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