and rendering it unsafe for full scale operation. In Mumbai High, 52 *per cent* of the critical/ major water injection rotary equipment were overdue for overhaul.

(Para 4.9 and 4.10)

With reference to Audit findings on Water injection surface facilities and equipment, Audit recommends that:

3. ***The company should ensure maintenance of the equipment availability data through SAP system and ensure generation of reports directly from SAP.***
4. ***The company needs to consider efficiency/ performance of the equipment for meeting the operational requirement while working out the 'system availability' of equipment. Management should ensure reliability and availability of equipment for un-interrupted operation.***
5. ***Management may extensively use functionalities under Plant Maintenance module in SAP system so as to get its intended benefit of aiding performance analysis, improving operational effectiveness and providing useful insights to Management decisions.***
6. ***The company should timely initiate proposals for overhauling and replacement/ revamping to ensure system availability. Also, Original Equipment Manufacturer recommendations for maintenance practices should be adhered to.***
7. ***The Replacement policy needs a relook to ensure that the efficiency of the aged pumps is also considered when repair versus replacement decisions are taken.***

Quality of water injection

The company failed to meet desired quality parameters, despite dilution of some of the quality parameters over a period. The quality of water in many water injection platforms was observed as inferior to the quality parameters currently followed by the company.

(Para 5.2 and 5.3)

The dosing of chemicals was not ensured to be within recommended levels and in large number of cases, 'nil' and lower dosing of chemicals was observed. This has consequences of plugging formation, pipeline leakage, etc. Discrepancies and inconsistencies were also noticed in reporting of the water quality. Important quality parameters were not captured due to non-functioning of quality measurement instruments.

(Para 5.4 and 5.5)

Quality of water is measured at water injection platform from where it was despatched and reported the quality of water injected into reservoir. However, due to corrosion in water injection lines, quality of water deteriorated en-route to wellheads. Thus, actual quality of water injected into reservoir was inferior to the quality reported at water injection platform.

(Para 5.6)

With reference to Audit findings on quality of water injection, Audit recommends that:

8. ***Due diligence while recording the data and feeding in SAP system should be ensured so that the desired quality parameters required for injection into the reservoir can be monitored and ensured.***
9. ***Dosing of adequate chemicals as per norms should be maintained so that quality parameters of water are monitored for timely corrective action.***
10. ***The Company needs to properly maintain the data of system and equipment availability of chemical injection system in future for monitoring and timely corrective action.***
11. ***Requisite quality of water injected into reservoir should be monitored throughout the water injection process and ensured till the well-head end for all parameters.***

Maintenance of water injection pipelines and injectors

Reports of the corrosion monitoring revealed that corrosion rate of water injection pipelines was above safe limit. Pigging helps to remove debris deposited in pipelines, control of microbes and monitoring of pipeline integrity. There was substantial shortfall in pigging operation against requirement and there was inadequate analysis of pigging samples. Internal corrosion was the primary reason for premature failure of water injection lines. Rather than mitigating the corrosion issues, the company reduced the design service life of water injection lines from 25 to 15 years. Time lag was observed between date of leakage and date of repair/ replacement which contributed to substantial loss of water injection.

(Para 6.1, 6.2 and 6.3)

To restore or improve the performance of a well, workover or well servicing activities are taken up. In Mumbai High field, workover was carried out only in 49.59 *per cent* wells against the wells planned. In Neelam and Heera fields, injection wells were serviced after a gap of 15-20 years. This had long term impact on reservoir pressure and ultimate oil recovery.

(Para 6.4)

Well stimulation is a well intervention procedure adopted as water injection wells were prone to plugging. Stimulation jobs were carried out in Mumbai High field and Neelam & Heera field in only 18 *per cent* and 39 *per cent* respectively against the approved workload. Situation did not improve even after hiring dedicated stimulation vessel for injection wells.

(Para 6.5)

With reference to Audit findings on maintenance of water injection pipelines and injectors, Audit recommends that:

12. ***Considering large number of pre-mature failure of lines, the company may strengthen corrosion monitoring system urgently. More locations away from the main injection pumps should also be taken up for corrosion monitoring in future.***

13. ***The company should adhere to defined frequency of the pigging of lines to ensure health of pipelines and to prevent its faster corrosion. The company should follow pigging operation strictly as per SOP by taking samples on each pig run and analyse them for required quality parameters and microbial growth for corrective actions.***

14. ***The company needs to institute a mechanism to workover these water injection wells in a timely manner and prepare action plan accordingly. This will help the company to keep water injection wells in healthy condition and ultimately to attain the goal of maintaining the reservoir pressure for increasing productivity of oil wells.***

15. ***The company should review its present practice/ policy of need based approach of stimulating water injection wells to make it in line with the best industry practices. This will help in taking preventive measures before serious damage occurs to the system or wellbore and to improve injectivity of wells.***

16. ***The company should regularly backwash the wells as per defined periodicity to improve injectivity of wells and increase water injection. Also resources planned/ mobilized for water injection may be considered separate from the requirements for producer wells.***

Impact of inadequate water injection

There was continuous decline in reservoir pressure due to inadequate water injection since inception of fields which impacted crude oil productivity and its ultimate recovery. Decline in reservoir pressure is further accentuated by higher gas production from the reservoir. Periodic recommendations of the Ministry on importance of water injection, its distribution and maintenance of reservoir health were not fully implemented.

(Para 7.1)

The Performance Benchmarking Group of the company did not benchmark key performance indicator of 'reservoir health' with world's leading exploration and production companies. Instead, it fixed static targets based on inputs received from its strategic business units. Further, effective 2019-20, the parameter 'reservoir health' is not part of the performance contract indicating lack of monitoring of reservoir health by the management.

(Para 7.2)

Shortfall in water injection is one of the significant reasons for less production of crude oil. At the request of Audit, in-house research institute, Institute of Reservoir Studies (IRS) of the company, used the existing simulation model to arrive at the crude that could not be produced due to lesser water injection and worked out oil deficit of 3.695 MMT during audit period. Audit reworked the IRS quoted oil deficit by considering actual operation losses which was 3.79 MMT. The value of oil deficit of 3.79 MMT due to less water injection worked out to ₹11,276.79 crore. Out of this, value of oil deficit was ₹7,802.50 crore for ONGC after considering the statutory levies and the balance ₹3,474.29 crore is revenue loss to the Government of India.

(Para 7.3)

With reference to Audit findings on impact of inadequate water injection, Audit recommends that:

17. ***Company may devise a time bound action plan to address pressure sinks by ensuring injection volumes to redevelopment scheme levels and avoid uneven areal spread of water injection.***

18. ***Company should fix the target considering benchmark of international/ industry best performance rather than achievable basis so as to evaluate true performance of its operation. Weightage of water injection may be increased in performance monitoring and benchmarking.***

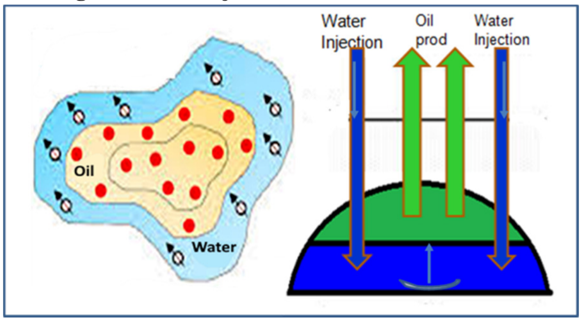
Management/ Ministry accepted (February/ June 2021) the above recommendations and assured that necessary steps are being taken to strengthen the processes. During the exit conference (September 2021), action initiated by the company on overhauling of equipment, improvement of water quality, installation of meters at unmanned platforms and connecting them to SCADA were explained.

Chapter 1

Introduction

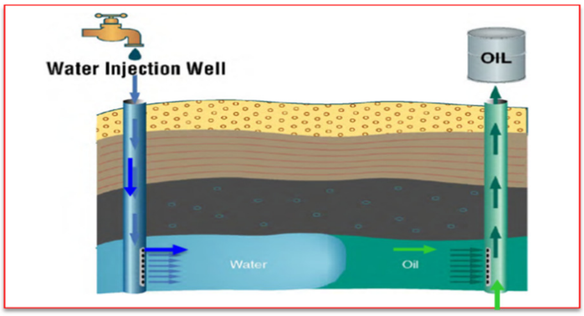
Oil and Natural Gas Corporation Limited (ONGC/ Company) is a Maharatna Public Sector Undertaking (PSU) contributing around 70 *per cent* of domestic production of crude oil in the country, of which around 59 *per cent* is produced from the western offshore nomination fields. Oil production is divided into three distinctive phases, *viz*., primary, secondary and tertiary. During the primary stage, the natural reservoir energy drives the production. The secondary stage is aided by injection of external fluid, commonly water or gas, into the reservoir to increase the pressure and thereby stimulate oil recovery. Water flooding remains the most prominent oil recovery method. In tertiary stage, Enhanced Oil Recovery[1] (EOR) method is required to produce residual oil trapped in reservoir. Primary and secondary methods combined produce up to 50 *per cent* of the oil in place and for the remaining oil trapped in the reservoir (residual oil), Enhanced Oil Recovery (EOR) method arises in the tertiary phase.

Fig 1.1 Water Injection: Pressure maintenance



The water is injected in the aquifer through several injection wells surrounding the production well.

Fig 1.2 Water injection: Sweep (water flooding)



The water is injected in the oil zone to create sweep effect.

Water is injected to support pressure of the reservoir (known as voidage replacement) and also to sweep or displace oil from the reservoir and push it towards the well. Water injection is one of the most useful techniques for enhancing the oil production not only because of the low cost of water but also because of the characteristics of water which helps sweep the trapped oil efficiently. It is the most successfully used secondary oil recovery method in oil fields of all sizes all over the world.

1.1 Water injection process at offshore

The water injection process consists of drawing raw seawater from the depth of about 30 metres by seawater lift pumps. This water is filtered and treated with chemicals to remove suspended solids, biological growth and dissolved oxygen. The treated water is pumped by injection pumps to various well platforms. Water injection facilities consist of water

[1] *EOR is a method of oil recovery by injection of materials not normally present in the reservoir.*

injection processing platform, water injection line, water injection well/ string[2], metering system for measuring the amount of water injected in each well/ wells, etc.

1.2 Development of Mumbai High, Neelam and Heera fields

Mumbai High field, located in the Arabian sea at about 165 km west-north west of Mumbai city in the western offshore, is the largest and most prolific oil field in India and was put in production in May 1976. The field has been divided into two blocks - North and South and has estimated initial-oil-in-place of 1,696 million metric tonnes. Mumbai High field progressed over a period of time through series of development programs since 1976. In order to improve oil recovery from the field, a major re-development[3] program was launched during 2000-01. Water injection in Mumbai High North field was initiated in April 1984 and three rounds of development took place from 2001 to 2018. Re-development scheme (Phase IV) approved in April 2019 is presently under execution. Mumbai High South field was put on production in 1980 and water injection commenced in 1987. The last three rounds of development took place from 2001 to 2018. Re-development (Phase IV) scheme approved in February 2019 is presently under execution.

Heera field was discovered in September 1977 and put on production in November 1984. Heera field produced oil under depletion drive[4] for about six years and water injection was started in September 1990. In this field, two rounds of development have happened during 2001-05. Heera re-development schemes Phase I and II (HRP I & II) were taken up from 2006 and 2012 respectively. HRP III was approved in May 2019 and is presently under execution.

Neelam field started in 1989 and full-fledged development commenced from 1993-94. Water injection in the field was started in 1994 for pressure maintenance. In order to improve oil recovery, a major scheme, *viz.,* 'Improved Oil Recovery (IOR)' was implemented in 2001-02 and completed by 2005-06. Neelam re-development scheme (NRP) launched in 2015, is presently in progress.

1.3 Water injection infrastructure

In western offshore, there are seven water injection platforms, five in Mumbai High field and two in Neelam-Heera fields having total capacity of 20.57 lakh bwpd (barrel of water per day) which were commissioned during the period from 1984 to 2006. The treated water is injected through 102 wellhead platforms in 315 wells/ strings (Mumbai High field) and 30 wellhead platforms in 80 injection strings (Neelam and Heera fields).

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[2] ***Injection well/ string - Injection well is a well through which water is injected into reservoir to maintain reservoir pressure. Injection well may have a single string or dual strings.***

[3] ***Redevelopment schemes are rolling plans. They are implemented for enhancing the oil recovery through Improved Oil Recovery (IOR) methods like using new inputs (producing wells/ injection wells), new platforms with facilities, pipelines to target bypassed oil and maintain reservoir pressure through water injection.***

[4] ***A depletion-drive reservoir is characterised by a rapidly increasing gas-oil ratio from all wells. After the reservoir pressure is reduced, gas evolves from solution throughout the reservoir. This is very inefficient as it will produce relatively little of original oil in place.***

Details of water injection infrastructure created in Mumbai High and Neelam and Heera fields are given in table 1.1.

Table 1.1: Water injection infrastructure/ expenditure

Description	Mumbai High field		Neelam & Heera fields	
	Number	Expenditure (₹ in crore)	Number	Expenditure (₹ in crore)
Platforms	5	2,607.01	2	928.49
Wells	260	1,017.51	73	647.55
Pipelines	130	3,945.16	33	930.39
Total		**7,569.68**		**2506.43**
Average annual Opex		**731.30**		**232.64**

Source: Data received from Central accounts (Mumbai region), ONGC.

Chapter 2
Mandate, Audit scope and Methodology

The Compliance Audit Report has been prepared under the provisions of Section 19-A of the Comptroller and Auditor General's (Duties, Powers and Conditions of Service) Act, 1971. The Audit has been carried out in line with the Regulations on Audit and Accounts, 2007 and Compliance Audit Guidelines of the Comptroller and Auditor General of India.

2.1 Scope and Audit objectives

The scope of Audit is to review performance of water injection in western offshore area of the company[5] for the period from 2014-15 to 2018-19 (with backward and forward linkages).

The objectives of the Audit were to assess whether:

1. the requirement of water injection planned in the annual water injection build-up plan was commensurate with the requirement envisaged in the field development schemes/ feasibility reports approved by the management and planned quantity was injected into the reservoir,

2. requisite water injection equipment were made available to inject required quantity of water into reservoir,

3. desired quality of water was injected into the reservoir, and

4. water injection facilities were maintained through corrosion monitoring, pigging of water injection lines, workover[6] of injectors, stimulation[7] operations of injection wells pipelines and backwash of injectors.

2.2 Audit criteria

The criteria for Audit were drawn from the policies/ guidelines/ norms adopted by the company as appearing in its manuals/ internal documents/ laid down procedures relating to reservoir health, quality/ quantity of injection water, maintenance/ replacement/ overhauling norms of equipment as per company and original equipment manufacturer (OEM) norms, maintenance and monitoring mechanism of water injection pipelines and wells/ strings, etc. The reports of international consultants appointed by the company/ its in-house research organisations were also considered **(Annexure-I)**.

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5 ***Western offshore assets include Mumbai High, Neelam & Heera and Bassein & Satellite. While Mumbai High and Neelam & Heera are mainly oil fields, Bassein & Satellite comprises gas fields. Further, water injection in Bassein & Satellite is adopted mainly for creating a barrier between the two fields. Bassein & Satellite is not covered in the current Audit.***

6 ***A workover or well servicing is any operation performed on a well to restore or improve the performance of a well.***

7 ***A well intervention procedure to improve injectivity.***

2.3 Audit methodology

An Entry Conference was held with the Management on 8 April 2019 in which Audit objectives, scope and methodology were discussed. Field Audit included collection and review of information/ documents, discussions with Management and was conducted from August 2019 to April 2020. University of Petroleum Energy and Studies (UPES), Dehradun was engaged as technical consultant for providing technical guidance to Audit. The draft Audit Report was issued to the Management/ Ministry of Petroleum and Natural Gas simultaneously on 15 December 2020. Response of the Management (February 2021) and the Ministry (June 2021) has been suitably incorporated in the Audit Report. The response and views expressed by the Management and Ministry during Exit Conference held on 8 September 2021 have also been suitably incorporated in the Report.

2.4 Acknowledgement

We place on record the cooperation extended by the Ministry and the Management and staff of ONGC in smooth conduct of the audit. We also place on record the cooperation extended by University of Petroleum Energy and Studies during the course of field Audit and finalisation of Audit Report.

Water Injection Header

Chapter 3
Planning and implementation of requirement of water injection

Water injection into an oil reservoir is carried out to increase the oil recovery by maintaining the reservoir pressure. This is accomplished by 'voidage replacement' *i.e.,* injection of water to increase the pressure to its initial level and maintain it near that pressure. Therefore, sufficient quantity of water needs to be injected.

3.1 Estimation of water injection requirement

The quantity of water injection requirement is based on the reservoir simulation model[8]. Voidage replacement ratio is the ratio of the volume of injected fluid to the volume of produced fluid. Voidage replacement ratio affects pressure distribution within the reservoir and evidently the oil production rate. Complete voidage replacement is optimal for reservoirs and is a common reservoir management practice[9]. For better reservoir management and optimal recovery, water injection should be at least 100 *per cent* of the produced fluid.

3.2 Planning of water injection quantity

Re-development schemes are implemented for improving oil recovery from the matured fields. Investment in such schemes is justified based on the envisaged incremental production profile. The production profile so drawn up stipulates water injection levels for achieving the production. Re-development schemes considered 100 *per cent* voidage replacement. Re-development schemes are approved by the Board while the annual plans are prepared at the Asset[10] level. The requirement of water injection provided in the approved re-development schemes and in annual water injection build-up plan is given in table 3.1 and 3.2.

Table 3.1: Mumbai High field (figures in barrels of water per day)

Year	Mumbai High South			Mumbai High North			Mumbai High Total			
	Redevelopment Scheme-Ph-III	Annual build-up plan	Diff.	Redevelopment Scheme-Ph-III	Annual build-up plan	Diff.	Redevelopment Scheme-Ph-III	Annual build-up plan	Diff.	% of shortfall
2014-15	623728	604000	19728	489843	456900	32943	1113571	1060900	52671	5
2015-16	782253	652300	129953	542895	427800	115095	1325148	1080100	245048	18
2016-17	786461	621900	164561	562031	375700	186331	1348492	997600	350892	26
2017-18	784145	622300	161845	559416	382360	177056	1343561	1004600	338961	25
2018-19	793774	577300	216474	548022	407300	140722	1341796	984600	357196	27

Source: Mumbai High North and Mumbai High South redevelopment plans Phase-III, Annual Build-up plans

[8] ***Institute of Oil & Gas Production Technology (IOGPT), ONGC.***
[9] ***Reference: Stanford University research paper, December 2015.***
[10] ***Asset refers to entity in ONGC involved in production activities.***

Table 3.2: Neelam & Heera fields (figures in barrels of water per day)

Year	Neelam			Heera			Neelam & Heera			
	Redevelopment Scheme	Annual build-up plan	Diff.	Redevelopment Scheme	Annual build-up plan	Diff.	Redevelopment Scheme	Annual build-up plan	Diff.	% of shortfall
2014-15	98225	61811	36414	202099	128550	73549	300324	190361	109963	37
2015-16	74625	62508	12117	205459	89542	115917	280084	152050	128034	46
2016-17	88130	96963	-8833	209234	142292	66942	297364	239245	58119	20
2017-18	120813	79800	41013	174848	165500	9348	295661	245300	50361	17
2018-19	142366	113808	28558	184393	172125	12268	326759	285933	40826	12

Source: Monthly Progress Report and Redevelopment schemes of Neelam and Heera

As can be seen from the above tables, the quantity of water injection as per the annual build-up plan has always been less than the requirement as per the re-development schemes. The gap between these two plans is increasing in case of Mumbai High field.

In this regard, Audit observed that the company prepared annual build-up water injection plans based on achievable water injection quantity, rather than requirement of injection as per the approved re-development schemes, which was based on 100 *per cent* voidage compensation. Annual water injection build-up plan is prepared under constraints considering the availability of rigs/ stimulation vessels, water injection infrastructure and pipeline network, etc. Instead of overcoming the constraints, the constraints were accepted as reality and planning process altered accordingly. This has resulted in continuous lower cumulative voidage compensation and decline in reservoir pressure and ultimately affected crude production and recovery.

Management admitted (January/ February 2020) that the lower cumulative voidage compensation is due to less planned injection in line with the available resources and planning lower quantity of water injection than the requirement. This resulted in creation of additional voidage, further drop in reservoir pressure and ultimately affected the crude oil production/ recovery.

Management added (February 2020) that in Neelam there is partial voidage compensation (20-25 *per cent*) from the aquifer support. However, Audit noticed that even after considering the above, planned voidage replacement ratio is less than the requirement.

Recommendation No. 1

Annual planning for water injection should emanate from the field development schemes. The company may devise a comprehensive catch-up plan to compensate the excess voidage created.

3.3 Implementation of water injection plan

Not only was the planned quantum of water injection sub-optimal *vis-à-vis* the requirement as per the development schemes, but even the reduced annual targets were not achieved. The actual water injection quantity with reference to the annual build-up plan during 2014-15 to 2018-19 is given in table 3.3. The field wise position is given at **Annexure-II**.

Table 3.3: Water injection with reference to Annual Plan

Year	Mumbai High		Neelam and Heera	
	Actual injection (bwpd)	Shortfall with reference to annual plan (%)	Actual injection (bwpd)	Shortfall with reference to annual plan (%)
2014-15	929072	12.43	177986	6.5
2015-16	950120	12.03	144945	4.67
2016-17	990500	0.71	174216	27.18
2017-18	922200	8.21	185315	24.45
2018-19	860156	12.64	183508	35.82

bwpd: barrel of water per day
Source: Annual built-up plans and sub-surface annual reports

The company could not inject the quantity planned even in the constraint based annual plan due to unavailability of inputs[11] planned in the annual plan and further leakages/ failure of water injection lines, delay in workover operation and stimulation jobs. This led to more voidage and depletion of reservoir pressure. Uneven distribution of water injection, both laterally and vertically, led to development of pressure sinks in some areas of the field. This impacted crude oil production and recovery.

3.4 Non-achievement of planned inputs

The annual water injection plan includes inputs by way of new injectors, conversion of producing wells to injecting wells and maintenance of injection wells. Mumbai High and Neelam and Heera could not provide most of the inputs of water injection annual build-up plan. The details of plan *vis-a-vis* actual implementation of various planned inputs during 2014-15 to 2018-19 of Mumbai High are detailed in **Annexure-III.**

Injectors are the wells through which water is injected in to the reservoir. The planned versus actual number of injectors during 2014-15 to 2018-19 is given in table 3.4.

[11] *New injectors, conversion of producing wells to injecting wells and maintenance of injection wells.*

Table 3.4: Plan versus actual injectors

Year	Plan (Nos.)						Actual (average) (Nos.)						Shortfall (Nos.)	
	MHN	MHS	MH	Neelam	Heera	N&H	MHN	MHS	MH	Neelam	Heera	N&H	MH	N&H
2014-15	119	188	**307**	11	61	**72**	97	152	**249**	11	52	**63**	**58**	**9**
2015-16	116	154	**270**	12	55	**67**	89	136	**225**	12	52	**64**	**45**	**3**
2016-17	99	146	**245**	19	58	**77**	89	131	**220**	14	53	**67**	**25**	**10**
2017-18	110	144	**254**	20	59	**79**	92	133	**225**	14	59	**73**	**29**	**6**
2018-19	117	167	**284**	22	64	**86**	99	131	**230**	20	60	**80**	**54**	**6**

MHN: Mumbai High North, MHS: Mumbai High South, MH: Mumbai High, N&H: Neelam and Heera
Source: Management response regarding number of injectors planned versus actual.

In Mumbai High and Neelam and Heera, non-availability of rig resources to convert producer wells to water injection wells[12], drill new injectors, using injectors as producers and lines leakages were the main reasons for non-achievement of planned inputs. Planned resources like drilling rigs, stimulation vessels were diverted for production activities.

Management/ Ministry stated (February/ June 2021) that as the availability of stimulation vessels and rigs improved, these jobs are being undertaken and shortfall liquidated on a continuous basis. It was further stated that closed water injection lines are addressed through pipeline replacement projects. Management added that rectification of pipeline between Heera water injection platform to HQ platform (an unmanned platform) in 2015-16 and the pipeline between unmanned platforms HR and HSA in 2017-18 had mitigated the gap in voidage replacement in Heera.

The reply needs to be viewed in light of the fact that during 2014-15 to 2018-19, the company could not provide most of the planned inputs for water injection. During 2019-20 and 2020-21 also, actual water injection was lower than the build-up plan. The fact that voidage replacement plan considers the constraints, but still could not be achieved, is a matter of concern.

3.5 Measurement of water injection quantity

Water injection quantity reported by the company is measured at main injection pump end of the injection platform. This quantity is allocated to various water injection wells. The treated water from the process platform reaches the wellhead and goes to the injection well via metering devices, which are meant for finding out the injection rate at each well. The company had installed meters at wellhead to measure quantity of water injected into the reservoir. In case of Neelam and Heera, the inadequate measurement at unmanned platforms had been commented in the internal reports and new meters were installed during 2013-18.

Audit observed that most of the meters in Mumbai High have become non-functional from 2007-08 onwards and the company failed to replace the non-functional meters in time. In

[12] ***Production wells which cease to produce economical level of production are converted to water injection wells to save additional expenditure on drilling new well.***

its absence, the rate of injection was measured by portable ultrasonic meters once in six months till October 2019. Presently, it is measured once in two months. The readings are instantaneous and then extrapolated for the day rate. Thus, there is no continuous online measurement at present. Further, with multiple leakages in injection lines noticed during 2014-15 to 2018-19, injection quantity measured and reported at main injection pump is not the correct quantity injected into the reservoir. This is proved by difference in test rates and actual injection volume.

M/s GCA, an international consultant appointed by the company, recommended for metering on individual well regularly and frequently to identify well problems. In-house task force observed that as on 1 September 2018, as against reported quantity of 9.24 lakh barrel of water per day (bwpd) at main injection pump end of Mumbai High field, testing data at wellhead indicated injection quantity was lesser by 1.41 lakh bwpd. Task force recommended for installation of flow meters and pressure transmitters at wellhead and connecting them to Supervisory Control and Data Acquisition (SCADA) system for online monitoring of injection rate. Management stated that as recommended by the task force, frequency of testing of wells is now done once in two months. Audit observed that even in June 2020, the gap between water injection measured at main injection pump end and at wellhead was 1.29 lakh barrel of water per day. Thus, the quantity measured at main injection pump end of injection platform is not an accurate assessment for reckoning the quantity of water injected into the reservoir.

Management/ Ministry assured (February 2021/ June 2021) that the company is expediting installation of meters at wellhead platforms and connect them to SCADA system in future for online measurement and effective monitoring and the project is likely to be completed in next three years.

The reply needs to be viewed considering the fact that initially all the water injection wells were equipped with individual meters. However, timely action was not taken for its replacement. It is a matter of concern that unreliable values are continued to be used in the simulation model for the reservoir.

Recommendation No. 2

Quantity of water injected has to be measured at unmanned platform end for better and timely monitoring. Integration of SCADA with the online meters may be considered in all the platforms.

3.6 Voidage replacement plan and achievement

As mentioned in Para 3.1, as against complete voidage replacement, the company could achieve only partial voidage compensation. The company commenced water injection six to eight years after commencement of field production in Mumbai High and Heera fields and historically there had been inadequate water injection. The planned voidage replacement ratio in Mumbai High and Neelam and Heera fields is given in table 3.5. It may be seen from the table that in both the fields, planned voidage replacement ratio has generally been less than 100 *per cent*.

Table 3.5: Plan v/s actual voidage replacement ratio (in percentage)

Year	L-III North#		L-II North		L-I North		L-III South		Neelam		Heera	
	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual	Plan	Actual
2014-15	104	88	96	93	30	38	60	57	34	29	71	87
2015-16	93	79	97	86	38	25	71	65	34	30	73	59
2016-17	86	78	72	74	33	63	68	71	48	34	89	69
2017-18	74	84	73	71	110	67	75	62	38	37	95	78
2018-19	83	85	65	76	79	49	70	61	46	41	88	86

***Source:** Management response regarding plan and actual Voidage Replacement Ratio and Mumbai High sub-surface Annual reports.*
 # L-I, II, III stands for Layer I, II, III

The injection build-up plans were drawn with voidage replacement of less than 100 *per cent* (except for L-III reservoir and L-I reservoir in Mumbai High North during 2014-15 and 2017-18 respectively). The injection quantity plan is based on the voidage replacement plan. Cumulative voidage compensation[13] in Mumbai High field as of March 2019 was only 54.43 *per cent*. Similarly, in Neelam & Heera fields, it was 42 and 78.8 *per cent* respectively. Audit observed that lower cumulative voidage compensation was due to inadequate planning of water injection requirement as well as lower water injection against the plan.

The voidage created, compensated and actual voidage replacement of major oil producing L-III layer of Mumbai High South, Mumbai High North, Neelam and Heera fields are provided graphically in **Annexure-IV**.

Performance of Mumbai High fields was evaluated by the worldwide petroleum consultants, William M. Cobb & Associates in June 2009. The consultant observed that cumulative voidage replacement ratio since the start of water injection is generally 0.502 (*i.e.,* <100 *per cent*) in all parts of the field, except the central area of Mumbai High South which is performing better than other areas due to higher water injection volumes. As a result, the reservoir pressure continued to decline in major portion of the fields, which resulted in decline in well productivity. The consultant recommended to increase water injection by adding more wells or by converting producers to injectors and to raise the effective cumulative voidage replacement ratio to at least 1.1 to 1.3 so that pressure can be increased. However, contrary to the recommendation and best reservoir practice, water injection planning in Mumbai High field was generally less than 100 *per cent* voidage replacement ratio.

[13] ***Cumulative voidage compensation refers to voidage compensated over voidage created since inception.***

In Neelam and Heera field, domain expert (M/s Ganesh Thakur) had suggested improving voidage compensation by improving injectivity[14], injection of peripheral wells to overcome water breakthrough, shifting/ profile modification/ side tracking of injectors.

Audit scrutiny revealed that lesser number of water injection strings was included in the annual injection plan against the approved development scheme numbers. Large number of strings was not available for water injection, due to leakages/ pre-mature failure in water injection lines and incomplete workover of water injection wells. These have been discussed in detail in chapter 6.

Management stated (April 2020) that the requirement of water injection as per the approved re-development plan is an ideal case. However, in reality while preparing the annual water injection plan, most of the conditions are not as per the re-development plan due to aged infrastructure and other real-time constraints. It further stated that efforts are made to overcome these constraints and as the availability of stimulation vessel and rigs improved, more strings would be available. With regard to Heera field, it was stated that the constraints have been addressed and the annual plan achieved is more than 90 *per cent* of re-development plan in recent years due to addressing line leakage and it would improve further. Ministry accepted (June 2021) that water injection was inadequate historically even though water injection was considered as critical input in all the development schemes and this had significantly affected well productivity.

3.7 Summing up

The company considered 100 *per cent* voidage replacement (quantity of water planned to be injected equal to the quantity of oil drawn) in its re-development schemes. However, the actual injection of water was inadequate as compared to re-development schemes. Besides, the annual plan prepared by Mumbai High and Neelam and Heera fields envisaged lesser quantity of water injection *vis-à-vis* the quantity as per the re-development schemes. Also the actual quantity of water injected was further lower than the quantity planned in annual plan. The constraints, viz., non-availability of rigs/ stimulation vessels, inadequate water injection infrastructure and pipeline network, etc., were considered as a norm while preparing the annual plan. Continuous lower voidage compensation resulted in decline in reservoir pressure and ultimately affected crude production and recovery.

The issues of unhealthy water injection infrastructure, poor water quality and inadequate maintenance of pipelines/ injectors which compelled the company for planning/ injecting lesser quantity of water are discussed in detail in Chapters 4 to 6.

[14] ***Injectivity measures the ability of a well to receive injected water. It may be impaired because of corrosion, scale and bacterial growth over the years.***

Main Injection Pump

Chapter 4
Water injection surface facilities and equipment

4.1 Water injection surface facilities

Water injection process platform processes seawater to make it suitable for injecting into the reservoir. The cleaned and treated seawater is pumped at high pressure for injecting into the reservoir through a number of injector wells. The water injection platforms (four in Mumbai High[15] and one each in Neelam[16] and Heera[17]) were commissioned during 1984 to 1994. Mumbai North Water Injection (MNW) platform of Mumbai High field was commissioned during 2006. The installed capacities of water injection platforms in Mumbai High were sufficient to meet the injection requirements of the re-development schemes. However, the delay in replacement/ overhauling of the equipment affected their reliability/ efficiency as discussed in the succeeding paragraphs.

4.2 Function of water injection equipment

The functions of water injection equipment are given in table 4.1.

Table 4.1: Functions of water injection equipment

Equipment	Function
Chlorinator	Marine organisms are abundant in seawater and they can form algae, barnacles or colonies of micro-organisms in the piping and equipment. Chlorinator unit, installed at inlet of Sea Water Lift Pump, generates hypochlorite by electrolysis of seawater. Chlorine, produced by the chlorinators, is injected as sodium hypochlorite in the water to kill the micro-organisms.
Sea Water Lift Pump	Seawater is lifted from approximately 25 to 30 meters below the sea level by Sea Water Lift Pump and pumped to the coarse/ fine filters.
Fine Filter	Fine filter is designed to remove all suspended solids of size greater than or equal to 2 microns from the seawater.
De-Oxygenation Tower system	Presence of oxygen in the seawater is the main reason for corrosion of pipelines, equipment etc. The De-Oxygenation Tower system is designed to treat, on a continuous basis, filtered sea water to reduce oxygen content of seawater, not exceeding 0.02 mg/ litre of dissolved oxygen.
Vacuum Pump	Vacuum Pump is designed to reduce dissolved oxygen level in the feed water from 7 ppm to 0.02 ppm.
Booster Pump	Booster Pump is designed to provide net pressure required for main injection pump at the pump's suction to the discharge pressure of 14.6 kg/ cm^2.
Main Injection Pump	Main injection pump is high-speed centrifugal pump, which provides required pressure for injection of the treated water to various injection wells.

[15] *South High Water Injection (1994), Water Injection South (1987), Infill Complex Water Injection (1988), Water Injection North (1984).*

[16] *Water Injection Neelam (1994).*

[17] *Water Injection Heera (1989).*

Equipment	Function
Dosing Pump	The chemical injection pump with manual stroke adjustment for capacity control is designed to inject chemicals (for various purposes) at required dosage in the injection water.
Source: Management response and IOGPT Report on 'Study on requirement of coarse filter in water injection complexes of Mumbai High'.	

The details of major equipment installed (running and standby) at water injection platforms at Mumbai High and Neelam and Heera fields is mentioned in **Annexure V**.

4.3 Critical and essential equipment

The company classified equipment installed at offshore facilities broadly into two categories, *viz*., critical equipment (which directly contribute to oil and gas production and meant for un-interrupted operation) and essential equipment (which do not directly contribute to oil and gas production but essential to support operations). Accordingly, the company categorised seawater lifting pumps, booster pumps and main injection pumps as 'critical' and chlorinators, fine filters, de-oxygenation tower and vacuum pumps as 'essential' equipment.

Audit observed that chemical dosing pumps were not considered as essential equipment. If the desired quality of water is not maintained at the platform, then it may corrode the water injection equipment, clog the wellbore and indirectly impact the crude oil production. Going by the definition of essential equipment adopted by the company, Audit is of the view that all chemical injection pumps should also be considered as essential.

Management/ Ministry stated (February/ June 2021) that as suggested by Audit, chemical dosing pumps would be considered for inclusion under essential equipment.

4.4 Equipment replacement/ revamping policy

As a sequel to C&AG Report No. 8 of 2006[18], the company formulated (2007) equipment replacement policy for all major equipment of offshore facilities. Design service life of water injection equipment formulated by the company as per the replacement policy is given at **Annexure VI**.

In this regard, Audit observed that this policy, however, has not been adhered to. As recorded in the internal documents, failure of equipment is attributed to poor maintenance practices, delay in overhauling, replacement/ revamping etc.

Management/ Ministry stated (February/ June 2021) that equipment package replacement/ revamping depends on the operating condition and age of the equipment. All decision pertaining to replacement/ retention of the equipment are being taken as per the extant replacement/ retention policy.

Audit is of the view that rather than having a timely approach, Management adopted a reactive approach for revamping of platform/ replacement of equipment after expiry of its

[18] ***Availability and Utilisation of Critical Equipment of Offshore Installation in ONGC.***

design operational life and system became unreliable. This affected the quantity and quality of water injection.

4.5 System and equipment availability

The term ‘equipment availability’ has been defined internally by the company as ‘the availability of particular equipment for operating purposes’. Equipment availability was taken care of by the standby equipment during the period of maintenance and repairs of equipment in operation. Similarly, ‘system availability’ of any critical equipment has been denoted as ‘availability of equipment (both operating and standby) for un-interrupted flow of production’. While setting the operational targets, the ‘system availability’ of 100 *per cent* was assured to the extent that the equipment down time was less than equipment standby time. Considering this philosophy, ONGC has set the target of 100 *per cent* for system availability and 95 *per cent* for equipment availability. The system availability of water injection equipment installed in various water injection platforms at Mumbai High and Neelam and Heera fields during the 2014-15 to 2018-19 is given in **Annexure-VII**.

In Mumbai High and Neelam and Heera fields, ‘system availability’ of critical equipment at platforms *viz*., Infill Complex Water injection, South High Water injection, Water Injection South and Neelam Water injection was below the target of 100 *per cent*. Similarly, at Infill Complex Water injection, Water Injection South, Neelam Water injection and Water Injection Heera platforms, ‘system availability’ of essential equipment was below the target of 100 *per cent.* Audit observed that though system availability of some of the equipment was denoted as 100 *per cent*, performance of the equipment was below par due to ageing, coupled with delay in replacement/ revamping.

Management/ Ministry stated (February/ June 2021) that it has taken many initiatives from time to time to improve the water injection quality and quantity. It is a regular ongoing process considering the matured field environment and the ageing of installed equipment/ systems/ sub-systems including the peripheral and control.

Audit is of the view that the company adopted a reactive approach rather than timely revamping of platform/ replacement of equipment, after expiry of its design operational life and after the system became unreliable. This impacted the quality and quantity of water injection.

4.6 Reliability of equipment availability/ system data

From the review of Monthly Progress Report (MPR) and Daily Progress Report (DPR) of equipment in Mumbai High, Audit observed that in a large number of cases, the equipment run/ standby/ maintenance hours were not matching with each other and to that extent equipment availability data was not reliable. Audit highlighted instances in Neelam MPRs, where equipment was continued to be shown as available with running hours, even when it was sent for repairs and where average dispatch of water injection was denoted even when running hours was nil for all injection pumps (**Annexure-VIII**).

Management stated (June 2020) that most of the reports are manually handled by different sections and departments; accepted that some error in manual data entry had taken place and that the teams at offshore have been advised to feed all data in SAP system for removing any discrepancies.

> ***Recommendation No. 3***
>
> *The company should ensure maintenance of the equipment availability data through SAP system and ensure generation of reports directly from SAP.*

4.7 Methodology for working out 'system availability' of equipment

System availability of equipment is one of the key indicators to measure the performance of the Asset. Audit however, observed instances where despite the system being 'available', it could not meet the performance criteria as discussed below:

- In Water Injection South platform, as against the planned injection of 247,115 bwpd during 2018-19, actual water injection was only 177,549 bwpd (shortfall of 28 *per cent*). However, system availability of main injection pumps was reported as 100 *per cent*, even though only one injection pump with capacity of 1.20 lakh bwpd was in operation during December 2017 to July 2018.
- The 'system availability' of fine filters in South High Water Injection platform during 2016-17 and 2017-18 was recorded as 100 *per cent*. However, the particle counts exceeded the operational limit of <2000 per ml due to inefficiency in operation of fine filters.
- The 'system availability' of the vacuum pumps was reported as 99 *per cent* in Neelam during 2014-15 to 2018-19. Out of 60 months, in 22 months the average dissolved oxygen level was higher than the prescribed level of 20 parts per billion (ppb). Of these, in 19 months higher dissolved oxygen levels matched with non-availability of vacuum pump. Similarly, in case of Heera, out of 25 months where dissolved oxygen levels were higher than the prescribed level of 20 ppb, 23 months matched with non-availability of vacuum pumps. The system availability of vacuum pumps was, however, denoted as 100 *per cent* in all the months.

Management stated (February 2021) that with 100 *per cent* system availability of main injection pumps, it is apparent that available injection pumps were adequate to meet the actual field requirement and injection pump was stopped due to other field conditions.

The reply is not borne out of facts as the second pump was partially available during the period December 2017 to July 2018 and after its restoration, the injection was restored to the planned levels as before. Audit is of the view that achievement of 'system availability' target without meeting the operational requirement is of diminished utility.

Recommendation No. 4
The company needs to consider efficiency/ performance of the equipment for meeting the operational requirement while working out the 'system availability' of equipment and the Management should ensure reliability and availability of equipment for uninterrupted operation.

4.8 Monitoring mechanism – Plant Maintenance module in SAP system

The company implemented SAP ERP system including the Plant Maintenance module in 2003. Plant Maintenance module is designed to meet the requirement of planned and unplanned maintenance of equipment, mapping of critical parts of equipment and their overhaul/ repair history. Processing of maintenance data can aid performance analysis, improve operational effectiveness, and provide useful insights to enable management decisions.

In this regard, Audit observed that Plant Maintenance module was not extensively used to obtain the intended benefits. It was used only for rotary equipment (pumps, motors) under maintenance. Static equipment[19] were not mapped and the maintenance activities and their details are not fed in the module. Equipment logs/ history of repairs/ make-wise performance of equipment could not be obtained from the Plant Maintenance module in the absence of data not being fed or lack of mapping.

Audit further observed that in large number of cases, day-wise equipment availability data does not match with the monthly equipment availability data. The equipment history, tripping details and monthly performance reports were also maintained outside the SAP system. The monitoring and control mechanism is not strengthened as envisaged, by selectively utilising the Plant Maintenance module and by relying on manual reports. The effectiveness of the Plant Maintenance module and the monitoring mechanism is thus undermined.

Management/ Ministry (February 2021/ June 2021) assured that all functionalities of Plant Maintenance module would be extensively used to get the intended benefit.

Recommendation No. 5
Management may extensively use functionalities under Plant Maintenance module in SAP system so as to get its intended benefit of aiding performance analysis, improving operational effectiveness and providing useful insights to Management decisions.

4.9 Delay in replacement/ revamping of equipment

4.9.1 Non-functional Chlorinators for more than eight years

Chlorination of seawater is the first step to get the desired quality of injection water. Raw seawater is chlorinated at the intake of seawater lift pump to control growth of both micro-organism and bacteria. The bacteria present in the seawater, which choke filters, can also

[19] ***Equipment having no moving parts-like fine filters, DO tower in water injection system.***

plug the formation. Bacteria, especially sulphate reducing bacteria which caused microbial induced corrosion, is extremely aggressive and in its worst form will lead to piping failures within a short period. Once established, microbial induced corrosion is difficult to be eliminated and may elevate into chronic maintenance and operating problem for years to come. In the absence of chlorine, even 90 *per cent* removal efficiency of particles >2 microns is difficult to achieve.

Design life of chlorinators is 15 years. Audit observed that the chlorinators installed with the platforms outlived their design life as early as 2002 to 2008 (except Mumbai North Water Injection platform which was commissioned in 2006). Chlorinators were replaced in Water Injection North Platform in 2012. The chlorinators stopped working in Water Injection South Platform (2009, 2012), Infill Complex Water injection platform (2010, 2017), South High Water Injection Platform (2010), Neelam Water Injection (2010) and Heera Water Injection (2010) Platforms. Presence of general aerobic bacteria and sulphate reducing bacteria in various stages of water injection system was observed in the absence of functioning chlorinators.

Institute of Engineering and Ocean Technology (IEOT), research and development institute of the company which conducted study (October 2012) on failure analysis of water injection pipelines in Neelam and Heera, mentioned that the chlorinator units were not in use since last few years in Neelam water injection platform and recommended the practice of use of primary biocide i.e., chlorine generated through electrolysis of seawater. The in-house committee which studied pre-mature failure of pipelines for Mumbai High and Neelam and Heera fields also observed (August 2014) that the presence of general aerobic bacteria and sulphate reducing bacteria at the main injection pump discharge was due to non-functioning of chlorinators, more or less at all the platforms. The committee recommended that proper functioning of chlorinator and regular injection of chlorine at seawater lifting pump inlet must be ensured or alternative chlorination system be considered.

Audit observed inordinate delay in finalisation of tender/ re-tender for chlorinators. In the absence of chlorinators, in large number of cases, general aerobic bacteria and sulphate reducing bacteria was observed at the fine filter itself. This resulted in continuous deterioration of fine filters and affected the quality of injection water. The poor quality of injection water also led to deterioration in water injection pipelines and contributed to their pre-mature failure.

Management stated (February 2021) that chlorinators are being replaced in phases; new units were commissioned at Neelam (March 2019) and at Heera (May 2019), being replaced at South High-Water Injection and Infill Complex Water Injection and new chlorinators along with other facilities will be installed at Water Injection South by September 2021.

The reply may be viewed in light of the fact that chlorinators in water injection platforms were not functional for more than 8-10 years, which have affected quality of water injection. The company has fixed operational life of 15 years for replacement of chlorinator and should have taken timely action for its replacement.

4.9.2 Delay in revamping of other equipment

The company had internally assessed 15-20 years as the estimated useful life of critical/ major equipment as per the equipment replacement policy of 2007.

In this regard, Audit observed that the policy was not adhered to and the equipment on the platforms were not functioning to the desired level due to prolonged use in the marine environment and ageing. Considering the lead period required for installation of any facility in an offshore platform, the proposals should be initiated much earlier. Delayed initiation of revamping process was observed indicating improper planning and lack of importance attributed to water injection. There were delays in replacement/ overhauling and in some cases, non-adherence to the recommended maintenance practices of OEM was observed. Meantime, condition of major systems and main equipment deteriorated and it was unsafe to continue its full-scaled operation. With reduced scale of operation at existing platforms along with safety constraints, the desired injection quantity/ quality envisaged for reservoir health maintenance to meet long term plans could not be achieved as depicted in table 4.2.

Table 4.2: Delay in revamping of equipment in water injection platforms and its impact

Platform	Installed in and completed 20 years	Proposal initiated (year) and approval (year)	Scheduled/ revised completion	Water injection equipment failures in platforms	Consequent effect on quantity/ quality
South High Water Injection	1994 and 2014	2009 and 2016	2019/2020	Frequent break down of vacuum pumps and non-availability of vacuum pumps	Water quality parameters exceeded the permissible limits, which affected water quality. Quantity pumped reduced from 2.37 lakh bwpd (2014-15) to 1.66 lakh bwpd (2018-19).
Water Injection South	1987 and 2007	2012 and 2019 (De-oxygenation tower revamped)	2021	4 Fine filters were not functional. Out of 4 vacuum pumps, 3 were under downtime during entire audit period. Out of 2 de-oxygenation towers only 1 was used while other (whose internals were damaged) was continuously kept under standby. System availability of booster pump was less than 50 *per cent* during 2018-19. One booster pump was under downtime since May 2015 (2 booster pumps slated to be installed only by May 2021). Against 5 main injection	Water quality parameters exceeded permissible limits, which affected water quality. Drop in injection quantity from 1.91 lakh bwpd (2014-15) to 1.77 lakh bwpd (2018-19). Capacity utilisation of only 36.06 *per cent.* Excessive De-oxygenation in injection water upto 3565 ppb.

Platform	Installed in and completed 20 years	Proposal initiated (year) and approval (year)	Scheduled/ revised completion	Water injection equipment failures in platforms	Consequent effect on quantity/ quality
				pumps installed, 3 main injection pumps were not working for extended period (more than 2 years).	
Infill Complex Water Injection	1988 and 2008	2010 (De-oxygenation tower) and 2011 (De-oxygenation tower and fine filters revamped)	2015	Even after revamping, the system availability of de-oxygenation tower and Fine Filters was below the requirement. Out of 2+1 operation philosophy, one booster pump was not available for operation during 2014 to 2017. However, it was maintained as standby during October 2016 to September 2017. Total 3 main injection pumps are required to cater to the demand of water injection, but only 2 main injection pumps are in operative condition.	Water quality parameters exceeded permissible limits. Average capacity utilisation of water injection capacity was only 42.96 *per cent*, which affect water injection quantity.
Water Injection Heera	1989 and 2009	2016 (Booster Pump) and 2018 (Booster Pump)	Main Injection Pumps yet to be replaced. De-oxygenation tower, Fine filters revamped in Sept 2019. All booster pumps are under replacement.	Even after revamp of De-oxygenation tower towers, Main Injection Pumps lack capacity to handle additional capacity. Frequent failures/ tripping in booster pump and main injection pump.	Shortfall in achieving water injection targets of Heera by 30 to 57 *per cent.* Quality of water, especially dissolved oxygen (upto 800 ppb levels) particle count, residual sulphite levels could not be maintained. Chemical dosing was not adequate resulting in failure to maintain the quality norms of injected water.
Water Injection Neelam	1994 and 2014		3 booster pumps replaced in Nov 2018. 2 main injection pumps to be replaced in 2021. 3 seawater lift pumps under replacement. Chemical dosing pump planned for replacement	Main Injection Pumps were not delivering as per their design capacity. Frequent failures/ tripping in booster pump and main injection pump. Against design philosophy of 2+1, only one booster pump was operated. Even reporting of system availability is not reliable. Lack of monitoring of chemical dosing pumps as 'data not captured'.	Only one main injection pump in operation in Neelam from February 2018. Achievement against redevelopment plan targets by Neelam was 48 *per cent* (2018-19).

Source: Data furnished by company in response to Audit requisitions and observations, Monthly Reports

Management attributed (February 2021) operational reasons and capital intensive nature of the projects for delay in revamping and stated that revamping is a regular ongoing process and the company has replaced/ revamped/ modified many equipment under various projects. It further stated that replacement/ revamping of aged equipment had resulted in improvement in quantity and quality of injected water. Management further added that the tripping is expected to be significantly reduced in view of revamping/ replacement of equipment.

Management response needs to be seen in light of the fact that the age of facilities exceeded the accepted age norms by many years resulting in failures/ inefficiencies of aged equipment and ineffective operation. Timely action would have avoided deficiencies in water injection operations.

Recommendation No. 6

The company should timely initiate proposals for overhauling and replacement/ revamping to ensure system availability. Also, Original Equipment Manufacturer recommendations for maintenance practices should be adhered to.

4.10 Overhauling of critical water injection equipment

A reference is invited to CAG Report[20] No. 8 of 2006, wherein *inter alia,* Audit commented on delay in carrying out overhaul of critical equipment and recommended that the company should follow OEM norms for overhauling. The Management accepted the Audit observation and cited procedural delays. During the current Audit, it was observed that the company has been following its overhaul norms for main injection pumps, booster pumps and seawater lift pumps which is less stringent than the norms prescribed by the OEM.

Audit observed that overhauling continued to be delayed in large number of critical/ major equipment even after considering own norms. As of February 2020, 52 *per cent* of critical/ major water injection rotary equipment in Mumbai High were overdue for overhaul. This indicated that despite the assurance provided in the Action Taken Note to the earlier Audit Report, non-adherence to the timely overhauls continued in large number of cases.

Also approval for specific extension to overhaul schedule from the competent authority was not obtained. Even where overhaul was done, it was much after the equipment attaining recommended norm prescribed by the OEM. Few such deficiencies are detailed below:

[20] *CAG Report on 'Availability and utilisation of critical equipment of offshore installations in ONGC'.*

a. Pumps were operated even after they were due for overhaul. There were instances where the pumps were sent for major repairs after frequent failures. In one case, the OEM had recorded that '*the unit has run substantially over the recommended overhaul period with damage that could have been prevented by following routine maintenance and monitoring of the unit'*. In view of extensive damage, equipment was declared (December 2019) beyond economical repair.

b. Certain pumps were shown as standby continuously and thereafter taken to repairs, thereby raising doubts on the reliability of equipment availability during the standby period in Neelam field.

c. There was considerable delay in initiating the proposals for overhauling (in some cases proposal for overhauling was initiated after the equipment ran more than the hours prescribed by original equipment manufacturer), approval and finalisation of tender for overhauling against the company norms. The average time lag between date of indent and actual completion of overhaul in Mumbai High was around 40 months[21]. Two main injection pumps at Neelam platform (out of four pumps) were at original equipment manufacturer workshop for four years.

d. Pumps which were overhauled/ major repaired, failed within few months of operation pointing out to the non-efficacy of such repairs.

e. At Neelam platform, only one main injection pump was operated against two required, when pumps were under overhaul for extended period or when more than one pump was sent for repair.

f. Equipment which outlived their design life were overhauled instead of getting them replaced based on assurance from OEM for additional running hours. However, failures/ tripping continued to adversely impact the deliverables and operational capacity even after overhauling.

Thus, there is lack of timely approach for maintenance/ overhauling of water injection equipment. CMD of the company had observed (April 2017) that overhaul of equipment is not being done after running stipulated hours, as contracts are not being awarded in time. CMD stressed that the overhaul be taken up without any delay to avoid loss of production due to process disruptions as a result of failure of such equipment.

Management/ Ministry stated (February 2021/ June 2021) that equipment can be operated, over and above the recommended period if all operating parameters are being maintained within limit. Actions are in place for overhauling of equipment/ replacement of pumps and are at different stages of implementation. The main injection pump which failed immediately after overhaul is under warranty repair.

Management reply needs to be seen in the context of tripping/ extended periods of non-availability and multiple failures of the aged equipment. This led to non-achievement of required injection volumes planned. Replacement of equipment is also much delayed

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[21] ***Average time taken for overhauling of critical equipment from the date the process started.***

leading to deficiencies in the operation. Management reply is silent on excessive time taken (average 40 months) for overhauling of the equipment, particularly in approval and finalisation of tender.

Recommendation No. 7

The Replacement policy needs a relook to ensure that the efficiency of the aged pumps is also considered when repair versus replacement decisions are taken.

4.11 Tripping of water injection equipment

Frequent tripping was observed in main injection pumps due to deteriorated condition of critical equipment, lack of effective maintenance/ overhaul and timely replacement. In Mumbai High, number of main injection pumps tripping in Infill Complex Water injection South High Water Injection and Water Injection South platforms was on higher side compared to other two platforms *viz*., Water Injection North and Mumbai North Water. This was due to delay in overhauling of main injection pumps which affected its system availability and resulted in loss of water injection. In Neelam and Heera, tripping of the main injection pumps was attributed to booster pump failures/ leakages and due to turbine generators tripping. There are multiple instances where only one main injection pump was available to maintain pressure. In case of Heera, most of the tripping was attributed to water injection line leakages.

Management/ Ministry stated (February 2021/ June 2021) that tripping is expected to significantly reduce going forward because of revamping/ replacement action taken for critical equipment and its peripherals.

Reply needs to be seen in the light of loss of water injection due to delayed revamping/ replacement action.

4.12 Summing up

The company could not ensure timely replacement/ overhaul of water injection equipment. Many of the equipment had outlived their design operational life, which impacted the operational availability and reliability of the equipment. Chlorinators, one of the crucial equipment ensuring quality of water, were not functioning for more than eight years in many water injection platforms. Timely revamping of critical equipment was also not ensured after their mandated running hours prescribed by the OEM and the company prescribed running hours. This resulted in frequent failures/ tripping of the equipment affecting both quality and quantity of water injected in the reservoir. Discrepancies were noticed in manual reporting which made the equipment performance data unreliable. In addition, Plant Maintenance module in SAP was not properly used to monitor maintenance/ equipment performance levels. Thus, the water injection facilities were insufficient to meet the water injection requirements.

De-oxygenation Towers

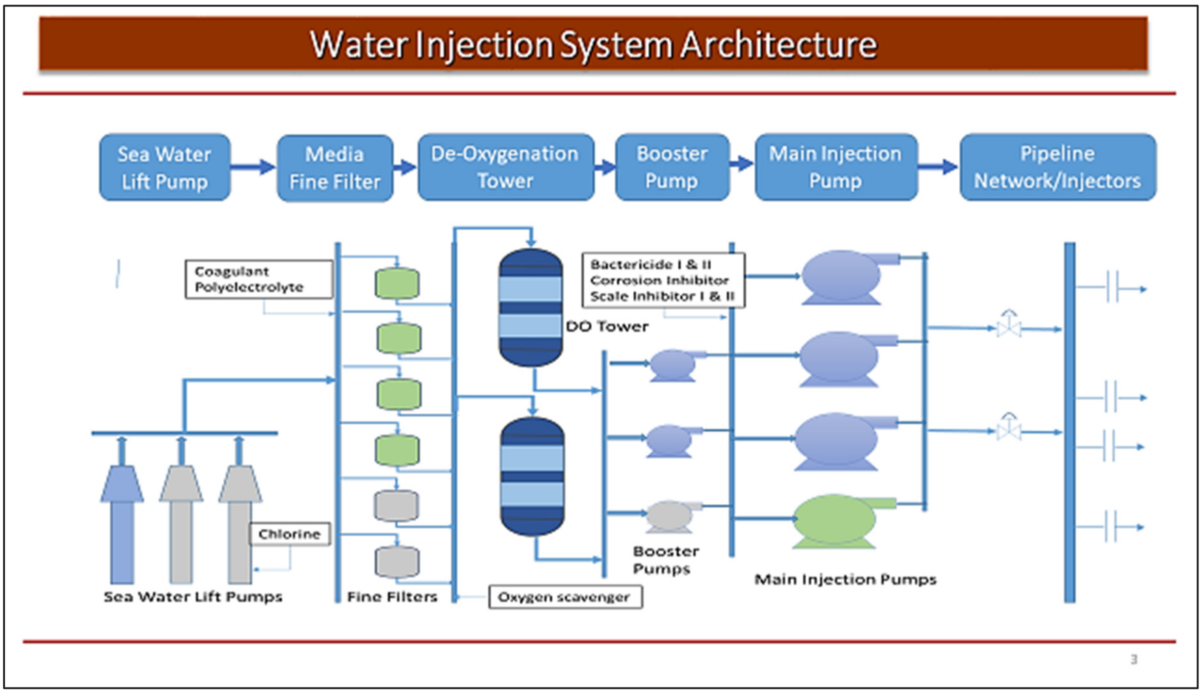
Chapter 5
Quality of water injection

In Western offshore oil fields of the company, seawater is the only source of water for injecting into reservoir, especially due to its ease of access. It, however, contains excessive salts, suspended solids, dissolved oxygen and is rich in flora and fauna. Therefore, its use may lead to number of operating problems like:

- Formation of scales in the injector and producer, which can be due to incompatibility between injection and formation water;
- Bacterial growth;
- Corrosion of equipment in the processing installation and pipeline injection network due to combined effect of oxygen and sodium chloride; and
- Plugging injection wells due to suspended solids, corrosion and bacterial by-products.

Hence it is essential that the seawater is treated effectively before it is injected. The treatment scheme for injection water is therefore designed to be such that water is free from above problems.

Fig 5.1 Water injection system architecture



5.1 Treatment of seawater

The equipment used in the water injection process has been described in Para 4.2. The treatment of seawater on water injection platform mainly comprises of following sub-processes:

- **Seawater lifting:** Seawater is lifted by seawater lift pumps and pumped to the coarse filters. Hypochlorite solution generated in chlorinator units is injected at the pump suctions to control marine growth in the seawater piping system.
- **Filtration:** The seawater is then passed through fine filters to remove suspended solids. The fine filter elements are automatically cleaned in a continuous backwash cycle with filtered water while operating. Coagulant/ polyelectrolyte are dosed into the filter inlet to help coagulate suspended solids.
- **De-oxygenation:** The filtered water is passed through de-oxygenation towers to reduce oxygen level to 200 ppb and oxygen scavenger chemical further reduces the dissolved oxygen to a permissible limit of <20 ppb. This prevents internal corrosion of equipment and pipelines. Dissolved oxygen ideally should be 'nil' in injection water.
- **Chemical injection:** A chemical injection system is provided for storing and injecting various chemicals into the water flood stream at various points in the system.

The treated water is pumped with the help of booster pumps and main injection pumps to water injection network.

5.2 Water quality parameters adopted by the company

The company has fixed water quality parameters suitable for injection of water into reservoir. The desired quality parameters and recommended dosing of water injection chemicals in western offshore oil fields is given at table 5.1.

Table 5.1: Desired quality parameters and recommended dosing of chemicals

Quality parameter	Quality limit		Name of chemical used to maintain quality parameter	Recommended dosing of chemical injected-MH/ N&H	Function of chemical	Dosing point	Measuring method to check quality parameters	Measuring point
	unit	limit						
Total suspended solid	Mg/ lt	<0.2	Coagulant/ Polyelectrolyte	0.4-0.8 ppm/ 0.2-0.3 ppm	Assist in coagulation and filtration	Filter inlet	Lab check	Filter outlet/ Main Injection Pump outlet
Millipore	Lt./ 30 minutes	>6	Coagulant/ Polyelectrolyte	0.4- 0.8 ppm/ 0.2 -0.3 ppm	Assist in coagulation and filtration	Filter inlet	Lab check	Filter outlet/ Main Injection Pump outlet
Turbidity	NTU	<0.2	Coagulant/ Polyelectrolyte	0.4 -0.8 ppm/ 0.2-0.3 ppm	Assist in coagulation and filtration	Filter inlet	Lab check	Filter outlet/ Main Injection Pump outlet
Particle count	No./ ml	<2000	Coagulant/ Polyelectrolyte	0.4 – 0.8 ppm/ 0.2-0.3 ppm	Assist in coagulation and filtration	Filter inlet	Lab check	Filter outlet/ Main Injection Pump outlet
Dissolved Oxygen	ppb	<20	Oxygen scavenger	10 ppm/ 2-10 ppm	Remove dissolved oxygen from	De-Oxygenation Tower	Lab check/ online	De-Oxygenation Tower outlet

Quality parameter	Quality limit		Name of chemical used to maintain quality parameter	Recommended dosing of chemical injected-MH/ N&H	Function of chemical	Dosing point	Measuring method to check quality parameters	Measuring point
	unit	limit						
					injection water			
Residual sulphite	Mg./ lt.	>1	Oxygen scavenger		Indicate residual presence of oxygen scavenger		Lab check	De-Oxygenation Tower outlet
Iron counts	Mg/ lt	<0.05	Corrosion inhibitor	20 ppm/ 10 ppm	Prevent corrosion	Booster pump inlet/ Main Injection Pump	Lab check	Main Injection Pump outlet
Sulphide	Mg/ lt.	Nil			Not a treatment parameter	Main Injection Pump	Lab Check	Main Injection Pump

Mumbai High (MH), Neelam & Heera (N&H)
Source: Management response received from Mumbai High, Neelam & Heera regarding desired water quality parameter adopted.

5.2.1 Downgrading water quality parameters

Over the period, the company diluted some of the water quality parameters as detailed at table 5.2.

Table 5.2: Dilution of water quality parameters

Quality parameter	Regional chemical lab report on test methods of water quality monitoring parameters (Feb 1984)	IRS Manual on 'Offshore Injection Water Quality' issued (Mar 1994)	Quality control testing procedures for chemist at offshore process platforms (Dec 1997)	Currently followed specifications (2014 - 19)
Suspended solids	0.1 mg/ litre		<0.1 mg/ litre	<0.2 mg/ litre
Particle count		<70 No./ litre	< 300 No./ litre	<2000 No./ litre
Millipore			> 10 litre/ 30 min	>6 litre/ 30 min
Dissolved Oxygen	15 parts per billion (ppb)			< 20 ppb
Residual Sulphite			> 0.1 mg/ litre	>1 mg/ litre

Source: Data/ Reports furnished by the company in response to Audit requisitions

Management/ Ministry stated (January 2020/ February 2021) that based on the field experience, reservoir conditions and other technical inputs, the injection water parameters were re-designed from time to time. The quality dilution needs to be seen in the context of the ageing of the water injection equipment as mentioned in Chapter 4.

5.3 Quality of injection water

The average quality of water measured at water injection platforms in Mumbai High and Neelam and Heera fields is given at **Annexure-IX**. It can be observed from the annexure that quality of water in almost all water injection platforms was inferior to the quality parameters currently followed by the company. The company failed to meet desired quality parameters, despite dilution of some of the quality parameters over a period of time. Further, some of the quality parameters (like dissolved oxygen, particle count, turbidity) showed a deteriorating trend.

Management/ Ministry stated (February/ June 2021) that the company had taken/ is taking requisite modifications/ revamping of water injection facilities to cater to the desired quality. The reply needs to be seen in the context of failure to maintain the quality of water over a long period of time which resulted in corrosion in pipelines/ equipment and affected injectivity of the wells. The delayed action is reactive and has consequential impact on costs involved and its efficacy.

5.4 Incorrect reporting of water quality parameters

Audit observed the following discrepancies and inconsistencies in reporting of the water quality:

i) While working out the monthly average of quality parameters, instances where it was beyond acceptable limits were excluded.

ii) Average water quality parameter of dissolved oxygen was reported as 'nil' even when dissolved oxygen was recorded at more than 200 ppb. Similarly, annual average was inconsistent with monthly figures.

iii) Dissolved oxygen in injection water was recorded within prescribed limits even though there was no consumption of oxygen scavenger.

iv) Consumption of oxygen scavenger was recorded even in days where the quantity was 'nil' in the chemical injection tank.

Thus, the quality of water recorded and reported by the company is not reliable. Management/ Ministry stated that some error in manual data entry has taken place and teams at offshore have been advised to take due diligence while recording the data and feeding in SAP system.

Recommendation No. 8

Due diligence while recording the data and feeding in SAP system should be ensured so that the desired quality parameters required for injection into the reservoir can be monitored and ensured.

5.5 Causes for poor water quality parameters

Poor quality of injection water was due to ageing of water injection facilities/ lack of proper maintenance which had already been discussed in Chapter 4. Non-availability of required water injection chemicals at water injection platforms, non-availability/ inefficient operation of chemical injection pumps also directly contribute to failure in maintaining the quality of injection water as mentioned at table 5.3.

Table 5.3 Details of 'nil' consumption of water injection chemicals during 2014-19

Platform	Both Coagulant and PAC		Oxygen scavenger		Water corrosion inhibitor		Bactericides	
	Days of nil consumption (a)	(a) / 5 years (in %)	Days of nil consumption (b)	(b) / 5 years (in %)	Days of nil consumption (c)	(c) / 5 years (in %)	Months* of nil consumption (d)	(d) *30 / 5 years (in %)
WIN	102	05.59	152	08.33	457	25.04	02	3.33
MNW	152	08.33	254	13.92	663	36.33	00	00
SHW	907	49.70	492	26.96	618	33.86	05	8.33
ICW	407	22.30	357	19.56	424	23.23	07	11.67
WIS	250	13.70	412	22.58	480	26.30	06	10.00
NLW	98	05.36	57	03.12	59	03.80	-	-
WIH	25	01.61	11	-	70	04.51	-	-

WIN- Water Injection North, MNW- Mumbai North Water Injection, SHW- South High Water Injection, ICW- Infill Complex Water Injection, WIS - Water Injection South, NLW – Neelam Water Injection and WIH – Water Injection Heera

Source: Platform daily production reports (DPR) and Chemistry monthly reports

*Company doses three types of bactericides alternatively each one after every 10 days.

As can be seen from the table, in large number of cases there was 'nil' consumption of chemical against recommended dosing norm (as denoted at table 5.1) due to non-availability of chemical at water injection platform and/ or deficiency of chemical injection pump.

In Mumbai High, in all the platforms there was low dosing of chemicals against the recommended dosing adopted by the company (details at **Annexure-X**). Water Corrosion Inhibitor was less than the recommended norms during 2014 - 2019 in Mumbai High. In case of Oxygen scavenger, except for Water Injection South and Infill Complex Water injection platforms during 2018-19, the dosing was less than the recommended norms during 2014-15 to 2018-19.

Wherever there was 'nil' consumption of oxygen scavenger, higher dissolved oxygen was recorded in injection water. In Neelam Water Injection platform for 54 days out of 1,826 days, there was 'nil' dosage of oxygen scavenger and it correlated with high dissolved oxygen levels at main injection pump (25 to 800 ppb) in those days and in Heera, in 43 months out of 60 months the consumption was less than 10 ppm. The residual sulphite was found to be 'nil' in 323 days (out of 1,826 days) in Neelam and 241 days (out of 1,551 days) in Heera, which indicated that desired level of dissolved oxygen was not maintained. In Heera, for 70 days, there was no dosing of water corrosion inhibitor at platform, of which 59 days it was due to no stock of the chemical at platform. Similarly, in Neelam, for 57 days there was no dosage of water corrosion inhibitor. During 52 months out of 60 months of 2014-15 to 2018-19, the dosage of water corrosion inhibitor at Neelam was lesser than the levels adopted by the company and in 1,756 days (out of 1,826 days) the iron count was more than 0.05 ppm at Neelam main injection pump end.

In case of water corrosion inhibitor, the company considered lesser dosage at 8 ppm for procurement against the dosage requirement of 20 ppm. The procurement was revised to 20 ppm from 2016-17 but the average consumption remained lower than the recommended norms.

Manuals[22], in-house research institutes[23] and committees[24] set up to study failure of pipelines and corrosion issues cited lack of injection of chemicals at required dosage as one of the main reasons for corrosion of equipment/ pipelines, injectivity impairment due to clogging of injection network. Despite time-to-time reiteration by various committees/ institutes, recommended levels of dosing of chemicals was not ensured. From the SAP data it was observed that pipeline leakages was the most significant reason for non-flowing of water injection wells.

Without proper dosing, the quality parameters could not be maintained. Corrosion inhibitors were required to prevent corrosion. Oxygen scavengers were required to absorb remaining oxygen molecules in downstream of De-Oxygenation towers as removal of dissolved oxygen is essential for internal corrosion of pipeline/ equipment. Poly Aluminium Chloride/ Polyelectrolyte/ Coagulants assist the filters to coalesce small, suspended particles. Insufficient dosing of the filtration chemicals and consequently presence of suspended solids may lead to formation plugging. Bactericides ensure that injection water is free from micro-organisms and thereby prevent microbial induced corrosion.

Management/ Ministry stated (February/ July 2021) that the concern of Audit regarding injection water quality is well taken and that various surface facilities are not working at their full efficiency at almost all platforms due to ageing. Management further stated that the company has taken up many initiatives from time to time to improve the water injection quality and quantity and it is a regular ongoing process considering the matured field environment and the ageing of installed equipment/ systems/ sub-systems. Management added that there are some extraneous factors also related to offshore operations like inclement weather conditions, limited storage space at platform, logistical problems and dosing pump issues.

Management reply is not convincing as the constraints brought out are controllable and poor quality of water is a long standing issue. In-house committee of the company also observed that excessive dissolved oxygen in injection water was the predominant reason for pre-mature failures of pipelines; besides frequent leakages, clogging of wellbores ultimately affected the water injection operations. Reply regarding logistics/ storage

[22] ***Regional Chemical Laboratory (RGL – February 1984), Manual on Offshore Injection water quality (March 1994), Corporate Oil Field Chemical specifications (2007) Premature failure of chemicals (August 2014).***

[23] ***IRS study report March 2011, 2012, IOGPT – Corrosion Study report (April 1994), IEOT (August 2012, October 2012).***

[24] ***Committee study report on premature failure of pipelines (August 2014), In-house committee report on water injection improvement (July 2012.***

constraints is also not convincing considering such large number of nil/ less consumption of chemicals. The average storage capacity of various types of water injection chemicals is more than two weeks' consumption. In addition, the company may consider storing chemicals at unmanned platforms and transporting to water injection platform when needed through dedicated boats assigned.

Management/ Ministry further stated (February/ June 2021) that Audit suggestion regarding storage of chemicals at unmanned platform is noted for further due diligence in order to avoid stock out situations.

Recommendation No. 9

Dosing of adequate chemicals as per norms should be maintained so that quality parameters of water are monitored for timely corrective action.

5.5.1 Incorrect reporting of chemical dosing

Audit observed that the method used for calculating average dosing of chemical during a particular month was incorrect as non-consumption days were exempted while calculating the average dosing. Since chemicals (except biocides) are to be dosed continuously to maintain quality of injection water, the methodology adopted resulted in incorrect reporting. Audit analysed the average dosing of chemicals for one year and observed that there was incorrect reporting in 43.33 *per cent* cases.

Management/ Ministry assured (February/ June 2021) corrective action.

5.5.2 Non-functioning of quality measurement instruments

Average life of the quality measurement instruments was seven years. Important quality parameters of particle count and total suspended solids were not captured due to non-functioning of quality measurement instruments. Particle count was not captured from April 2014 onwards in Infill Complex Water platform. Particle size analysers for Water Injection South, Infill Complex Water, South High Water Injection and Water Injection North and turbidity meter for Water Injection South platform were purchased long back. The equipment was non-functional/ outdated without original equipment manufacturer support.

Management/ Ministry stated (February/ June 2021) that new particle analysers have been installed at Water Injection South, Water Injection North and Mumbai North water injection platforms and under commissioning in Infill Complex Water injection and South High Water injection platforms. Turbidity meters have been installed at platforms Water Injection South, Infill Complex Water, South High Water Injection and Water Injection North at main injection pump end.

Management action needs to be seen in light of continued disuse/ failure to capture crucial quality parameter.

5.5.3 Inefficiency/ non-availability of chemical injection pump

Various water injection chemicals at desired doses at pre-defined frequency are required to be injected (dosed) continuously to maintain the desired quality of injection water. Thus, sufficient dosing capacity of chemical dosing pumps is required to be in operation mode continuously.

Audit observed that in 26 *per cent* of nil dosage days (1,597 out of 6,127 days), there was no dosing of chemicals even though chemical was available in the Mumbai High platforms and in Heera, in 50 days out of 106 days of nil consumption, stock was available but not dosed. However, status of injection pump was invariably shown as in operative mode. Further, system availability of all the injection pumps was shown as 100 *per cent* even though in large number of cases, actual dosing of chemicals were lower than the recommended doses despite stock available on platform (38 *per cent* excluding the nil dosage cases mentioned above). This was due to dosing constraints (non-availability of chemicals and dosing pump issues) as admitted by the Management. Audit is of the view that definition of 'system availability' needs review.

In the absence of day wise data, month wise chemical injection pump data furnished to Audit could not be relied upon.

Management stated (August 2019) that being small pumps, running hours of the pumps are not monitored/ captured in SAP and hence equipment availability of these pumps could not be verified. Management/ Ministry added (February/ June 2021) that running hours of chemical dosing pumps are now maintained at platform and feasibility of installing hour meters for each dosing pump and logging them in Distributed Control System (DCS)/ SAP system would be explored.

Recommendation No. 10
The Company needs to properly maintain the data of system and equipment availability of chemical injection system in future for monitoring and timely corrective action.

5.6 Non-measurement of water quality at wellhead

Quality of water is measured at water injection platform from where it is despatched and reported as quality of water injected into reservoir. From water injection platform, treated water flows through pipelines to various wellheads from where it is injected into reservoir through various water injection wells/ strings. The quality of water further deteriorates before it reaches the reservoir due to corrosion in water injection lines. Thus, actual quality of water injected into reservoir was inferior to the quality measured and reported at water injection platform. This has led to plugging of wellbore and impairment in injectivity of injection wells/ streams and ultimately impacted planned water injection program.

Various in-house committees, ONGC institutes - Institute of Reservoir Studies and Institute of Oil and Gas Production Technology in their study reports recommended to measure quality parameters at wellhead. The observations and recommendations of these study reports is summarised in **Annexure-XI**. Audit observed that in spite of specific guidelines for measuring all water quality parameters at wellhead issued by the Regional Chemical Laboratory (RGL) in February 1984 and reiterated by the Institute of Reservoir Studies (March 1994 and March 2011), in-house committee (July 2012) and Institute of Oil and Gas Production Technology (August 2014), the same is not regularly measured and reported at wellhead end.

Audit compared the quality of water measured at water injection platforms and wellhead for one year (2017-18) and the details are placed at **Annexure-XII**. It may be seen from the Annexure that there was significant deterioration in the quality of water from water injection platform to wellhead. The average iron content and turbidity in Mumbai High platforms increased up to 30.24 times and 25.42 times respectively from water injection platform to wellhead. Injection water with higher particle counts and turbidity measurements is more prone to plug the formation faster. This showed the ineffectiveness of the chemicals used to combat corrosion due to severity of corrosion in water injection pipeline network.

In case of Neelam and Heera, there was no planned periodicity for recording the samples in unmanned platforms and the coverage was not for all platforms. The Institute of Engineering and Ocean Technology (IEOT) in its report had observed (October 2012) that it may not be prudent to draw any inference from the unmanned platform readings as systematic and adequate data of water quality is not available. The monitoring of water quality injected into reservoir at unmanned platform had not improved yet (March 2019). Chemistry analysis also did not cover all the water injected quality parameters as covered in Mumbai High (for example, general aerobic bacteria/ sulphate reducing bacteria was not covered in case of Heera). Samples from backwash/ back flow from wells were not being taken. In unmanned platforms of Heera, particle count was reported in only five days during 2014-15 to 2018-19 and in all these five days, it was not within the adopted limits of 2,000 units/ ml (ranging from 2,855 to 4,818). In Neelam, where the unmanned platform data was reported (222 cases), turbidity was not maintained within the limits in 218 cases, particle count not within prescribed limit in 177 cases; Millipore and total suspended solids were not determined in 211 out of the 222 cases. In case of Heera, turbidity deteriorated from main injection pump end to the unmanned platform up to 11.54 times.

In its study, Institute of Reservoir Studies stated (March 1994) that "…*if the continuous presence of high concentration of iron in injection water at wellheads indicate that the pipeline network carrying the injection water might have become severely corroded. Once the pipeline becomes severely corroded then the possibility of the effectiveness of a corrosion inhibitor gets considerably reduced*".

Management stated (January 2020) that quality monitoring at unmanned platforms is carried out, as and when required and all out efforts are made to maintain quality through regular pigging of water injection lines, backwash of wells as well as intermittent monitoring of various quality parameters at unmanned platforms. Management further stated that quality at wellhead platforms is measured manually once in a quarter in Neelam and Heera due to logistic/ manpower constraints even though it is to be checked once in a month and there is no provision in SCADA/ DCS to get the online parameters presently. Management admitted that it is difficult to monitor the injection water parameters at the wellhead end on a regular basis due to logistical constraints and diversion of manpower in attending unplanned/ unexpected process upsets or shutdowns which occur in mature fields.

The response did not explain the deviation from documented guidelines/ recommendations by various institutes/ in-house committees for not measuring the water quality parameters at all the wellheads regularly (weekly/ monthly) and identifying reasons for deterioration of water quality on the way to wellheads. The company needs to measure the water quality parameters at all the wellheads as per the recommended periodicity to monitor the quality of water injected into the reservoir for timely corrective action.

Management/ Ministry stated (February/ June 2021) that sampling coverage of unmanned platforms has been enhanced in last six months and sampling is carried out at individual platforms instead of only at the endpoints as followed earlier. Management assured that monitoring of water quality parameters at well head platforms will be ensured as per SOP/ recommended periodicity. Analysis of general aerobic bacteria/ sulphate reducing bacteria has been started at well head platforms (Heera).

Recommendation No. 11

Requisite quality of water injected into reservoir should be monitored throughout the water injection process and ensured till the well-head end for all parameters.

5.7 Summing up

Audit noticed gaps in maintaining the quality of water injected vis-a-vis the quality parameters adopted by the company and downgrading of its own accepted quality parameters. Audit also noticed incorrect reporting of water quality parameters and continuing gaps of control in ensuring compliance to corrective actions recommended by internal agencies. Non-availability of equipment coupled with non-adherence to quality parameters by not dosing the chemicals at required level casts serious concern on efforts to enhance production and reservoir health. Thus, desired quality of water was not injected into the reservoirs.

Water Injection Well

Chapter 6
Maintenance of water injection pipelines and injectors

In order to sustain continuous water injection at desired flow, health of water injection lines and injectors needs to be maintained and monitored. As discussed in earlier chapters, failure to meet the quality parameters of the injected water and due to aged equipment, the threat of corrosion is real. To avoid corrosion of lines and impairment in injectivity of wells/ strings, timely maintenance is required. The maintenance and monitoring activities of injection lines and injector consist of the following activities:

(a) Maintenance and monitoring of injection lines:

- Chemical injection at process platforms to maintain injection water quality.
- Monitoring of corrosivity of injection water at main injection pump outlet and at respective water injection pipeline segments.
- Maintenance of water injection pipelines by pigging[25] of injection lines based on corrosivity and flow parameters, external health assessment of pipelines.
- Need based repair of pipelines using in-house resources.
- Periodic replacement of pipelines as per replacement policy/ need based.

(b) Injector health maintenance:

- Workover of injector wells by rig intervention.
- Well stimulation[26] jobs for injectivity enhancement.
- Regular backwash[27] of injectors for improving injectivity.

Audit examined the maintenance activities of pipelines and injectors during 2014-15 to 2018-19 and observed shortcomings which impacted the planned water injection operations and crude oil production/ recovery. These shortcomings are discussed in the subsequent paragraphs.

6.1 Corrosion monitoring

Corrosion monitoring programme plays a vital role in corrosion control. The offshore pipeline group of the company carries out corrosion monitoring studies through linear polarisation resistance probes. The safe limit of water injection pipelines corrosion is <2 mils per year mpy[28]. Corrosion above 5 mpy is considered high and above 10 is considered severe. The work of corrosion monitoring of water injection lines was

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[25] ***Pig is a small, sphere or disc apparatus that is used to sweep a flow line. Pigging is done for pipeline cleaning (commissioning, debris cleaning), line management (liquid removal, corrosion inhibitor dispersal and wax removal), and line inspection.***

[26] ***Well stimulation is a well intervention on water injection well to increase flow of water into reservoir.***

[27] ***Backwashing water injector is a method to remove the near wellbore damage and restore a significant amount of lost injectivity.***

[28] ***Mils per year is used to give the corrosion rate in a pipe, a pipe system or other metallic surfaces. It is used to calculate the material loss or weight loss of metal surfaces (Mils is 1000th of an inch).***

entrusted to third party (corrosion technologist) who monitors the corrosion rates at the designated pipeline location.

Audit examined 45 *per cent* of linear polarisation resistance probe study reports (261 out of 582 studies) for Mumbai High field, and 100 *per cent* of study reports (68 studies) for Neelam and Heera field, which were conducted by third party during 2014-15 to 2018-19. Audit observed that in all the study reports examined, corrosion rate was above the safe limit of <2mpy. The average corrosion rate of linear polarisation resistance probe studies is given at table 6.1.

Table 6.1: Average corrosion rate of injection lines

Field	Platform	LPR probes (Nos.)	Average corrosion rate (mpy)	
			Min	Max
Mumbai High	Water Injection North	15	3.57	5.73
	Water Injection South	57	5.14	8.24
	Infill Complex Water Injection	56	4.25	6.55
	South High Water Injection	37	5.03	8.16
	Mumbai North Water Injection	96	3.72	5.55
Neelam & Heera	Neelam	20	1.69	10.76
	Heera	48	4.32	6.61

LPR: Linear Polarisation Resistance
Source: Reports of third party probe reports

As reported by in-house committees[29] and the corrosion technologist, low dosing of oxygen scavenger and other chemicals contributed to corrosion of water injection network at faster rate.

Further, Audit observed that location of most of the linear polarisation resistance probes was at the main injection pump end. The purpose of conducting an independent probe-analysis so close to the point where it is monitored internally (main injection pump end) is not clear. Linear Polarisation Resistance probe can assess performance/ efficiency of the water corrosion inhibitor chemical and other corrosion related parameters up to a limited distance. It would be better served if it is taken at multiple locations rather than only at the main injection pump end.

Management/ Ministry (February/ June 2021) stated that corrosion monitoring is undertaken at representative selective locations at injection water pipeline sector; however, as suggested by Audit more locations will be taken up in future contracts.

Recommendation No. 12

Considering large number of pre-mature failure of lines, the company may strengthen corrosion monitoring system urgently. More locations away from the main injection pumps should also be taken up for corrosion monitoring in future.

29 IRS report on Water quality and Injectivity Assessment of Mumbai High (2011), Institute of Oil & Gas Production Technology (2012), In-house committee on pre-mature failure of water injection lines (August 2014).

6.2 Pigging of water injection lines

Pigging helps to remove debris deposited in pipelines and is one of the most effective and economical methods for control of microbes and monitoring of pipeline integrity. As per the company's Standard Operating Procedure (SOP) of November 2016, pipelines required periodic pigging. The annual workload for pigging is assessed based on the inputs given such as pigging frequency, availability of pipelines, flow characteristics, fluid composition etc. The pipeline group prepares annual pigging plan based on pigging frequency as per OISD code/ inspection and report requirement and SOP of the company. There was substantial shortfall in pigging operations *vis-à-vis* annual pigging plan as could be seen from the table 6.2.

Table 6.2 Pigging plan versus actual

Year	Mumbai High			Neelam & Heera		
	Approved workload (Nos.)	Actual pigging (Nos.)	Pigging achieved v/s approved (%)	Approved workload (Nos.)	Actual pigging (Nos.)	Pigging achieved v/s approved (%)
2014-15	326	83	25	104	66	63
2015-16	344	101	29	88	75	85
2016-17	405	61	15	72	47	65
2017-18	386	73	19	72	43	60
2018-19	460	148	32	72	79	110
Total	**1,921**	**466**	**24**	**408**	**310**	**76**

Source: Reports and replies furnished by the company

It is further seen from the table 6.2 that actual achievement was only 24 *per cent (*Mumbai High field) and 76 *per cent* (Neelam and Heera fields) of the approved workload.

SOP of the company prescribed to collect sample after completing flushing for analysis for iron count, sulphate reducing bacteria, total suspended solids and turbidity. SOP also prescribed to continue flushing of the line and check Millipore[30] rate. Water injection is resumed only when the Millipore level is achieved.

In this regard, Audit observed the following:

6.2.1 Mumbai High field

- As against 981 actual pig runs, samples were reported in only 246 pig runs. Out of 246 samples, in 235 cases (95.52 *per cent*) Millipore test results were not reported and thus, to that extent the utility of pigging was diluted. Resumption of water injection without clearing Millipore test was a deviation from the SOP.

- In none of the samples, iron count and total suspended solids was within the required quality parameters and turbidity was within limits in only one sample.

[30] ***Millipore test is a quality check of treated water to analyse the presence of suspended solids before and after filter, before injection pumps and injection wells. Millipore rate of flow above 6 litres/ 30 minute is considered an acceptable parameter.***

- In 161 samples, sulphate reducing bacteria was observed and in 33 samples, it was shown 'under observation' and in 25 it was kept blank.

6.2.2 Neelam-Heera fields

- Only 129 pigging samples were reported as against 310 pig runs (41.6 *per cent).*
- Sulphate reducing bacteria was found present in 34 out of 83 pigging samples in Heera and in 35 out of 48 cases in Neelam.
- 49 cases were denoted with blank data/ as 'under study' in Heera and 13 such cases observed in Neelam.
- General aerobic bacteria presence was found in 67 pigging samples out of 83 in Heera and 37 pigging samples out of 48 in Neelam.
- In Neelam, all recorded cases (40) were found with iron content more than the desired level of 0.05 ppm. Heera field did not analyse the iron content in the pigging sample.

Management stated (March/ April 2020) that lesser number of pigging operations against plan was primarily due to disruption/ non-performance of service contractor (four months in 2016-17), non-availability of pigging contract for more than one year and due to manpower (chemist) constraints. It was also stated that reporting of Millipore test will be ensured in future and higher iron count and total suspended solids may be a cumulative effect of less corrosion inhibitor dosing, at times ingress of dissolved oxygen due to malfunctioning of de-oxygenation towers. Management further stated that efforts are being made for optimum doses of corrosion inhibitor and to keep the sulphate reducing bacteria count as 'nil' through sterilisation using three types of bactericides alternately and in future, the results for the iron content analysis shall be recorded as part of the monthly progress report in Heera. Management/ Ministry further added (February/ June 2021) that with the contract for pigging in place, efforts are being made to pig all pipelines as per their scheduled frequency and collection and analysis of post pigging samples are being carried out as per SOP and will be ensured in future as well.

The reply needs to be viewed in light of the fact that (i) recommendations for periodic pigging and sampling analysis made in the previous in-house reports on water injection were not considered, (ii) though the SOP of the company mentioned for analysis of post pigging samples for every line after pigging, there is substantial shortfall in carrying out pigging of lines against requirement, inadequate sample analysis, off specifications quality of water injected into reservoir. Reply is silent on lab results awaited/ not available cases.

Recommendation No. 13

The company should adhere to defined frequency of the pigging of lines to ensure health of pipelines and to prevent its faster corrosion. The company should follow pigging operation strictly as per SOP by taking samples on each pig run and analyse them for required quality parameters and microbial growth for corrective actions.

6.3 Pre-mature failure of water injection lines

In-house committees[31], international consultants and the company's research institutes (1994 to 2018) had expressed concern over the accelerated corrosion of water injection lines due to poor quality of water, inadequate pigging of lines and low/ stagnant velocity of lines and recommended remedial measures to restore the quality of water within quality parameters, increase frequency of pigging, etc. The in-house committee had concluded that internal corrosion was the primary reason for premature failure of lines.

Rather than mitigating the corrosion issues, Audit observed that the company reduced (October 2003) the design service life of water injection lines from 25 to 15 years. This was done due to failure of large number of lines on account of internal corrosion. Review of pipelines replaced during 2014-15 to 2018-19 revealed that number of lines had even failed much before attaining the revised design service life of 15 years due to the reasons highlighted above. Further, during 2014-15 to 2018-19, 85 leakages of 44 lines were attended in Mumbai High and eight lines were attended in Neelam and Heera fields. Considering the time lag between date of leakage and date of repair of lines/ replacement, there is substantial loss of water injection. As of March 2019, 48 wells (60 strings) in Mumbai High and eight wells in Neelam and Heera were closed due to line leakages. In WN1 platform of Neelam, injection suspended since 2011 could not be resumed even after a new injection line was commissioned to connect Neelam Water injection (NLW)-WN2 due to pending leakage line replacement. The WN2-WN1 line was subsequently replaced in Pipeline Replacement Projects (PRP)-V in 2018. The Committee appointed for augmentation and distribution of water injection in Mumbai High also reiterated (October 2018) that frequent leakages can be minimised by maintaining the injection water quality as per recommended parameters and preventive maintenance of equipment.

Management stated (April 2020) that failure of pipelines is mainly caused by low flow rate in a sector and when wells were closed for reservoir monitoring. Management accepted that due to line leakage, there is decrease in liquid deliverability and pressure drop. It was also stated that maximum water injection lines of Neelam and Heera fields are now coflex[32] lines in view of its corrosion resistance property and lower maintenance. Management/ Ministry further stated (February/ June 2021) that collection and analysis of post pigging samples are being carried out as per SOP and will be ensured in future as well.

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[31] ***Caproco International (1998), in-house committees (2012, 2014).***

[32] ***A flexible pipe is a configurable product made up of several layers. The main components are leak proof thermoplastic barriers and corrosion-resistant steel wires.***

The response has to be seen in the light of inadequate implementation of the recommendations of in-house committees/ international consultants and failure to maintain the quality of injection water.

6.4 Workover of injectors

A workover or well servicing is any operation performed on a well to restore or improve its performance. Once a well is put on injection, at some stage of its operating life, it may inject water below its capacity due to either formation related or mechanical problems or both. Therefore, injection well needs repair or replacement of surface facilities. Institute of Oil and Gas Production Technology (IOGPT), research institute of the company, had suggested that the condition of tubing needs to be checked periodically in the interval of 5, 8, 11 and 15 years from last workover. In Mumbai High field, against 123 wells planned for workover, it was carried out only in 61 wells (49.6 *per cent*). The major reason for deviation/ shortfall was non-availability of rigs.

In-house committee constituted for study on water injection improvement in Mumbai High observed (July 2012) that one of the reasons for less water injection is poor well conditions. The committee observed that large number of water injection wells were having tubulars older than ten years and needed servicing. These wells over the period with continuous water injection were suspected to have injectivity loss due to corroded/ damaged tubing and casings and plugging of wellbore and required immediate servicing. Committee recommended 104 wells for workover jobs for wellbore clean out, tubing change, casing repair, gas lift installation for facilitating flow back of wells. It estimated servicing of these 104 wells would enhance the injection of wells by 117,000 bwpd.

The Company hired (April 2015) two dedicated rigs for three years for workover jobs for servicing these identified wells. Only 62 *per cent* of the rig days were used for workover operation while the rig was diverted for additional drilling activities based on work priority for remaining 821 days. During the period 2015-16 to 2017-18, out of identified 100 wells (4 wells already serviced before deployment of dedicated rigs), only 23 could be covered leaving 77 wells pending for workover. It was observed that injectivity in these 23 wells had improved after workover operations. During subsequent period, no separate rig was hired for servicing the remaining wells. This indicated that more emphasis was given for oil production ignoring the long-term impact of less water injection on reservoir pressure and ultimate recovery of oil.

Management stated (March 2020) that workover plan is worked out considering the rig resources available and priority of the wells. Management/ Ministry further added (February/ June 2021) that to address reservoir related issues, wells are planned for intervention on development schemes and other rig interventions are prioritised on need base to address safety.

The reply indicated that due importance was not given for water injection wells. Dedicated rigs hired for workover of water injection wells were diverted to other operations and there is no plan to service left over identified wells to improve injectivity. The need for servicing of wells was also emphasised in the subsequent in-house committee report (August 2014) which stated that "…*several water injector wells/ strings which are more than 20 years old and require workover job to rectify tubing leakage and/ or casing damage for effective water injection… backwash, stimulation and workover must be regularly adopted to keep the well bore clean and maintain injectivity*".

The workover plan of Neelam and Heera fields was not made available to Audit and hence, Audit is unable to verify whether the water injection wells due for workover were attended to. IOGPT had commented (September 2016) on long gap between workover of water injection wells leading to damages to tubings and increased workover costs. Of the 63 wells under injection in Heera field, 39 were not worked over even once since beginning. Of these 63, eight wells are in operation since 1991 to 2010 and the wells were worked over after a gap of 15-20 years. In Neelam field, out of 24 wells under injection, 11 have not been worked over at all, of which, nine wells were more than 17 years old.

Audit observed that injector wells were closed permanently/ temporarily due to casing damages. An injection well in Heera was closed since December 2017 due to annular valve leakage resulting in less water injection of 12,000 bwpd. Casing leak is a serious safety issue. The safety rules in Chapter XVI of Oil Industry Safety Directorate Manual lays down the stipulations for well barriers and corrective action in case of well barrier failures. Non-compliance of safety regulations could lead to serious implications. Considering the huge gap between two workover jobs and some water injection wells were not worked over since its inception, there is a need for a comprehensive policy for workover/ maintenance of water injection wells.

Management/ Ministry stated (February/ June 2021) that based on outcome of regular monitoring from injection rate, pressure recorded, survey and other reservoir diagnostic plots/ analysed studies, wells are planned for workover. If the desired quantity of water injection is not achievable/ achieved by stimulation, then well is shortlisted for workover. Management/ Ministry further stated that the audit recommendation for preparing an action plan for workover of injection wells was noted.

Management reply needs to be viewed in light of the fact that there is a long gap of 10-15 years between workover jobs of water injection wells and shortfall against the planned workover jobs.

Recommendation No. 14

The company needs to institute a mechanism to workover these water injection wells in a timely manner and prepare action plan accordingly. This will help the company to keep water injection wells in healthy condition and ultimately to attain the goal of maintaining the reservoir pressure for increasing productivity of oil wells.

6.5 Stimulation jobs of injection wells

Well stimulation[33] is a well intervention procedure adopted as water injection wells were prone to plugging of wellbore with scaling/ microbial growth/ residual biomass and microbial induced corrosion. Frequent stimulation job is required to maintain the desired injectivity. In the past, stimulation job in the company was strictly driven based on the resource available. An in-house committee observed (August 2014) that inadequate stimulation is one of the reasons for less water injection and recommended that procedures of stimulation jobs must be regularly adopted to maintain injectivity. Against the desired frequency of once in two years as suggested by the international consultant M/s. GCA, the frequency of stimulation was once in 5.8 years (Mumbai High) and 4.4 years (Neelam and Heera). The company reviewed (2013) its trouble shooting approach of stimulation jobs and decided to have proactive preventive approach as recommended by the consultant to make it in line with the best industry practices. Based on this, stimulation methodology with frequency of once in two years was worked out and one stimulation vessel was hired for a period of three years for western offshore.

In this regard, Audit observed that despite hiring dedicated stimulation vessel, the company, on annual basis planned less number of stimulation jobs of injection wells against the approved workload. In Mumbai High, against approved workload of 680 stimulation jobs, only 157 jobs were planned (23 *per cent*); of this only 120 jobs were carried out (18 *per cent*). Similarly, in Neelam and Heera, against the approved workload of 176 jobs, only 69 stimulation jobs were carried out (39 *per cent*). To the Audit query seeking annual plan details, Neelam and Heera stated that "*Plan of stimulation wells is not prepared and the stimulation workload in water injection wells is worked out on a continuous basis throughout the year*".

Management/ Ministry stated (February/ June 2021) that workload for stimulation jobs is optimised as per available resources and additional stimulation vessel is being hired so that focus can also be given for water injection stimulation jobs.

Reply needs to be viewed from the fact that dedicated stimulation vessel was diverted to stimulation of oil wells. The allotment of stimulation vessel resources to the water injection wells for all fields was only 3.5 *per cent* in 2016-17, 3.8 *per cent* in 2017-18 and 1.4 *per cent* in 2018-19. This showed prioritisation of stimulation of oil wells over injection wells at the cost of reservoir health.

Recommendation No. 15

The company should review its present practice/ policy of need based approach of stimulating water injection wells to make it in line with the best industry practices. This will help in taking preventive measures before serious damage occurs to the system or wellbore and to improve injectivity of wells.

[33] ***Stimulation jobs include acid, solvent and chemical treatments to improve the permeability of the near-wellbore formation, enhancing the injectivity/ productivity of a well.***

6.6 Backwash of injectors

Over a period, some unwanted material like corrosion particles, dead micro-organisms, etc., get accumulated near wellbore and are required to be removed/ cleaned to improve wellbore conditions. Backwashing water injector is an additional method to remove the near wellbore damage and restore a significant amount of lost injectivity. In the backwash process, the injector is flowed back to clean up any formation damage. Samples of backwash fluid are an important indicator of quality of injected water and offer insights about the water injection process. Injector wells needs to be backwashed at regular intervals to avoid impairment of reservoir permeability or reduction in injectivity. Audit observed that there was substantial shortfall in backwash activities against plan as given in table 6.3.

Table 6.3: Plan v/s actual backwash jobs

Year	Mumbai High field			Neelam & Heera field	
	Plan (Nos.)	Actual (Nos.)	Achievement (in percentage)	Plan	Wells backwashed (Nos.)
2014-15	377	433	114.9	NA	8
2015-16	406	408	100.5		4
2016-17	366	344	94.0		12
2017-18	355	235	66.2		4
2018-19	314	178	56.7		7
Source: Data furnished by Management					

It may be seen from the table that there is decreasing trend in achievement of backwash of injectors in Mumbai High fields.

6.6.1 Mumbai High: An internal committee observed (July 2012) that in Mumbai High, back flow of limited number of water injection wells was being done. Committee observed that out of 291 strings only 132 strings were equipped with gas lift valve and thus could be backwashed regularly; the remaining 159 strings needed gas lift valve provision and hence, the committee proposed remedial action. Status of compliance to the recommendations was not provided to Audit. A Task Force constituted in Mumbai High reiterated (October 2018) that regular backwashing of injectors has a positive impact on well injectivity and recommended backwash of injectors once in six months.

Examination of the data of water injection backwash samples furnished to Audit revealed that periodicity for backwash is more than a year per injector[34]. Of 334 injectors, no backwash was carried out in 26 injectors and around 158 injectors were due for backwash considering time interval of more than six months from their last backwash. Audit observed that wells where gas lift valves were not installed were overdue for backwash. In Mumbai North West platform, in 42 cases out of 77 records made available to Audit, backwash samples were not taken thereby rendering backwash process ineffective. Management did not offer any comment on non-achievement of backwash plan and details of wells which are backwash compliant.

[34] ***Injection well/ string - Injection well is a well through which water is injected into reservoir to maintain reservoir pressure. Injection well may have single string or dual strings.***

6.6.2 Neelam & Heera: As compared to Mumbai High field which has monthly plan for backwash of water injection wells, Neelam and Heera field does not have a streamlined approach for backwash. Only in 35 cases, backwash of water injection wells was carried out during 2014-15 to 2018-19 against the requirement to carry out once in six months for each injector. The backwash details shared by the company indicated that the process was not regularly followed. The samples were not analysed, thereby rendering the efforts ineffective.

Management stated (December 2019/ February 2020) that no sample was collected during the process of backwash due to non-availability of sample point required for the equipment and hence lab analysis of samples was not available. However, it has been decided to carry out at least 3-5 water injector backwash jobs every month in Neelam and Heera fields and prepare a detailed chemistry analysis report of the backwash water sample collected. Management/ Ministry assured (February/ June 2021) that backwash plan will be strictly adhered to in future.

Recommendation No. 16

The company should regularly backwash the wells as per defined periodicity to improve injectivity of wells and increase water injection. Also resources planned/ mobilised for water injection may be considered separate from the requirements for producer wells.

6.7 Summing up

Audit noticed higher levels of corrosion in all the platforms than the desired level which is a matter of concern. The company could not adhere to the periodic pigging plan for removal of debris deposited in the pipelines. Besides, non-monitoring of pigging samples defeated the purpose of carrying out the exercise. Audit also noticed pre-mature failure of pipelines in view of high dissolved oxygen and non-maintenance of flow velocity. It was also noticed that periodical workover/ stimulation of injectors were not carried out leading to loss of injectivity/ safety issues. Resources hired exclusively for water injection wells were diverted to oil wells at the cost of reservoir health. Thus, pipelines and injection wells were not maintained as per requirement and the workover, stimulation and backwash operations of injection wells were not carried out effectively, leading to drop in injectivity.

Chapter 7
Impact of inadequate water injection

Failure to maintain the planned quantity and desired quality of injection water adversely impacted the voidage compensation and consequently the decline in reservoir pressure and ultimately the crude oil production. As the reservoir pressure goes down, gas starts evolving from the reservoir thereby reducing the oil permeability.

7.1 Reservoir health and monitoring

Since inception of fields, due to inadequate water injection, there was continuous decline in reservoir pressure which impacted crude oil productivity and its ultimate recovery.

Audit observed that reservoir pressure in Mumbai High, Neelam and Heera fields has been on continuous decline from its initial pressure level. The initial reservoir pressure at the time of commencement of production in Mumbai High field was 2,250 psi[35] and reservoir pressure at the start of water injection was 2,100 psi. The reservoir pressure in major oil producing layer of Mumbai High North (L-III) declined from 1,625 psi in 2014 to 1,585.2 psi in December 2019 and in Mumbai High South (L-III), it declined from 1,562 psi in 2014 to 1,551.7 psi in December 2019. In Heera field, reservoir pressure dropped from initial reservoir pressure of 2,100 psi to 900-1,200 psi in November 2019. The initial pressure at Neelam field was around 2,100 psi, which declined to 1000-1520 psi in November 2019.

Decline in reservoir pressure due to deficient water injection is further accentuated by higher gas production from the gas cap in the reservoir. Increasing Gas/ Oil Ratio[36] is an indication of reduced reservoir pressure. As the reservoir pressure goes down, gas starts evolving in the reservoir, thereby reducing the oil permeability.

External domain experts/ consultants engaged by the company and its internal task force/ committees (1990-2019) had highlighted **(Annexure-XIII)** the decline in reservoir pressure and reiterated the need to address low pressure areas, improve voidage compensation and thereby reservoir health.

Ministry through its technical arm, Director General of Hydrocarbons (DGH) has also periodically raised concern over insufficient water injection and its impact on reservoir health and well productivity. In its periodical production review meetings, DGH had also stressed upon importance of water injection and maintenance of reservoir health as mentioned below:

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35 Measurement unit of pressure - Pound per square inch (psi).

36 Gas/Oil ratio is the ratio of volume of gas that comes out of solution, to the volume of oil at standard conditions (vol./vol.).

- Reservoir management is poor in Mumbai High and Heera; pressure drop is observed in Mumbai High fields. The water injection is not successful due to poor areal[37] distribution and inadequate quantity. Uneven areal spread of water injectors/ water injection rates resulted in pressure sinks in reservoir while inadequate water injection/ low voidage replacement ratio is responsible for decline in average reservoir pressures. Pressure sinks/ reservoir pressure depletion results in well productivity decline. Thus, water injection does not support the reservoir as envisaged. DGH suggested (April 2018) improving areal distribution by suitable pattern between the injectors and the producers.

- Oil production in Neelam-Heera field was constrained due to pressure sink in north Heera area (May 2017) and DG-DGH observed (August 2018) that '*despite high quality reservoirs of Neelam-Heera, production has been hampered due to mismanagement of resources'*.

- Pressure in Mumbai High and Neelam-Heera fields has dropped significantly. The prime reason for alarming fall in productivity of reservoirs of Mumbai High/ Heera fields is attributed to sharp decline in reservoir pressure due to low cumulative voidage compensation. Once pressure is low, water injection does not get effective in terms of sweeping the oil to producers and it short circuits to the nearby producer. With irregular/ insufficient injection, the objective of maintaining reservoir pressure was not achieved. Total water injection rate may have to be increased substantially and reservoir pressure has to be restored adequately (February 2021).

Had the above recommendations been implemented fully, it would have helped in maintaining the reservoir pressure.

Management/ Ministry stated (February/ June 2021) that in Mumbai High during last two years concerted action has been taken and as a result water injection level was increased from 7.5 lakh bwpd in June 2018 to 9.5 lakh bwpd in April 2020 and the water injection plan is to increase to 11.5 lakh bwpd by March 2021. It was also stated that wells with high Gas Oil Ratio were closed as part of reservoir management.

Management/ Ministry reply needs to be viewed in the light of the fact that actual water injection in Mumbai High during 2019-20 and 2020-21 was also less than the plan. During 2019-20, as against average water injection of 11.31 lakh bwpd in annual plan, the actual average water injection achieved was only 9.35 lakh bwpd (17 *per cent* deficit). Similarly, during 2020-21 as against average water injection of 10.51 lakh bwpd planned in build-up plan, the actual average water injection was only 8.86 lakh bwpd (15.76 per *cent* deficit).

[37] ***Areal distribution – geographical spread.***

Further, the in-house committees[38] as well as consultants[39] have repeatedly recommended increasing the water injection volumes to augment the reservoir pressure.

Considering the delayed commencement of injection, with the continuing gap between re-development scheme injection levels and actual injection, ageing infrastructure and well maintenance issues, it is uncertain that the company would be able to achieve voidage replacement of 100 *per cent* in near future and maintain the envisaged pressure levels and reservoir health.

Recommendation No. 17

Company may devise a time bound action plan to address pressure sinks by ensuring injection volumes to redevelopment scheme levels and avoid uneven areal spread of water injection.

7.2 Performance benchmarking

The performance benchmarking group of the company was created in March 2002 and its main functions were to develop and monitor performance contracts[40]; developing benchmarks for activities of the company with world's leading exploration and production companies. The benchmarking group identifies Key Performance Indicators (KPIs) of each Strategic Business Unit (SBU) within the company. KPIs flow from the MoU parameters with the Ministry and include other SBU critical parameters. The KPI of 'reservoir health' includes targets for 'water injection' and 'reservoir pressure maintenance' (this was introduced from 2015-16 onwards). Performance of KPI of 'reservoir health' is evaluated based on the target proposed by the SBU (Asset).

Audit observed that the benchmarking group did not benchmark all the above KPIs with world's leading exploration and production companies. With regard to the KPI on reservoir pressure in performance contract, the company maintained static target of maintaining reservoir pressure only at 70 *per cent* of the pools/ reserves.

Management stated (June 2020) that considering the achievement history, a SMART (Specific, Measurable, Achievable, Relevant, Time-bound) KPI of 70 *per cent* was fixed in 2016-17. Management/ Ministry further stated (February/ June 2021) that due diligence over benchmarking KPIs with world's leading exploration and production companies would be taken up.

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[38] ***Multi-Disciplinary Team (MDT) report on 'Facility cost optimisation and water injection improvement in Mumbai High'- July 2012, Task Force Report on 'Augmentation and redistribution of water injection in MH field'-October 2018.***

[39] ***International consultant M/s Gaffney, Cline & Associate was engaged for consultancy work for implementation of MH redevelopment schemes since 2000 and international petroleum consultants William M Cobb & Associates, INC was engaged (August 2009) to review water injection operation in Mumbai High field.***

[40] ***Performance contract is a tool for evaluation of performance of strategic business units, entered with the head of SBU.***

Management reply needs to be viewed in light of the fact that annual water injection plan was prepared considering the constraints based on achievable quantity and always less than the requirement as per the field development plan. In view of continuous depletion in reservoir pressure, uneven distribution of injection among different layers and resultant lower production of crude oil, keeping such static 70 *per cent* target by management for evaluation of field performance under this KPI has defeated its purpose. Besides, Audit noticed that from 2019-20, the parameter of reservoir health is not part of the performance contract indicating lack of monitoring of reservoir health by top management. The MoU signed by the company with the Ministry does not contain any parameter on reservoir health.

Recommendation No. 18

Company should fix the target considering benchmark of international/ industry best performance rather than achievable basis so as to evaluate true performance of its operation. Weightage of water injection may be increased in performance monitoring and benchmarking.

7.3 Impact on crude oil production

Shortfall in water injection is one of the significant reasons for less production of crude oil. The company prepares its production profile based on simulation model of its reservoirs. Audit requested management to estimate the impact on crude oil production due to deficient water injection. The company's in-house research institute, Institute of Reservoir Studies used the existing simulation model by changing the water injection quantity of the re-development scheme levels with the actual injection achieved to arrive at the crude that could not be produced due to lesser water injection. Institute of Reservoir Studies conveyed (July 2020) that in comparison with production as per feasibility report (base plus incremental), there is oil deficit of 3.695 MMT[41] due to less water injection during 2014-15 to 2018-19.

Audit observed that the company reported actual operation loss at different rates at these fields during 2014-15 to 2018-19. The actual operating loss reported by the company ranged from 0.64 to 2.35 *per cent* (Mumbai High), 3.55 to 11.22 *per cent* (Heera) and 0.03 to 16 *per cent* (Neelam). Audit, therefore, reworked the management quoted oil deficit of 3.695 MMT by considering the actual loss reported during 2014-15 to 2018-19 which worked out to 3.79 MMT. The value of oil deficit of 3.79 MMT due to less water injection worked out to ₹11,276.79 crore **(Annexure-XIV A, B)** during 2014-15 to 2018-19. Management/ Ministry stated (February/ June 2021) that the value of oil would be ₹7,802.50 crore for ONGC after considering the statutory levies. Thus, the balance ₹3,474.29 crore is revenue loss to the Government of India.

41 This oil deficit was calculated considering an operation loss at 6 per cent.

Management stated (February 2021) that oil deficit estimated by Institute of Reservoir Studies for the period 2014-19 is not permanent but deferred production, for which firm development plans are under implementation.

Management response is not justified. Directorate General of Hydrocarbons (DGH) observed (February 2021) with regard to the reservoir performance analysis of Mumbai High and Neelam and Heera fields that once reservoir pressure is low, water injection does not get effective in terms of sweeping the oil to producer and it short-circuits to the nearby producer through low-pressure zone. Even no enhanced oil recovery process would be effective in low pressure reservoir.

Further, Ministry in its reply stated (June/ July 2021) that:

i) Maintaining reservoir health has been a chronic problem. Historically, there has been a shortage of adequate water injection even though all the development schemes envisaged water injection as a critical input to maintain reservoir pressure and improve secondary oil recovery.

ii) Maintaining good reservoir health and adequate reservoir pressure is *sine qua non* for achieving globally comparable recovery factor in Mumbai High and Neelam Heera fields.

iii) EOR process will not be effective in the low-pressure reservoir. Also, once the pressure is low, water injection does not become effective in terms of sweeping the oil to producer and it short-circuits to the nearby producer through low pressure path, further reducing oil output from producer wells.

iv) Systematic efforts at revamping the complete water injection infrastructure and boosting up reservoir pressure through adequate quantity and quality of water injection is essential. There is considerable scope for improvement, as stated earlier, and significantly raising the cumulative recovery factor hitherto achieved.

v) Projected increase in recovery factor by 2039-40 (33 *per cent* in Mumbai High field) is low as compared with similar reservoirs worldwide. Field development and production teams need to work in cohesion keeping in mind the long-term gains by maintaining the reservoir health.

Consultant, M/s Boston Consulting Group (India) Pvt. Ltd., engaged by the company, for formulation of ONGC Energy Strategy - 2040 also observed (December 2018) that *'ONGC's recovery rate in mature fields currently stands at 25-35 per cent. In comparison, best-in-class global peers have achieved recovery rates of 45-55 per cent'*.

Management stated (June 2020/ February 2021) that production comes from base production as well as new inputs. Hence, total production provides a more realistic measure of field performance. As on 1 April 2020, in case of Mumbai High and Neelam and Heera fields, the cumulative production was 609.439 MMT against plan production of 613.105 MMT with a shortfall of 3.666 MMT.

Reply of the Management is not tenable. The company considered planned production after allowing six *per cent* loss. The average loss in case of Mumbai High during 2014-15 to 2018-19 was 1.43 *per cent*. Further, actual production reported by the company was inclusive of non-crude oil elements *viz.,* Basic Sediments & Water (BS&W)[42], Off-gas[43] and condensate quantity[44] which are not part of crude oil production as per the PNG Rules. Excluding non-crude oil elements in reported production, the difference between the cumulative production and actual production till April 2020 worked out to 43.88 MMT.

DGH also agreed (July 2021) with Audit that 'non crude oil elements' (BS&W, Off-gas and condensate) should be excluded for the purpose of determining the production figure of 'crude oil' in line with Rule 3(b) of PNG Rules, 1959 as amended from time to time.

Further, Consultants (M/s. GCA, M/s. Beicip Franlab) of international repute were engaged by the company as per directives of the Ministry to independently assess remaining recoverable reserves of hydrocarbon volumes of Mumbai High, Neelam and Heera fields. As per the Consultant report covering the period 2019-2040, the estimate of the consultant was lower than the company estimate by 16.12 MMT for the period 2019-2040.

7.4 Summing up

Audit noticed inadequate water injection with less than one voidage replacement ratio since inception of water injection operations. It may be pertinent to note that the company could achieve cumulative voidage compensation of only 54.43 *per cent* in Mumbai High, 78.8 *per cent* in Heera and 42 *per cent* in Neelam fields as of March 2019. Audit also noticed uneven distribution of injection water amongst different layers, continuous drop in reservoir pressure, development of pressure sinks and production from high gas/ oil ratio wells impacting well production. With the current re-development plans on hand from

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[42] ***Basic Sediment and Water (BS&W) refer to volume of non-hydrocarbon containments which is made up of dirt (sediment) and water. In ONGC offshore, partially stabilised crude oil containing BS&W is measured for reporting production of crude oil. This partially stabilised crude oil is dispatched from offshore to onshore terminal (Uran Plant) for complete stabilisation wherein BS&W from partially crude oil is removed.***

[43] ***Off-gas is dissolved gas in partially stabilised crude oil which is separated during stabilisation process of crude oil at Uran plant and added to reported gas production.***

[44] ***Condensate: Liquid hydrocarbon which is lighter than Crude Oil, having an API Gravity greater than 45 is referred as Condensate. Basically, no condensate exists in the reservoir at reservoir conditions i.e. temperature and pressure of the reservoir. During the flow of gas from the well bore to the surface, the pressure and the temperature of the well fluid undergo change i.e. reduction in both the temperature and pressure, and as a result heavier hydrocarbon components of the gas get condensed in the form of condensate.***

these mature fields, and in view of continuous decline in the profile envisaged, recovery of cumulative oil deficit of 60 MMT (43.88+16.12) is unlikely. This loss cannot be considered as deferred production as claimed by the company but a permanent loss. Further, even for exploitation of a part of this oil deficit, additional investment is required and this needs review from the point of economical oil recovery.

Chapter 8
Conclusion

Major share of crude oil production (59 *per cent*) of ONGC comes from the western offshore fields. Mumbai High and Neelam-Heera fields are major oil producers which have been operating from 1976 and 1984 respectively and therefore, these mature fields are susceptible to decline in production. Water injection is a critical input for reservoir health management and for increasing crude oil recovery from the reservoir. Injection of required quantity of water at desired levels is necessary to maintain the reservoir pressure at its initial level. The company in its re-development schemes considered complete voidage replacement (liquid drawn equal to water injected) at 100 *per cent*. ONGC commenced water injection six to eight years after commencement of field production in Mumbai High and Heera. The total cumulative voidage compensation achieved was only 54.43 *per cent* (Mumbai High), 42 *per cent* (Neelam) and 78.8 *per cent* (Heera) as against 100 *per cent* voidage compensation.

Planning of water injection quantity in annual plan was always lower than the injection quantity requirement as per re-development schemes and actual water injection quantity was further lower. Constraints of availability of rigs/ stimulation vessels, water injection infrastructure and pipeline network, etc., were considered as a norm for preparation of annual plan. This resulted in continuous lower cumulative voidage compensation.

The company could not ensure timely replacement /overhaul of water injection equipment; many of the equipment outlived their design operational life, which impacted the operational availability and reliability of the equipment. Revamping of critical equipment was also not ensured in time after their mandated running hours prescribed by the Original Equipment Manufacturer and the company prescribed running hours. This resulted in frequent failures/ tripping of the equipment affecting both quality and quantity of water injected in the reservoir. Thus, the water injection facilities were insufficient to meet the water injection requirements.

Audit noticed gaps in maintaining the quality of water injected vis-a-vis the quality parameters adopted by the company and downgrading its own accepted quality parameters. Audit also noticed incorrect reporting of water quality parameters and continuing gaps of control in ensuring compliance to corrective actions recommended by the internal agencies. Non-availability of equipment coupled with non-adherence to quality parameters by not dosing the chemicals at required level raises concern on efforts to enhance production and reservoir health.

Audit noticed higher levels of corrosion in all the platforms than the desired level which is a matter of concern. Audit also noticed pre-mature failure of pipelines in view of high dissolved oxygen and non-maintenance of flow velocity. The pipelines and injection wells were not maintained as per requirement and the workover, stimulation and backwash operations of injection wells were not carried out effectively, leading to drop in injectivity.

As recorded by in-house committees/ institutes, the remedial actions were delayed, insufficient and ineffective as pressure sinks had developed in certain areas and pipelines were damaged beyond repairs. Continued lesser voidage compensation had resulted in pressure sinks in producing fields. Director General of Hydrocarbons, the upstream regulator of the Ministry of Petroleum and Natural Gas, expressed concern on decline in reservoir pressure, inadequate water injection and poor reservoir management. International benchmarking is not adopted by the company for fixing targets. Inadequate water injection and poor reservoir management resulted in rapid decline in production; however, the corrective actions were lethargic.

Thus, water injection in the field was effected due to ageing of injection infrastructure, frequent pipeline leakages due to poor quality of injection water, non-implementation of envisaged inputs and to some extent, production from high gas-oil ratio wells. This led to drop in reservoir pressure sharply and impacted crude oil production. Even by the estimate by the company itself at the request of Audit, this deficient water injection impacted loss of production of crude worth ₹7,802.50 crore to ONGC and revenue loss of ₹3,474.29 crore to the Government of India during 2014-15 to 2018-19.

(Raj Ganesh Viswanathan)
Deputy Comptroller and Auditor General
(Commercial) and Chairperson, Audit Board

New Delhi
Dated: 13 December 2021

Countersigned

(Girish Chandra Murmu)
Comptroller and Auditor General of India

New Delhi
Dated: 14 December 2021

ANNEXURES

Annexure-I
(as referred to in Para 2.2)
Consultants/ in – house Reports cited in the Audit Report

Sl. No.	Name of the consultant	Year	Category
1	RGL report on Water quality monitoring parameters (February 1984)	1984	In-house
2	Bombay High review committee by Das Gupta	1990	In-house committee
3	Caproco International Ltd. Report on Corrosion problem and recommendation remedial measures	1998	International
4	Mumbai High and Neelam Heera Water Injection projects by Ganesh Thakur (2007)	2007	International
5	Evaluation of the Mumbai High field by William Cobb & Associates	2009	International
6	Project memorandum of M/s. GCA regarding Achieving 40% recovery in Mumbai High field	2009	International
7	IRS report on Injection Water quality and injectivity assessment of Injectors of Mumbai High	2011	In-house institute
8	Failure analysis of Water Injection pipeline by Institute of Engineering and Ocean Technology	2012	In-house institute
9	Report on facility cost optimisation and Water Injection improvements in Mumbai High	2012	In-house committee
10	Peer review of the Field Development Plan for Mumbai High South Ph-III by M/s. Bayphase	2014	International
11	Committee report on Pre-mature failure of water injection pipelines	2014	In-house committee
12	Review of tubing metallurgy for water injection wells Institute of Oil & Gas Production Technology	2016	In-house institute
13	Task force committee report on Augmentation and Redistribution of Water Injection in Mumbai High	2018	In-house committee
14	Performance analysis of recently side-tracked wells Institute of Oil and Gas Production Technology (IOGPT)	2018	In-house institute
15	ONGC Energy Strategy -2040 by The Boston Consultancy Group	2018	International
16	ONGC offshore five fields peer review by Gaffney, Cline & Associates (Mumbai High)	2019	International
17	ONGC offshore five fields peer review by Gaffney, Cline & Associates (Heera)	2019	International
18	ONGC offshore five fields peer review by Beicep Franlab (Neelam)	2019	International

Annexure-II (as referred to in Para 3.3)

Plan v/s Actual Water Injection in Mumbai High, Neelam and Heera fields										
Year	**Mumbai High South**					**Mumbai High North**				
	Requirement as per redevelopment plan-bwpd	Water injection build-up plan-bwpd	Actual water injection -bwpd	Shortfall actual WI-w.r.t. redevelopment plan (%)	Shortfall in WI-w.r.t. build-up plan (%)	Requirement as per redevelopment plan-bwpd	Water injection build-up plan –bwpd	Actual water injection -bwpd	Shortfall Actual WI-w.r.t. redevelopment plan (%)	Shortfall Actual WI-w.r.t. build-up plan (%)
2014-15	623728	604000	534689	14.28	11.48	489843	456900	394383	19.49	13.68
2015-16	782253	652300	582880	25.49	10.64	542895	427800	367240	32.36	14.16
2016-17	786461	621900	613800	21.95	1.30	562031	375700	376700	32.98	-0.27
2017-18	784145	622300	519200	33.79	16.57	559416	382360	403000	27.96	-5.40
2018-19	793774	577300	470402	40.44	18.10	548022	407300	389755	29.31	4.89
			Average	**27.19**	**11.62**				**28.42**	**5.41**

Year	**Heera**					**Neelam**				
	Requirement as per redevelopment plan-bwpd	Water injection build-up plan-bwpd	Actual water injection-bwpd	Shortfall Actual WI-w.r.t. redevelopment plan (%)	Shortfall in WI-w.r.t. build-up plan (%)	Requirement as per redevelopment plan-bwpd	Water injection build-up plan – bwpd	Actual water injection-bwpd	Shortfall Actual WI-w.r.t. redevelopment plan (%)	Shortfall actual WI-w.r.t. build-up plan (%)
2014-15	202099	128550	119667	40.79	6.91	98225	61811	58319	40.63	5.65
2015-16	205459	89542	86657	57.82	3.22	74625	62508	58288	21.89	6.75
2016-17	209234	142292	108872	47.97	23.49	88130	96963	65344	25.85	32.61
2017-18	174848	165500	121876	30.30	26.36	120813	79800	63439	47.49	20.50
2018-19	184393	172125	115462	37.38	32.92	142366	113808	68046	52.20	40.21
			Average	**42.85**	**18.58**				**37.61**	**21.14**

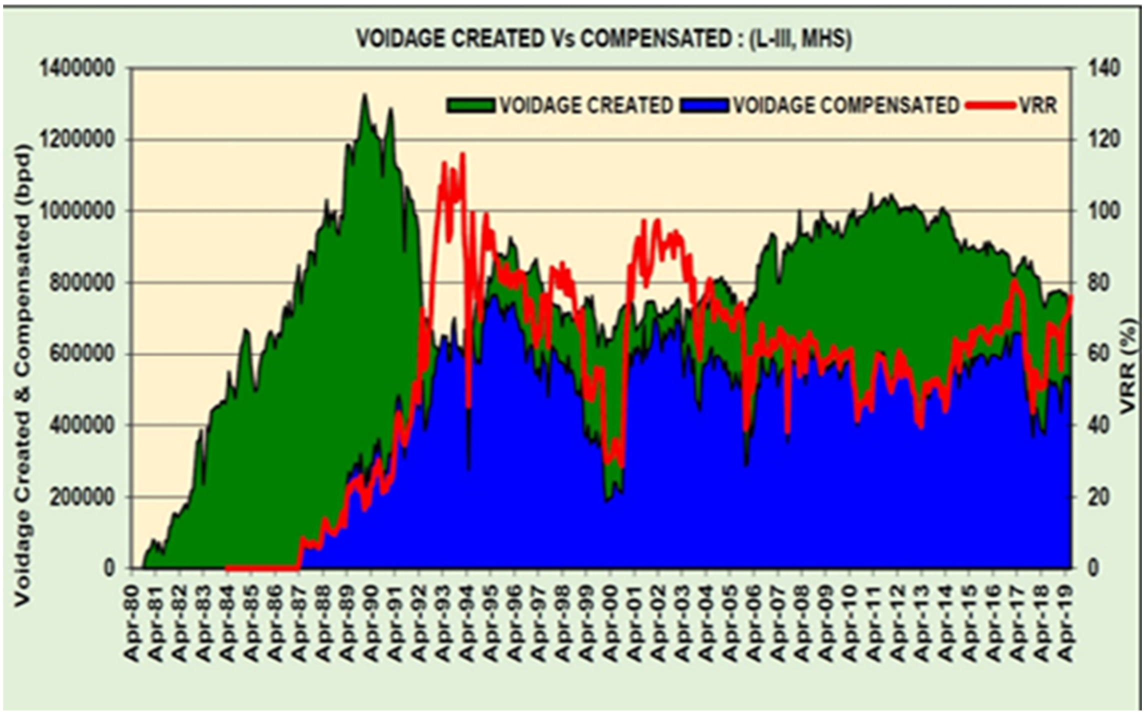
Bwpd - Barrel of water per day

Annexure III
(as referred to in Para 3.4)
Plan versus execution of annual plan inputs

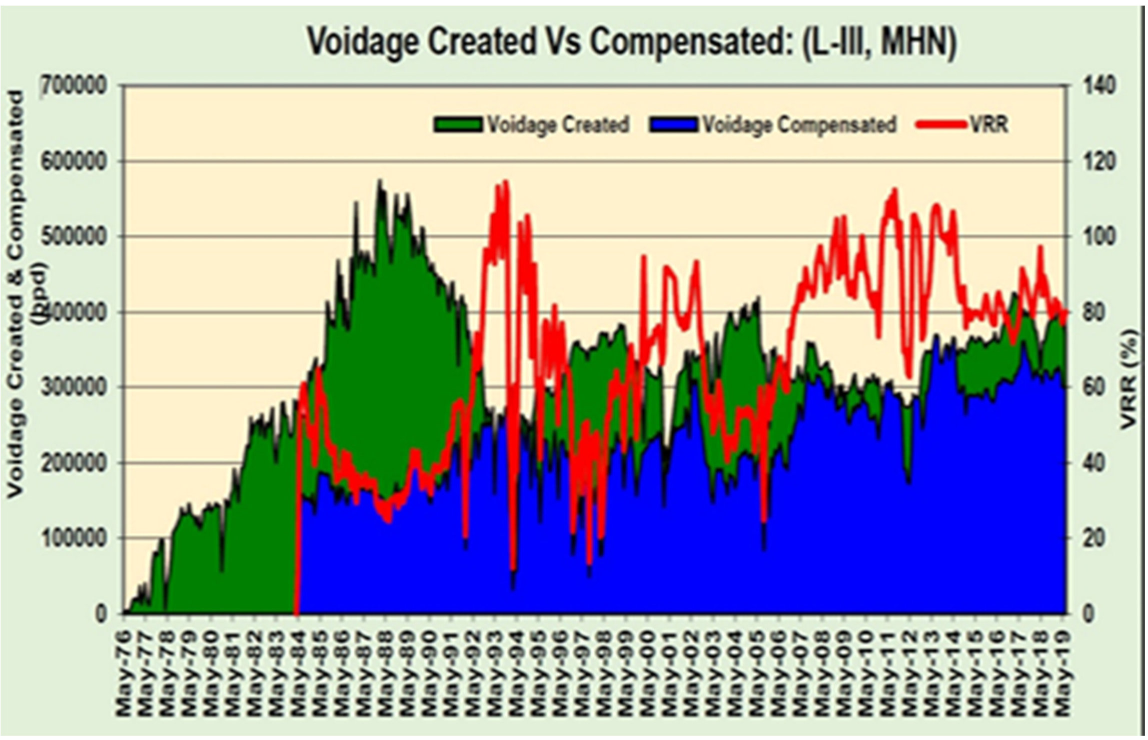
						2014-15		
Sl. No.	**Particulars**	**Planned**			**Actual**			**Shortfall -MH**
		MHN	**MHS**	**MH**	**MHN**	**MHS**	**MH**	
1	New water injector drilling strings	2	0	2	0	0	0	2
2	Workover jobs (WOJ)//Side track (ST) in existing water injectors strings	14	5	19	4	3	7	12
3	Rig less water injector conversion strings	6	7	13	5	6	11	2
4	Resumption of water injection strings	7	33	40	5	28	33	7
5	Stimulation strings	10	24	34	9	11	20	14
						2015-16		
Sl. No.	**Particulars**	**Planned**			**Actual**			**Shortfall-MH**
		MHN	**MHS**	**MH**	**MHN**	**MHS**	**MH**	
1	New water injector drilling strings	2	0	2	0	0	0	2
2	Rig less water injector conversion strings	3	3	6	0	0	0	6
3	Choke size increase strings	1	0	1	1	0	1	0
4	WOJ/ST in existing water injectors	30	30	60	7	8	15	45
5	MIP for additional injection	1	3	4	0	2	2	2
6	Resumption of water injection strings	9	0	9	3	1	4	5
7	Stimulation	16	34	50	12	23	35	15
8	Strings for PFA replacement	0	9	9	0	4	4	5
						2016-17		
Sl. No.	**Particulars**	**Planned**			**Actual**			**Shortfall-MH**
		MHN	**MHS**	**MH**	**MHN**	**MHS**	**MH**	
1	New water injector drilling	2	0	2	0	0	0	2
2	Rig less water injector conversion	0	2	2	0	0	0	2
3	WI conversion after Work over/ side track	2	0	2	0	0	0	2
4	WOJ/ST in existing water injectors	3	6	9	2	1	3	6
5	Choke size increase	3	0	3	2	0	2	1
6	Resumption of water injection	11	8	19	10	8	18	1
7	Stimulation	9	28	37	6	10	16	21
						2017-18		
Sl. No.	**Particulars**	**Planned**			**Actual**			**Shortfall-MH**
		MHN	**MHS**	**MH**	**MHN**	**MHS**	**MH**	
1	New water injector drilling	2	0	2	3	0	3	-1
2	Rig less water injector conversion	8	4	12	5	0	5	7
3	WI conversion after Work over/ side track	7	4	11	1	0	1	10
4	WOJ/ST in existing water injectors	9	11	20	3	7	10	10
5	Profile modification jobs	3	0	3	0	0	0	3
6	Resumption of water injection	2	7	9	2	7	9	0
7	Stimulation	18	18	36	5	23	28	8
						2018-19		

Sl. No.	Particulars	Planned			Actual			Shortfall-MH
		MHN	MHS	MH	MHN	MHS	MH	
1	New water injector drilling	3	0	3	1	0	1	2
2	Rig less water injector conversion	4	5	9	3	5	8	1
3	WI conversion after workover/ side track	6	6	12	0	1	1	11
4	WOJ/ST in existing water injectors	6	5	11	1	2	3	8
5	Profile modification jobs	4	0	4	2	0	2	2
6	Resumption of water injection	9	17	26	10	38	48	-22
MHN - Mumbai High North, MHS - Mumbai High South, MH - Mumbai High								

Annexure-IV
(as referred to in Para 3.6)
Mumbai High South

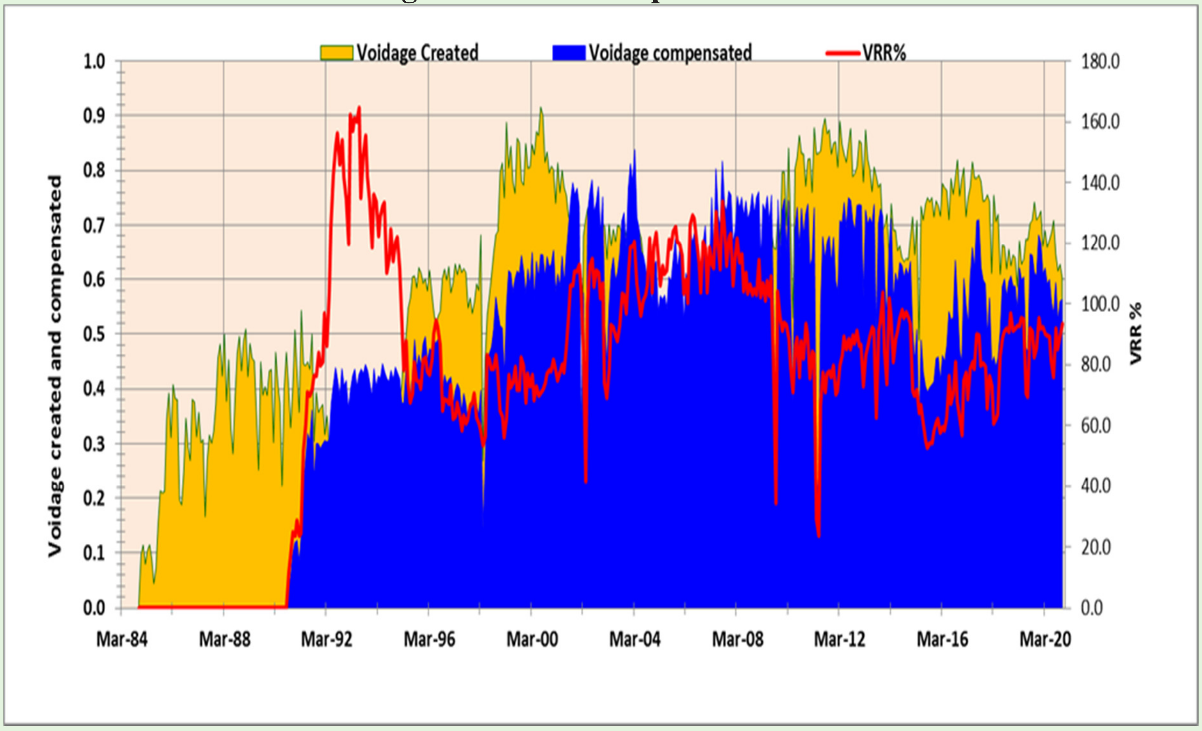


Mumbai High North

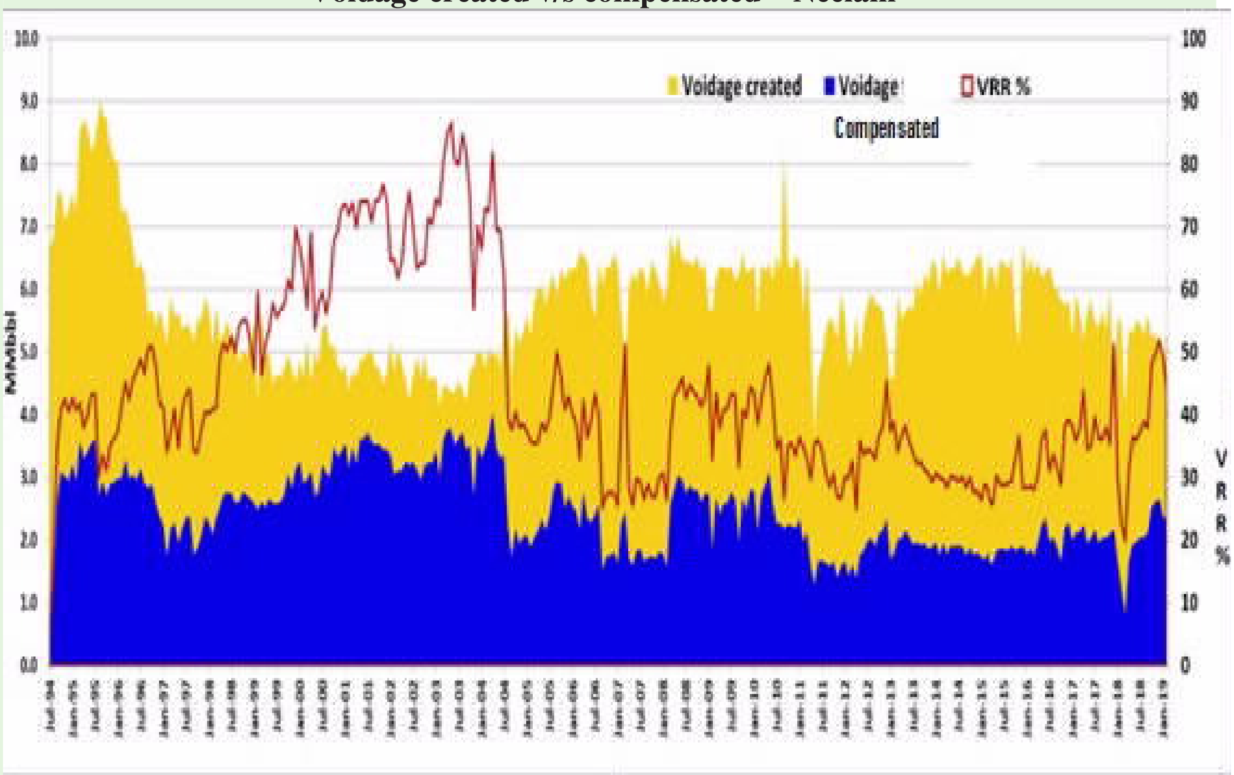


VRR - Voidage Replacement Ratio

Voidage created v/s compensated - Heera



Voidage created v/s compensated – Neelam



VRR - Voidage Replacement Ratio

Annexure V
(as referred in Para 4.2)
Major Water Injection equipment

Platform	Major equipment installed	Installed quantity	Standby philosophy
Mumbai South			
Water Injection South (WIS)	Sea Water Lift Pump	3	2R +1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	4R+1SB
	Fine Filter	12	10R+1SB+1BW
	DO Tower	2	2R
	Vacuum Pump	4	2R+2SB
	Chlorinator	2	1R+1SB
Infill Complex Water Injection (ICW)	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	4R+1SB
	Fine Filter	6	4R+1SB+1BW
	DO Tower	2	2R
	Vacuum Pump	4	2R+2SB
	Chlorinator	2	1R+1SB
South High Water Injection (SHW)	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	4R+1SB
	Fine Filter	7	6R+1SB
	DO Tower	2	2R
	Vacuum Pump	4	2R+2SB
	Chlorinator	2	1R+1SB
Mumbai High North			
Mumbai North Water Injection (MNW)	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	4R+1SB
	Fine Filter	5	4R+1SB
	DO Tower	2	1R+1SB
	Vacuum Pump	4	2R+2SB
	Chlorinator	2	1R+1SB
Water Injection North (WIN)	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	4R+1SB
	Fine Filter	8	6R+1SB+1BW

Platform	Major equipment installed	Installed quantity	Standby philosophy
	DO Tower	2	2R
Heera			
Heera Water Injector	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	5	3R+2SB
	Fine Filter	6	4R+2SB
	DO Tower	1	1R+0SB
	Vacuum Pump	2	1R+1SB
	Chlorinator	1	1R+0SB
Neelam			
Neelam water Injection (NLW)	Sea Water Lift Pump	3	2R+1SB
	Booster Pump	3	2R+1SB
	Main Injection Pump	4	2R+2SB
	Fine Filter	6	4R+2SB
	DO Tower	2	1R+1SB
	Vacuum Pump	4	2R+2SB
	Chlorinator	1	1R+0SB
Note: R-Running, SB-Standby, BW-Backwash			

Annexure-VI
(as referred to in para 4.4)
Replacement life of water injection equipment

Equipment	Replacement life (whichever is earlier)
Main Injection Pump	20 years or 1,50,000 hours
Sea Water Lift pump	15 years or 1,10,000 hours
Booster Pump	Not furnished to Audit
Chlorinator	15 years
Dosing Pump	10 years
Other small pump	10 years
LT motors (<25 KW)	10 years
LT motors (>25 KW)	15 years
Vacuum pump-DO tower	Condition based**
Vacuum pump motor-DO tower	Condition based**
Fine Filters/coarse filters	Condition based**

**** This equipment are not falling into specific provisions of the policy and therefore, its replacement is decided on the basis of specific condition/performance/repair economics.***

Annexure-VII
(as referred to in para 4.5)
System availability of water injection

Infill Complex Water Injection Platform								
Year	SWLP	BP	MIP	VP	DO Tower	Fine Filters	Coarse Filters	Chlorinators
2014-15	100	99.1	94	100	77.6	88.5	0	22.54
2015-16	100	99.9	72.3	100	84.3	91.0	0	47.77
2016-17	98.8	100	82.2	98.1	99.4	94.2	0	46.02
2017-18	100	100	97.9	100	97	98.0	0	0
2018-19	100	100	100	98.7	98.5	99.5	0	0
Mumbai North Water Injection Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	100	100	100	100	100	100	0	100
2015-16	100	100	100	100	100	100	0	100
2016-17	100	100	100	100	100	100	0	100
2017-18	100	100	100	100	100	100	0	100
2018-19	99.8	100	100	100	100	100	0	100
South High Water Injection Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	100	98.9	98	99.1	100	100	0	0
2015-16	99.8	100	99.9	83.7	100	100	0	0
2016-17	99.5	98.7	99.6	98.8	100	100	0	0
2017-18	98.9	97.4	97.4	74.2	100	100	0	0
2018-19	87.3	92.9	85.5	75.9	100	93.5	0	0
Water Injection North Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	100	100	100	100	100	100	0	100
2015-16	100	100	100	100	100	100	0	99.58
2016-17	100	100	100	87	100	100	0	100
2017-18	100	100	100	100	100	87.5	0	100
2018-19	100	100	100	100	100	84.4	0	98.97
Water Injection South Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	100	98.7	99.5	48.8	100	63.1	0	0
2015-16	100	99.8	99.9	14.3	100	58.2	0	0
2016-17	100	91.0	99.1	65.2	99.6	58.2	0	0
2017-18	100	85.0	100.0	66.1	99.9	62.4	0	0
2018-19	100	49.3	100.0	50.0	69.7	64.9	0	0
Water Injection Heera Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	100	100	100	100	99.8	100	0	0

2015-16	100	100	100	100	99.8	100	0	0
2016-17	100	100	100	100	99.7	100	0	0
2017-18	100	100	100	100	99.5	100	0	0
2018-19	100	100	100	100	99.6	100	16	0
Neelam Water Injection Platform								
Year	**SWLP**	**BP**	**MIP**	**VP**	**DO Tower**	**Fine Filters**	**Coarse Filters**	**Chlorinators**
2014-15	99.40	100.00	99.00	99	100	100	0	0
2015-16	99.89	100.00	99.46	99	100	100	0	0
2016-17	100.00	100.00	100.00	99	100	100	0	0
2017-18	99.30	100.00	86.68	99	100	100	0	0
2018-19	99.60	100.00	93.76	99	100	100	0	0

Source: Management response of Mumbai high and Neelam Heera regarding Equipment availability and System availability.

SWLP - Sea Water Lift Pump, BP - Booster Pump, MIP - Main Injection Pump, VP - Vacuum Pump , DO Tower - De-oxygenation Tower

Annexure-VIII
(as referred to in Para 4.6)

Instances of running hours/ despatch data in Monthly reports during repair

Month/ Year	Running hrs	Standby hrs	Maintenance/ Downtime hrs	Availability (%)	Main Injection Pump (MIP) 6680 at repairs - April 2014 to March 2018
May 2014	24	0	720	3.2	
July 2014	24	0	720	3.2	
August 2014	24	0	720	3.2	

Running hour (MIP) shown nil but water despatch reported

Month/ Year	Main Injection Pump (MIP)	Running hrs.	Standby Hrs.	Maintenance/ Downtime Hrs.	Availability (%) (monthly)	MIP despatch data reported in the Monthly reports
October 2015	MIP 1	0	742	2	99.7	295732
	MIP 2	0	742	2	99.7	
	MIP 3	0	0	744	0.00	
	MIP 4	0	0	744	0.00	

Booster Pump (TAG No. 6620) - running hour depicted same as maintenance/ downtime hour

Month/ Year	Running hrs.	Standby hrs.	Maintenance/ Downtime Hrs.	Availability (percentage)
December 2016	666	78	666	10.5
January 2017	711	33	711	4.4
February 2017	558	114	558	17.0
March 2017	537	205	539	27.6
April 2017	655	63	657	8.8
May 2017	663	79	665	10.6
June 2017	675	43	677	6.0
July 2017	219	523	221	70.3
August 2017	219	523	221	70.3

Annexure-IX
(as referred to in Para 5.3)
Average quality of injection water

MUMBAI HIGH ASSET						
WIS Platform						
Parameter	**Limit**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
TSS (Mg/Lt)	<0.2	0.212	0.242	0.2632	0.27	0.287
Millipore (Lt/30 minutes)	>6	10.159	9.133	Particle analyser (PA) not working	7.5	7.8
Turbidity (NTU)	<0.2	0.213	0.176	Turbidity meter not working	0.25	0.231
Particle count No./ml	<2000	PA not working			845	1104
Dissolved Oxygen (ppb)	<20	491.65	2251.083	2059.8	3565	2858
Residual Sulphite (Mg/lt)	>1.0	0.981	0.767	0.542	0.21	Nil
Iron Count (No/ml)	<0.05	0.092	0.060	0.07275	0.080	0.089
Sulphide (Mg/lt)	Nil	Nil	Nil	Nil	Nil	Nil
ICW Platform						
Parameter	**Limit**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
TSS (Mg/Lt)	<0.2	0.180	0.166	0.177	0.211	0.17
Millipore(Lt/30 minutes	>6	9.183	10.80	9.55	7.3	7.1
Turbidity (NTU)	<0.2	0.183	0.157	0.1825	0.21	0.177
Particle count No./ml	<2000	PA not working				
Dissolved Oxygen (ppb)	<20	93.96	206.33	497	415	Nil
Residual Sulphite (Mg/lt)	>1.0	0.474	0.660	0.60	0.51	0.44
Iron Count (No/ml)	<0.05	0.048	0.052	0.049	0.062	0.053
Sulphide (Mg/lt)	Nil	Nil	Nil	Nil	Nil	Nil
SHW Platform						
Parameter	**Limit**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
TSS (Mg/Lt)	<0.2	0.165	0.175	0.22	Sampling point not available	
Millipore(Lt/30 minutes	>6	11.11	9.244	7.78	Sampling point not available	
Turbidity (NTU)	<0.2	0.205	0.217	0.235	0.31	0.33
Particle count No./ml	<2000	771.85	1444.583	2200	3246	3875
Dissolved Oxygen (ppb)	<20	1253.43	1367.583	2029.8	2050	1237
Residual Sulphite (Mg/lt)	>1.0	0.752	0.531	0.70	0.80	0.29
Iron Count (No/ml)	<0.05	0.081	0.113	0.212	0.235	0.22
Sulphide (Mg/lt)	Nil	Nil	Nil	Nil	Nil	Nil
MNW Platform						
Parameter	**Limit**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
TSS (Mg/Lt)	<0.2	0.194	0.201	0.19	0.188	0.190
Millipore(Lt/30 minutes	>6	8.909	8.641	9.52	8.3	8.2
Turbidity (NTU)	<0.2	0.223	0.197	0.19	0.19	0.18
Particle count No./ml	<2000	1310.49	**PA not working**		774	1234
Dissolved Oxygen (ppb)	<20	62.31	75.167	45.33	52	Nil
Residual Sulphite (Mg/lt)	>1.0	0.886	1.057	0.75	0.57	0.69
Iron Count (No/ml)	<0.05	0.059	0.048	0.050	0.061	0.057
Sulphide (Mg/lt)	Nil	Nil	Nil	Nil	Nil	Nil
WIN Platform						
Parameter	**Limit**	**2014-15**	**2015-16**	**2016-17**	**2017-18**	**2018-19**
TSS (Mg/Lt)	<0.2	0.87	0.415	0.33	0.32	0.244
Millipore(Lt/30 minutes	>6	8.26	8.058	7.34	8	8.2
Turbidity (NTU)	<0.2	0.38	0.32	0.31	0.3	0.24
Particle count No./ml	<2000	2132	PA not working	2313	2213	PA not working
Dissolved Oxygen (ppb)	<20	244	104	85	165	Nil
Residual Sulphite (Mg/lt)	>1.0	1.04	1.063	1.05	1.05	0.717
Iron Count (No/ml)	<0.05	0.04	0.047	0.048	0.045	0.049
Sulphide (Mg/lt)	Nil	Nil	Nil	Nil	Nil	Nil

Neelam Field

Parameter	Limit	2014-15	2015-16	2016-17	2017-18	2018-19
TSS (Mg/Lt)	<0.20	0.36	0.26	0.29	0.26	0.27
Millipore(Lt/ 30 minutes	5-7 MIN	4.70	6.55	6.08	5.85	5.42
Turbidity (NTU)	<0.20	0.35	0.23	0.26	0.25	0.29
Particle count No./ml	<2000	2545.83	1084.58	1285.92	2344.00	1266.01
Dissolved Oxygen (ppb)	<20	16.92	20.87	10.27	65.74	37.75
Residual Sulphite (Mg/lt)	1.0 MIN	1.00	0.87	1.00	1.02	0.81
Iron Count (No/ml)	<0.05	0.31	0.20	0.15	0.04	0.25
Sulphide (Mg/lt)	NIL	Nil	Nil	Nil	Nil	Nil

Heera field

Parameter	Limit	2014-15	2015-16	2016-17	2017-18	2018-19
TSS (Mg/Lt)	<0.20	0.18	0.19	0.20	0.32	0.78
Millipore(Lt/ 30 minutes	5-7 MIN	7.82	7.79	7.29	5.49	3.82
Turbidity (NTU)	<0.20	0.12	0.13	0.19	0.30	0.31
Particle count No./ml	<2000	991.00	1144.92	1859.17	1391.17	2499.84
Dissolved Oxygen (ppb)	<20	38.47	55.39	23.28	52.01	202.23
Residual Sulphite (Mg/lt)	1.0 MIN	1.17	1.15	1.26	0.81	0.92
Iron Count (No/ml)	<0.05	0.04	0.04	0.04	0.17	0.07
Sulphide (Mg/lt)	NIL	Nil	Nil	Nil	Nil	Nil

Source: Mumbai high, Neelam Heera Chemistry Monthly Reports

Annexure-X
(as referred to in Para 5.5)
Lower dosing of water injection chemicals against recommended norms

Coagulant							
Year	**Dosing norm-ppm**	**WIN**	**WIS**	**ICW**	**SHW**	**MNW**	**Average**
2014-15	0.4 to 0.8	0.19	0	0	0.2	0.2	0.12
2015-16		0.43	0	0.26	0	0.37	0.21
2016-17		0.15	0	0.01	0	0.18	0.07
2017-18		0.18	0	0.41	0	0.29	0.18
2018-19		0.26	0	0.37	0	0.44	0.21

Poly Aluminium Chloride (PAC)							
Year	**Dosing norm-ppm**	**WIN**	**WIS**	**ICW**	**SHW**	**MNW**	**Average**
2014-15	0.4 to 0.8	0.4	0.64	0.41	0.21	0.42	0.42
2015-16		0.62	0.53	0.35	0.23	0.47	0.44
2016-17		0.88	0.82	0.45	0.13	0.44	0.55
2017-18		0.55	1.59	0.14	0	0.21	0.50
2018-19		0.73	1.12	0.7	0	0.22	0.55

Oxygen scavenger							
Year	**Dosing norm-ppm**	**WIN**	**WIS**	**ICW**	**SHW**	**MNW**	**Average**
2014-15	10	5.25	6.94	7.35	5.6	8.41	6.71
2015-16		7.07	8.7	6.75	5.83	8.58	7.39
2016-17		8.12	7.46	7.96	5.17	5.32	6.81
2017-18		7.14	5.2	7.92	4.93	5.95	6.23
2018-19		7.61	11.15	10.13	8.87	7.46	9.04

Water Corrosion Inhibitor							
Year	**Dosing norm- ppm**	**WIN**	**WIS**	**ICW**	**SHW**	**MNW**	**Average**
2014-15	20	5.81	7.33	8.67	4.83	7.59	6.85
2015-16		7.27	8.31	8.81	5.56	8.63	7.72
2016-17		8.75	6.65	11.03	3.58	5.56	7.11
2017-18		2.78	5.33	6.08	2.12	2.79	3.82
2018-19		8.02	10.75	9.82	6.24	9.99	8.96

Annexure-XI
(as referred to in Para 5.6)
Recommendations on measurement of water quality at wellhead

Sl. No.	Institute study report	Observations	Recommendations
1.	IRS Manual on Offshore Injection Water Quality - March 1994	Emphasis of monitoring needs to be laid at the well heads rather than at the process platforms. But, unfortunately, reverse is the case at Mumbai High, where energy as well as manpower is utilised at the process platforms and monitoring at the wellheads is being neglected. In the process, wellheads are not being regularly monitored in a planned way, and thus operational engineer is unaware of the quality of the water injected inside the reservoir. Irregular monitoring carried out at wellheads indicate that the injection water quality is bad and not as per specifications. But, it seems that, this fact has not been taken up seriously and no remedial measures have been undertaken to improve the injection water quality so as to bring it back within operational limits.	Weekly monitoring of all water quality parameters at all wellhead
2.	IRS study report on Injection water quality and injectivity assessment of injectors in Mumbai High - March 2011	Deterioration in water quality parameters in injection lines during transportation from fine filters to wellhead. In most of the back wash samples, total suspended solids (TSS) and turbidity was quite high and filterability was quite low than the desired value. Reduction in sulphate irons and increase in iron content indicates sulphate reducing bacteria (SRB) activity. Reduction in calcium, magnesium, bicarbonate indicate tendency for scaling.	Regular monitoring of water quality after fine filter, injector header and wellhead is needed.
3.	In-house committee report on Facility cost optimisation and water injection improvement in Mumbai High - July 2012	Analysis of pigging flushing water and backflow water analysis revealed that deterioration in water quality parameters in injection lines during transportation from fine filters to well head. In most of the back wash samples, high total suspended solids and turbidity and low filterability observed. SRB and scaling activity due to reduction in sulphate irons and increase in iron content, reduction in calcium, magnesium, bicarbonate.	Regular monitoring of water quality after fine filters, injection header and wellhead.
4.	IOGPT report on Premature failure of water injection lines - August 2014	In Mumbai High North, impairment in injectivity due to tubing leakage/ casing damage mainly due to corrosion which has taken place over the years because of poor injection water quality and Mumbai High South poor injectivity in the wells on account of impairment/ chocking of formation due to foreign material reaching into the formation along with injected water. Non availability of desired chemical affect the maintaining water quality	Regular monitoring of water injection quality at unmanned platforms including presence of oxygen, particle counts, Millipore test, residual sulphite, corrosion rate and SRB count on monthly basis.

Annexure XII
Deterioration in water quality on the way to wellhead (as referred in Para 5.6)

Sl. No.	Water quality measured at process complex				Water quality measured at Unmanned platform				Deterioration in water quality from WI platform to wellhead (in number of times)	
	Process platform	Date of sampling	Iron content (mg/lt)	Turbidity (NTU)	Well Head	Date of sampling	Iron content (mg/lt)	Turbidity (NTU)	Iron content (mg/lt)	Turbidity (NTU)
1	BHS	10.11.18	0.088	*	SB-1	10.11.18	2.8	*	31.8	*
2	BHS	10.11.18	0.088	*	SB-2	10.11.18	1.6	*	18.2	*
3	MHN	04.06.16	0.04	0.19	N11	04.06.16	2.1	1.76	52.5	9.26
4	MHN	09.07.16	0.059	0.19	N11	09.07.16	0.9	2.4	15.3	12.63
5	MHN	02.05.16	0.04	0.17	N15	02.05.16	1	1.2	25.0	7.06
6	MHN	29.05.16	0.04	0.18	N15	29.05.16	3	1.06	75.0	5.89
7	MHN	14.06.16	0.04	0.21	N15	14.06.16	1.5	1.08	37.5	5.14
8	MHN	05.07.16	0.054	0.19	N16	05.07.16	1.2	0.63	22.2	3.32
9	MHN	21.05.16	0.04	0.17	NB	21.05.16	0.6	1.1	15.0	6.47
10	MHN	10.06.16	0.04	0.19	NB	10.06.16	1.2	0.6	30.0	3.16
11	MHN	11.07.16	0.058	0.2	NB	11.07.16	1.2	0.94	20.7	4.70
12	MHN	05.05.16	0.04	0.17	NS	05.05.16	0.9	1.3	22.5	7.65
13	MHN	09.07.16	0.059	0.19	NS	09.07.16	0.6	1.22	10.2	6.42
14	MHN	19.05.16	0.04	0.16	NW	19.05.16	0.9	3.87	22.5	24.19
15	MHN	10.09.18	0.069	0.19	NS	10.09.18	>1.0	8.3	*	43.68
16	MHN	10.09.18	0.069	0.19	WA	10.09.18	>1.0	13	*	68.42
17	MHN	25.11.18	0.047	0.2	N5	25.11.18	<1.0	4.7	*	23.50
18	MHN	05.05.16	0.04	0.17	WA	05.05.16	2.4	4.1	60.0	24.12
19	MHN	10.09.18	0.069	0.19	WA	10.09.18	>1.0	13	*	68.42
20	MHN	05.05.16	0.04	0.17	WA	05.05.16	2.4	4.1	60.0	24.12
21	MHN	20.05.16	0.04	0.18	WI4	20.05.16	0.3	0.14	7.5	0.78
22	MHN	11.07.16	0.058	0.2	WI4	11.07.16	0.6	0.99	10.03	4.95
23	MHN	01.06.16	0.04	0.16	WI6	01.06.16	0.6	2.55	15.0	15.94
24	MHN	09.09.18	0.069	0.19	N11	09.09.18	>1.0	2.83	*	14.89
25	MHN	29.05.16	0.04	0.18	N15	29.05.16	3	1.06	75.0	5.89
26	MHN	01.08.16	0.06	0.23	N15	01.08.16	1.2	1.1	20.0	4.78
27	MHN	21.08.16	0.047	0.18	N15	21.08.16	0.9	0.94	19.1	5.22
28	MHN	07.09.18	0.07	0.18	N15	07.09.18	>1.0	11.7	*	65.00
29	MHN	10.09.18	0.069	0.19	N19	10.09.18	>1.0	2.4	*	12.63
30	MHN	29.11.18	0.46	0.18	N19	29.11.18	<1.0	7.44	*	41.33
31	MHN	28.11.18	0.047	0.19	RS5	28.11.18	<1.0	5.45	*	28.68
32	MHN	28.11.18	0.047	0.19	RS5	28.11.18	<1.0	5.45	*	28.68
33	MHN	28.11.18	0.047	0.19	NV	28.11.18	<1.0	2.87	*	15.11
34	MHN	04.12.18	0.048	0.18	NV	04.12.18	<1.0	2.87	*	15.94
35	MHN	22.01.19	0.047	0.18	ZC	22.01.19	<1.0	28	*	155.56
36	MHN	22.02.19	0.049	0.18	ZC	22.02.19	<1.0	28	*	155.56
37	WIN	13.12.17	0.048	0.37	W13-3	13.12.17	1.8	2.88	37.5	7.78
38	WIN	13.12.17	0.048	0.37	W13-3	13.12.17	1.7	2.75	35.4	7.43
39	WIN	13.12.17	0.048	0.37	W13-3	13.12.17	1.7	2.29	35.4	6.19
40	WIN	28.03.18	0.043	0.22	W12	28.03.18	1.4	*	32.6	*
								Average	**30.24**	**25.42**

Source: Monthly Performance Reports of Chemistry section

**** Data not available***

Annexure XIII
(as referred to in Para 7.1)

Gist of observations and recommendations of consultants/ internal committees of the company on reservoir health

(i) **Bombay High Review Committee** headed by Shri A.B. Das Gupta was appointed (April 1990) by the Ministry of Petroleum & Natural Gas to find answers related to various issues including pressure maintenance facilities. The Report stated (November 1990) that greater voidage was caused by the excess gas production from wells with high Gas Oil Ratio and delayed implementation of water injection. If gas was coming from LIII reservoir (major producing reservoir) it could be ending up with lower recoveries than would be feasible through a more stringent control of GOR. The reservoir could not be expected to give the predicted ultimate recoveries unless GOR was kept within the cut-off point.

(ii) **M/s. Ganesh Thakur**, an international consultant was engaged (2007) by the company to address the low-pressure areas and to improve voidage compensation/ reservoir health and sweep efficiency. The project report recommended for accelerated water injection, injection build up for achieving 100 *per cent* voidage replacement, and stimulation of low Injectivity wells in Mumbai High field. In Heera, it was observed that with increased water injection, once the pressure increases to about 1500 psi from the then levels of 1200 psi, the oil rate was estimated to increase.

(iii) **M/s William Cobbs and Associates,** an international consultant appointed (August 2009) by the Company to conduct a workshop on water injection stated that the cumulative voidage replacement ratio, since start of injection was less than one and as a result, reservoir pressure continued to decline in the field resulting in decline in well productivity. For effective voidage replacement, the consultant suggested to keep VRR values greater than 100 *per cent* (usually 110 to 130 *per cent*).

(iv) **In-house taskforce** constituted by Mumbai High for Augmentation and Redistribution of water injection in Mumbai High field stated (October 2018) that uneven distribution of water injection has led to the differential depletion in the reservoir laterally and within layers, resulting localised pressure sinks and/ or high-water production in different parts of the reservoir. Taskforce emphasised for effectiveness of water injection for pressure maintenance and improving sweep by targeting Incremental voidage compensation levels of 100 to 120 *per cent* and re-distributing injection water.

(v) **M/s. Gaffney, Cline & Associates (GCA)** was appointed by the company to perform an independent review of ONGC production profile for Mumbai High field. In its report (December 2019), GCA concluded that disruption and/ or delay in water injection contributed to higher decline in production, through reduced well productivity and declining reservoir pressure. It recommended improving sweep efficiency and restoring reservoir energy, focusing on injection plan and increasing voidage replacement ratio and maintaining voidage replacement above 100 *per cent*. GCA opined that Management production profile could be achieved only if water injection is maintained at high level of efficiency and recommended to maintain integrity of injection network.

(vi) **M/s. GCA** was also appointed to perform independent review of production profile of Heera field. In its report, M/s.GCA stated (December 2019) that the profile is valid only if water injection is maintained as per the HRP III redevelopment scheme. Historically, water injection was not stable due to several reasons including injection shutdowns and that pressure sinks had developed in some parts of Heera. Reduction in water injection by 21 *per cent* during 2012-19, had resulted in liquid rates dropping by 21 *per cent*. GCA recommended ONGC to conduct an extensive pressure surveillance programme as the available pressure data was sparse and incoherent.

Annexure-XIV A
(as referred to in Para 7.3)

Statement indicating value of deficit due to insufficient water injection in Mumbai High field

Mumbai High Field Year	ONGC working			Audit working								
	FR recommended simulation model with 6% losses (MMT)	FR recommended with actual WI-simulation model with 6% losses (MMT)**	Oil short-fall (MMT)	Oil shortfall without 6% losses (MMT)	Actual losses (%)	Oil short-fall (MMT)	PPAC crude oil rate per bbl (US$)	Exchange Rate US$=₹	Value of oil deficit (₹ in crore)	ONGC Realised crude oil rate per bbl net of subsidies & levies	ONGC realisation value less of subsidy and statutory levies (₹ in crore)	Loss of revenue to Govt. (₹ in crore)
	(a)	(b)	(c)= (a)-(b)	(d)= (c)*100/94	(e)	(f)= (d)-(d*e/100)	(g)	(h)	(i)=(f)*(g)*(h)*7.6 *$10^6/10^7$	(j)	(k)	(l)= (i)-(k)
2014-15	9.018	8.873	0.145	0.154	0.64	0.153	84.156	61.15	599.44	36.35	258.92	340.52
2015-16	8.995	8.625	0.371	0.395	0.64	0.392	46.166	65.46	900.71	32.71	636.42	264.29
2016-17	8.84	8.323	0.517	0.550	1.55	0.541	47.558	67.09	1,312.98	35.88	990.69	322.29
2017-18	8.567	7.971	0.596	0.634	2.35	0.619	56.427	64.18	1,704.10	40.44	1226.44	477.66
2018-19	8.056	7.39	0.666	0.709	1.96	0.695	69.880	69.90	2,578.78	50.77	1873.35	705.43
Total	**43.476**	**41.182**	**2.295**	**2.441**		**2.401**			**7,096.01**		**4985.82**	**2110.19**

*****The production as per simulation model has been reworked by the Management after changing only the water injection quantity as per actual.***

Annexure-XIV B

(as referred to in para 7.3)

Statement indicating value of deficit due to insufficient water injection in Neelam & Heera fields

Heera Field Year	ONGC working			Audit working								
	FR recommended simula-tion model with 6% losses MMT	FR recommended with actual WI-simulation model with 6% losses MMT**	Oil Shortfall MMT	Oil Shortfall without 6% losses MMT	Actual losses (%)	Oil Short-fall MMT	PPAC crude oil rate per bbl US$	Exchange Rate US$=₹	Value of oil deficit (₹ in crore)	ONGC Realised crude oil rate per bbl net of subsidies & levies	ONGC realis-ation value less of subsidy and statutory levies (₹ in crore)	Loss of revenue to Govt. (₹ in crore)
	(a)	(b)	(c)= (a)-(b)	(d)= (c)*100/94	(e)	(f) = (d) - (d*e/100)	(g)	(h)	(i)=(f)*(g)*(h)*7.6*10⁶/10⁷	(j)	(k)	(l)= (i)-(k)
2014-15	2.174	1.979	0.195	0.207	6.44	0.194	84.156	61.1471	759.05	36.35	327.88	431.17
2015-16	2.223	1.982	0.241	0.256	0.00	0.256	46.166	65.4611	588.85	32.71	417.20	171.65
2016-17	2.199	1.949	0.25	0.266	3.55	0.257	47.558	67.0896	622.02	35.88	469.33	152.70
2017-18	2.117	1.844	0.273	0.290	10.16	0.261	56.427	64.1781	718.11	40.44	516.84	201.27
2018-19	1.979	1.638	0.341	0.363	11.22	0.322	69.88	69.901	1195.62	50.77	868.58	327.03
Total	**10.692**	**9.392**	**1.3**	**1.383**		**1.290**			**3883.66**		**2599.84**	**1283.82**

Neelam Field Year	ONGC working			Audit working								
	FR recommended simula-tion model with 6% MMT	FR recommended with actual WI-simulation model with 6% losses MMT**	Oil Short-fall MMT	Oil Shortfall without 6% losses MMT	Actual losses (%)	Oil Short-fall MMT	PPAC crude oil rate per bbl US$	Exchange Rate US$=₹	Value of oil deficit (₹ in crore)	ONGC Realised crude oil rate per bbl net of subsidies & levies	ONGC realisa-tion value less of subsidy and statutory levies (₹ in crore)	Loss of revenue to Govt. (₹ in crore)
	(a)	(b)	(c)= (a)-(b)	(d)= (c)*100/94	(e)	(f)= (d)-(d*e/100)	(g)	(h)	(i)=(f)*(g)*(h)*7.6*10⁶/10⁷	(j)	(k)	(l)= (i)-(k)
2015-16	0.763	0.755	0.008	0.009	3.06	0.008	46.166	65.4611	18.95	32.71	13.43	5.52
2016-17	0.701	0.675	0.026	0.028	3.52	0.027	47.558	67.0896	64.71	35.88	48.83	15.89
2017-18	0.639	0.61	0.029	0.031	16	0.026	56.427	64.1781	71.32	40.44	51.33	19.99
2018-19	0.710	0.674	0.036	0.038	0.03	0.038	69.88	69.901	142.13	50.77	103.26	38.88
Total	**2.813**	**2.714**	**0.099**	**0.105**		**0.099**			**297.12**		**216.84**	**80.28**
NH Total						**1.389**			**4180.77**		**2816.68**	**1364.10**

*** The production as per simulation model has been reworked by the Management after changing only the water injection quantity as per the actual.*

Glossary	
Asset	It refers to an entity that is involved in production of oil & natural gas from the existing wells and transportation of oil and gas for processing and supply to consumer.
Backwashing – Fine filters	Backwashing of Fine filters is a method of reversing the flow so that impurities are removed from the filter.
Backwashing - Injector	Backwashing water injector is an additional method to remove the near wellbore damage and restore a significant amount of lost injectivity.
Bactericide	Amine/ Aldehyde based chemical which are slug injected at desired rate and periodicity to kill all bacteria susceptible to amine/ aldehyde. Non-Amine Non-Aldehyde (NANA) based chemicals are also slug injected at desired rate and periodicity to kill all bacteria. All these three types of bactericide are slug dosed alternatively to avoid the risk of insensitivity development by microbes with one particular type of biocide.
Build up plan	Annual plan prepared by the Asset for injection of water.
Coagulant	Chemical to aid the Fine Filters by helping to coalesce very small suspended solid particles into larger particles, which are easier to filter out of water.
Corrosion inhibitor	This chemical is injected to prevent corrosion of the equipment and pipelines by coating the inside surfaces.
Cumulative voidage compensation	Cumulative compensation of voidage created due to withdrawal of liquid.
Defoamer	Reduces surface tension in the filtered seawater to the Deoxy Vacuum Towers and thereby reduces foaming tendency of the water as it goes from pressure across the flow control valve to the vacuum in the tower.
Dissolved oxygen	Parts of oxygen dissolved in injection water.
Dosing pump	Chemical injection system is one of important component of water injection system. Various water injection chemicals at desired doses at pre-defined frequency are required to be injected (dosed) continuously during water injection operation to maintain the desired quality of injection water.
Enhanced Oil Recovery (EOR)	EOR is oil recovery by injection of materials not normally present in the reservoir.
Equipment availability	Availability of that particular equipment for operating purposes.
Executive Committee (EC)	The Executive Committee consists of Chairman and Managing Director and Directors in the whole time employment of the company and is authorised to sub- delegate the powers vested in them to the Executives below Board level in the interest of the work of ONGC.
GAB	General Aerobic Bacteria.
GOR	Gas Oil ratio.
IEOT	Institute of Engineering and Ocean Technology, ONGC (at Panvel, Mumbai).

Injectivity	Rate of injection into the reservoir. Well injectivity is affected by presence of solids, biological matter, corrosion products etc. in the injection water.
IOGPT	Institute of Oil and Gas Production Technology, ONGC (at Panvel, Mumbai).
IRS	Institute of Reservoir Studies, ONGC (at Ahmedabad).
Key Performance Indicator (KPI)	KPI is a quantifiable measure used to evaluate the success of an organisation, employee, etc. in meeting objectives for performance.
MIC	Microbe Induced Corrosion.
OEM	Original Equipment Manufacturer.
Oxygen Scavenger	Destroys the remaining dissolved oxygen in the bottom of the De-oxygenation Tower by reacting with it to form non-oxidising chemical.
PM Module	Plant Maintenance (PM) Module of SAP system.
Pigging	Pig is a small, sphere or disc apparatus that is used to sweep a flow line. Primary reasons for pigging may be (i) line cleaning (commissioning, debris cleaning), (ii) line management (liquid removal, corrosion inhibitor dispersal and wax removal), and (iii) line inspection (intelligent pigging). It is also carried out to ensure the integrity of the pipelines. It is one of the most effective and economical method for control of microbes.
Polyelectrolyte	Similar to coagulant but uses a different chemical reaction that causes the small-suspended solid particles to cluster into larger particles for easier filtering.
Scale inhibitor	This chemical is injected to prevent calcium/ strontium scale from forming on the inside of the piping and equipment.
Secondary recovery	Secondary recovery involves the injection of water to re-pressurise the reservoir and displace the oil. Water flooding is the most common secondary method.
SRB	Sulphur reducing Bacteria.
System Availability	Availability of equipment (both operating and standby) for uninterrupted flow of production.
Voidage Replacement Ratio (VRR)	VRR is defined as the volume of injected fluid to the volume of the produced fluid.
Injection well/ String	Injection well is a well through which water is injected into reservoir to maintain reservoir pressure. Injection well may have a single string or dual strings.
Production wells and injection wells	Production wells which cease to produce economical level of production are converted to water injection wells to save additional expenditure on drilling new well.
Upstream	Upstream is a term for the operations stages in the oil and gas industry that involve in exploration and production.