भारत सरकार
जल शक्ति मंत्रालय
जल संसाधन, नदी विकास और गंगा संरक्षण विभाग

भूजल मॉडलिंग और रिपोर्ट तैयार करने के लिए मानक संचालन प्रक्रिया

Standard Operating Procedure for Ground Water Modelling & Report Preparation

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Purpose of this document

As per MoJS Guidelines dated 24.09.2020 published in the Gazette of India vide Notification number S.O. 3289 (E) and its Amendment Notification dated 29.03.2023 published in the Gazette of India vide Notification number S.O. 1509 (E), impact assessment report is mandatory to obtain NOC for ground water withdrawal. The objective of submission of the said report is in-line with the Hon'ble NGT directions wherein it was directed that there should be "no general permission for withdrawal of ground water, particularly to any commercial entity, without environment impact assessment of such activity on individual assessment units in cumulative terms covering carrying capacity aspects by an expert committee".

Ground Water Modelling is one of the integral part of the impact assessment report. It has been observed that despite the clear instructions mentioned in the guidelines as well as comments/ suggestions offered during the meetings of Expert Appraisal Committee (EAC), instructions/suggestions given to the consultants/Institutions in the special meetings organized with them and also after the scrutiny of reports, the quality of the reports is not up to the acceptable standards. Over the period refinements in groundwater modelling approach has evolved including different predictive scenarios. Also, some undertakings are required from the ground water modeler considering the limitations of modelling.

The main objective of the accreditation of the ground water professionals is to ensure that reports of acceptable standards should be submitted by them for obtaining NOC from CGWA. This requires interventions from CGWA side, as a lot of time is elapsed in scrutiny of reports. This SOP has been prepared in order to facilitate the accredited ground water professionals in preparation of the Ground Water Modelling and its presentation as report in-line with Impact Assessment Report (IAR) and Comprehensive Hydrogeological Report (CHR). This document provides guidance and a consistent, structured approach for preparation of Ground Water Model and its presentation as report in support of their proposal for NOC application.

The organization of the ground water modelling report should include the following sections:

- Title Page
- Table of Contents

Chapter 1. Introduction
Chapter 2. Hydrogeological Characterization
Chapter 3. Model Conceptualization
Chapter 4. Groundwater flow model
Chapter 5. Model prediction
Chapter 6. Conclusion and recommendation

- List of Figures
- List of Tables
- Annexure

The chapter wise contents which should be incorporated, is discuss as under

A: GUIDELINES FOR CHAPTERS OF THE MODELLING REPORT

1. Introduction

The model should be designed in a manner that the system simulation on a numerical modelling platform is able to accomplish the following desired objectives of the study:

1. Assessment of the impact of proposed withdrawal on the regional/local hydrology like the groundwater reserve & dynamics,
2. Predicting the impact on groundwater level
3. Reporting radius of influence
4. Surface-groundwater interaction
5. Water quality, in case of saline-fresh water interface (Coastal areas or Inland salinity area)
6. In the event of an unacceptable impact predicted by the model, a proposal for the contingency and mitigative measures that needs be implemented. It is desired to prove efficacy of the same using the model.
7. Additionally, in case of mining projects, estimation of mine seepage as per the approved mine plan.

There should be a brief description of geology, drainage and hydrogeology of the area. The existing data from CGWB/ State/ other stakeholders generated during various studies like NAQUIM, hydrogeological studies/ investigations/ EIA etc., may be utilized to produce and formulate the model. The report should have detailed Hydrogeological setup (Aquifer parameters, Sources & Sinks), Model area (boundary), Model Grid size and number. Based on the objective of the study and availability of data, the grid size and number shall be formulated, accordingly the area shall be discretized, clearly indicating the number of active and inactive cells. The justification for grid size and number may be clearly mentioned. The hydrogeological data should be analyzed to demarcate the physical boundary conditions of the study area. The

same should be matched with the model boundary conditions during conceptualization of the model.

2. Hydrogeological characterization

Proper characterization of the hydrogeological conditions at a site/area is mandatory in order to have a better understanding of hydrogeological setup, groundwater condition and flow. This level of characterization requires more site-specific fieldwork than just an initial assessment, including more monitoring wells, and field parameters. Without proper site characterization, it is not possible to select an appropriate model or develop a reliably calibrated model. The following minimum hydrogeological information is required for characterization.

1. Regional geologic data depicting surface and subsurface geology.
2. Topographic data (including surface-water elevations, if available).
3. Location of surface-water bodies and measured stream-discharge and stage (water level) data (if available).
4. Groundwater table elevation with proper contour intervals.
5. Location of the monitoring, exploratory wells.
6. In case of renewal mining project cases, the piezometer shall reflect the head of the aquifer being dewatered on account of the ongoing dewatering activity. In case, it is not so, a representative piezometer may be installed to comply with the above requirements.
7. 3-D Aquifer disposition of the local/regional area, Fence diagram based on the available lithological log/composite log of the study area.
8. Hydrogeological parameters viz., Hydraulic Conductivity, Transmissivity, Specific yield, Specific Storage /Storativity etc.
9. Estimates of hydraulic conductivity from aquifer performance tests and/or slug test data or other methods.
10. Preferably layer cross sections drawn both parallel and perpendicular to groundwater flow directions.
11. Number of aquifers identified with description of aquifers being exploited
12. Measured hydraulic-head data.
13. Mapping of groundwater sources and sinks (GW recharge and draft), their location and estimation/calculation of flow rate etc.

3. Model Conceptualization

Model conceptualization is the process in which data describing field conditions are assembled in a systematic way to describe groundwater flow processes at a site. The model conceptualization aids in determining the modelling approach and which model software to use with year and version. The objective of the study here desires conceptualization of a three-dimensional groundwater flow model under transient condition. Which based on site specific condition can be a constant or variable density (used in case of aquifers with fresh/saline water interface) flow model.

1. Information on the adequacy of data to describe the hydrogeological conditions at the site.
2. Information of site area and model area.

3. Layer wise top, bottom and thickness.
4. Groundwater flow direction and rates, as applicable.
5. Number of aquifers identified and modelled, aquifer system composed of more than one aquifer or single aquifer.
6. Sources of recharge to the aquifer (rainfall or recharge from other sources like river/surface water body, irrigation return flow, or AR structures etc.); spatial & temporal variations in the same (as applicable).
7. Modes of groundwater withdrawal and spatial & temporal variations in the same
8. Information about the aquifer parameters, their heterogeneity and anisotropy over the site/model area.
9. Boundary conditions used for the model area with proper justification in & around the perimeter of the model domain.
10. Stage of River, lakes, reservoir and formulation of strategy for their simulation under transient condition.
11. Identification of the stress period (preferably monsoon and non-monsoon) setup to be adopted for the model and an appropriate time step.
12. Model start time and the initial conditions. If pre-historic data is not available, then suitable strategy for incorporation of the initial conditions in the model needs to be formulated or ground top elevation may be considered for initial condition. The model start time may be set considering climatic year.

4. Groundwater flow model

Groundwater modelling is a hydrogeological tool which simulates the groundwater system of an area of interest. A computer-based replica of the real system is designed using algorithms which primarily incorporate the variables of the equation for three-dimensional groundwater flow in to the computational framework. The models are calibrated and validated with historic data, so as to give confidence for future predictions. It can easily give an insight in to the present complex interactions between hydrogeological factors like groundwater recharge & withdrawal, variations in the groundwater reserve & dynamics, surface-groundwater interaction etc. and can predict the system response to any possible changes in the variables. A description of the groundwater flow model should elaborate on the following aspects:

1. Description of the hydrogeologic framework of the modelled domain with a schematic drawing.
2. For a realistic model mass balance-based assessment of the impact of local groundwater withdrawal on the local groundwater reserve, surface-groundwater dynamics etc., it is desired to keep the bounds of the modelled domain as bounds of the buffer zone; or somewhat beyond it. However, this may vary if the site condition demands so. If larger areas are used for modelling, zone budget for a zone comprising only the active cells in the buffer zone should be discussed.
3. If modelled domain is larger or smaller than the buffer area, a justification for the size selection shall be provided.
4. Hydro stratigraphic framework and layers of the model indicating hydraulic properties of the aquifer system and their incorporation in the model.
5. Grid design, active/inactive cells (as per ***Annexure-I***).

6. Description about the simulation period, initial head for the layers, stress period setup and the time step used.
7. It is desired that a climatic year is divided in to minimum two stress periods: Monsoon & Non-monsoon. If better data set regarding month/season wise variation in the groundwater recharge/withdrawal etc. are available, then a climatic year can be subdivided in to more than two stress period with proper data-based justification for the same.
8. Description about the source (recharge in to groundwater system) and sink (withdrawal from the groundwater system) in tune to the stress period setup used in the model; and any variations in the same. The source of the data should be mentioned.
9. The Evapo -Transpiration (ET) package may be added in cases where the DTWL is less than 2m bgl or upto the root zone for a substantial period of a year. The source of data for The Potential Evapo-Transpiration (PET) may be provided. In all cases, where the ET package has been used, the extinction depth should be explicitly mentioned.
10. Description of the boundary condition incorporated at bounds of the modelled domain with proper justification for the same using initial head contours, preferably extended somewhat beyond bounds of the modelled domain. The boundary condition at bounds of the modelled domain could be: specified head; specified flux; head dependent flux (GHB) etc. Description of other boundary conditions also may be provided.
11. In case specified flux/specified head/General Head Boundary is taken at the bounds of the model, the values used for the same for different stress periods may be shown as a Table, if required.
12. Coastal boundaries should be simulated with constant head boundary & the values used should be defined in the table.
13. Perennial Rivers should be simulated as Rivers with stages varying in tune to the stress period setup.
14. Lakes, Reservoir, Ponds etc. should only be simulated as constant head if data for sufficiently long time indicate no seasonal and long-term variations in the hydraulic head; otherwise suitable packages like Reservoir/Lake package etc. may be used for simulation. Alternately, they may be simulated as water body with head changing in tune to the stress period setup.
15. Mine seepage may be estimated by simulating mine as drain as per the approved mine plan using the Drain package.
16. For renewal cases, the mine seepage estimated through the model should be verified with the actual mine dewatering data and the same may be discussed in EAC.
17. Industrial withdrawal should be entered in the grid specific to the well location.
18. Solver and the software used for modelling to be mentioned.
19. Sensitivity analysis.
20. Model calibration should be attempted with the historical water level head data of the modelled domain and a plot of observed versus simulated head should be displayed. A table comparing the observed and model simulated head with estimated residual error should be given.
21. Three years of historic water level data is desired for prediction of NOC period and next five/ten years.

22. In case of non-availability of historic water level data within the core zone, the modeller should endeavour level best to use regionally interpolated historic water level heads for calibration.
23. The sensitive model parameters identified should be discussed and the model parameters where changes were made for calibration should be clearly mentioned specifying the amount/percentage of the changes made in the initial values.
24. The permissible limits for Root Mean Square (RMS) and Normalised RMS shall be <= 5m and 10% respectively.
25. Mean Absolute Error (MAE), and the range of residual error needs to be reported explicitly.
26. It is mandatory to have both RMS and NRMS errors within the limits mentioned for treating the model as realistic. In complex aquifer systems with limited data availability, on case-to-case basis, relaxation can be done to have at least one of these parameters within the prescribed limits. Which is subject to acceptable MAE and range of residual errors.
27. On the basis of sensitivity analysis, it is advised for manual calibration by making systematic changes in the identified parameters.
28. If automatic model -calibration using software suits like PEST etc.is used, then the report should specifically mention the parameters used for automatic calibration, range of values specified for automatic calibration and the calibrated range of values for the parameters. The percentage changes in the seed and optimized values of the parameters. In such cases undertakings are to be submitted by the modeller. (***Annexure-IIA and IIB***).
29. The model verification may be done for verifying the model output and if needed further calibration may be done.
30. Observed and model generated contours shape matching.
31. Model generated water level hydrographs to be verified with respect to available water level hydrograph based on available observed data.
32. Cumulative mass balance (Model Summary) to be discussed for start and end of the NOC period, that is for the baseline scenario and scenario after the impact of groundwater withdrawal. If model design requires discussions on cumulative mass balance (Layer Summary) for assessing the impact, the same may be done. Along with tabular presentation of data, graphical presentation is also desired with preferably blue colour for 'Inflows' and Red for 'Outflows', and both bars side by side for each category (e.g. Storage, River etc.).
33. As mentioned above, if larger areas are used for modelling, the mass balance for a window/zone aligned along the buffer zone should be discussed.
34. Limitations and uncertainty of the model should also be discussed.

5. Model prediction

1. Model generated water level contour map for start and end of the NOC period, and for next 5 years and 10 years. Discussions about possible changes in groundwater dynamics on account of the proposed withdrawal/dewatering. Maps with legible velocity vectors

with magnitudes may also be used for this. Standard colour for inward (blue) and outward (Red) vectors should be used.

2. Model generated map showing variations in the drawdown for start and end of the NOC period, and for next 5 and 10 years and discussions about the same.
3. Reporting of the estimated area/radius of influence from the site of groundwater withdrawal/dewatering for the NOC period and for next 5 and 10 years.
4. Prediction of temporal variations in mine seepage, baseflow and in/out from surface water bodies (like Ponds, reservoir etc). In case of mine seepage, necessary reporting on mine seepage for the NOC period.
5. Projection of the cumulative mass balance (Model Summary) for end of the NOC period, and next 5 and 10 years. If model design requires discussions on cumulative mass balance (Layer Summary) for assessing the impact, the same may be done. Along with tabular presentation of data, graphical presentation is also desired with preferably blue colour for 'Inflows' and Red for 'Outflows', and both bars side by side for each category (e.g. Storage, River etc.).
6. ***Business as-it-is Scenario*** and ***Aquifer Resilience Scenario*** to be generated for Impact Assessment Report or Comprehensive Hydrogeological Report like

FOR INDUSTRY:

I. A scenario assuming that industry will continue with the same ground water withdrawal for next 2/3/5/10 year.
II. A scenario for assessing aquifer resilience, assuming cessation of withdrawal after a suitably selected duration of time.

FOR MINE and INFRASTRUCTURE:

I. A scenario with the prosed dewatering/withdrawals as per the mine plan for next 2/3/5/10 year.
II. A scenario for assessing aquifer resilience assuming cessation of dewatering / withdrawal after a suitably selected duration of time.

7. The above-mentioned scenario should attempt to make specific comment about the way the groundwater dynamics will change in future and comment on aquifer resilience in terms of timelines (month/year). These aspects can be discussed with water level contours, drawdown variations etc. in the buffer area.
8. It should also be endeavored to discuss the estimated drawdown on account of the baseline regional groundwater withdrawals and comparison of the same with the cumulative drawdown on account of addition of the proposed withdrawals, for a better understanding of the impacts.
9. The study should propose contingency and mitigation measures that will be implemented in the event that unacceptable impacts occur. If possible, a scenario simulating the impact of mitigation measures.

6. Conclusion and recommendation

The conclusion should be in-line with the objective of the study i.e., impact of GW withdrawal/dewatering quantum applied for obtaining NOC, on the surrounding hydrogeological regime. It must necessarily evaluate the potential for unacceptable impacts that is likely to occur as a result of the water withdrawal. The predicted decline in water levels/

heads in next 5 to 10 years along with desaturation of aquifer/layers, if any shall be reported. It should propose contingency and mitigation measures that should be implemented in the event that unforeseen unacceptable impacts occur. The model results must communicate to stakeholders, including the public, regulators, and decision-makers, in a clear and concise manner. It is also suggested to maintain the model by updating the data and recalibrating the model periodically to ensure that it remains accurate and relevant.

B. SUBMISSION OF SOFT COPY OF THE MODEL

All the consultants preparing ground water model are essentially to submit the model backup along with its basic executable files to CGWA for archival. The name of software with version used may be reported along with executable files / data files.

C. CHECK LIST FOR PRESENTATION IN EXPERT APPRAISAL COMMITTEE (EAC)

1. Live model may be kept ready during the EAC.
2. Map showing the study area and the model area clearly indicating the groundwater withdrawal/dewatering site.
3. Conceptualization of the model and details as per ***Annexure-I***.
4. If modelled domain is larger or smaller than the buffer area, a justification for the size selection shall be provided.
5. Model layer design in tune to the aquifer disposition of the local/regional area based on fence diagram/ lithological log/composite log of the study area.
6. Map showing boundary condition incorporated at bounds of the modelled domain with proper justification for the same using initial head contours.
7. Description of other boundary conditions.
8. Model calibration data and plots with statistics of Root mean square (RMS), normalised RMS, error percentage etc.
9. Mean Absolute Error (MAE), and the range of residual error needs to be reported explicitly.
10. Map showing observed and model generated contours shape matching.
11. Model generated water level hydrographs preferably along with water level hydrograph based on available observed data.
12. Model generated water level contour map for start and end of the NOC period, and for next 5 years and 10 years.
13. Model generated map showing variations in the drawdown for start and end of the NOC period, and for next 5 and 10 years.
14. Reporting of the estimated area/radius of influence from the site of groundwater withdrawal/dewatering for the NOC period and for next 5 and 10 years.
15. Prediction of temporal variations in mine seepage, baseflow and in/out from surface water bodies etc.
16. Mine seepage for the NOC period. The mine seepage estimated through the model should be verified with the actual mine dewatering data and the same may be discussed in EAC
17. Mass balance to be discussed for start and end of the NOC period, that is for the baseline

scenario and scenario after the impact of groundwater withdrawal and next 5 and 10 years. Tabular presentation of data and graphical presentation with preferably blue colour for 'Inflows' and Red for 'Outflows', and both bars side by side for each category (e.g. Storage, River etc.).

18. Model generated scenario assuming that project will continue with the same ground water withdrawal for next 2/3/5/10 year.
19. Model generated scenario for assessing aquifer resilience, assuming cessation of withdrawal/dewatering after a suitably selected duration of time.

D. MODELLING REPORT DOCUMENTATION

- The report based on the modelling study detailing the modelling approach and findings should be documented chapter wise as detailed above under section A: Guidelines for chapters of the modelling report.
- All data sources should be explicitly acknowledged in the report and preferably be included as part of the report.
- The calculations etc. used for preparing the model data set should be appropriately included in the report

List of Tables

Besides, the tables required for discussions as per various subheads mentioned above under section A: Guidelines for chapters of the modelling report, it should be ensured that the following data tables are integral part of the report:

1. Well coordinate data for OBS or Extraction Wells or Proposed Extraction for Industry
2. Hydraulic head data
3. Elevation of model top and bottom
4. Hydraulic conductivity or transmissivity, and specific yield/Storativity
5. Aquifer test or slug test data
6. Recharge and discharge data
7. Model calibration and verification result showing a comparison of measured and simulated calibration targets and residuals.
8. Results showing the range of adjustment of model parameters and resulting change in hydraulic heads or groundwater flow rates.
9. Other data, not listed above, may lend itself to presentation in tabular format. Where appropriate, the aquifer for which the data apply should be clearly identified in each table.

List of Figures

Besides, the figures required for discussions as per various subheads mentioned above under section A: Guidelines for chapters of the modelling report, it should be ensured that the following figures are integral part of the report:

1. Regional location map with topography.
2. Site map showing well locations, and site topography.
3. Geologic cross sections (preferably parallel and perpendicular)
4. Map showing the measured hydraulic-head distribution.
5. Maps of top and/or bottom elevations of aquifers and confining units.

6. Map depicting aquifer heterogeneity as used for simulation.
7. Map depicting aerial variations in recharge and groundwater withdrawal (as applicable)
8. Model grid with location of different boundary conditions used in the model.
9. Simulated hydraulic-head, drawdown, radius of influence etc. maps, with graphical presentation of mass balance.

List of Annexures

It should be ensured that the necessary and relevant data may be appended as Annexures, if required.

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Annexure I

The tabular details of model design should be presented as follows:

Parameter	**Value**
Grid	Nos of Column X Nos of Rows Size of Grid m x m, Nos of active grid and Nos of Inactive grid
Top of Layer (m amsl) range of elevation	Layer 1 Layer 2 Layer 3
Bottom of Layer (m amsl) range of elevation	Layer 1 Layer 2 Layer 3
Initial Heads (m amsl)	Layer 1 Layer 2 Layer 3
Aquifer Type	Layer 1 : Layer 2 : Layer 3 :
Boundary Conditions Used **(At bounds of the modelled domain and others)**	Specified Head; Specified Flux; Head dependent flux etc.
K (m/ Day) ***Seed value and optimised value may be provided***	Layer 1 : Layer 2 : Layer 3 :
Specific yield (%) ***Seed value and optimised value may be provided wherever Automated Calibration is done.***	Layer 1 : Layer 2 : Layer 3 :
Storage Parameters ***Seed value and optimised value may be provided wherever Automated Calibration is done***	Layer 1 : Layer 2 : Layer 3 :
Range of Recharge applied *for Core & Buffer zones*	mm/day
Draft applied	
Proposed Draft applied for the firm (NOC)	

Note*: The rows and headings in the above table are suggestive, if required more rows can be added, headings modified to give a better synoptic view of the data used along with the reference of source of data for the modelling.*

Annexure II A

Letter head of Company/Firm/Project Proponent /Consultant

File no: Date:

LETTER OF UNDERTAKING (LUT)

(*applicable for Applications in **MINE / INFRASTRUCTURE** Category*)

It is to certify that I, _____ (name) _____, _____ (designation) _____, _____ (office) _____, have applied for new/renewal of NOC for groundwater withdrawal vide Application No. _____; Project Name:_____ for the quantity of _____ KLD/ _____/ KLY. The previous NOC for groundwater withdrawal was issued for the quantity _____/ KLD, _____/ KLY vide NOC No. _____ dated _____.

Further, it is to undertake:

1. that, the aquifer parameters, recharge, abstraction, stress period set up, initial head etc., used in the ground water modeling are same as the data presented during _____Internal EAC/External EAC meeting dated _____and they are in tune with the field hydrogeological conditions.
2. that the mine seepage i.e. _____KLD / _____KLY has been estimated from all the faces and bottom of the pit/pits as per the approved mine plan.
3. that the year wise approved mine plan has been suitably incorporated in the ground water modeling and simulation of mine seepage is based on the same.
4. that, it is certified that the aquifer parameter(s) i.e., _____, ____, and _____ optimized using PEST/Auto calibration, are in the range of realistic aquifer parameters as per the site-specific hydrogeological conditions.
5. the reported mine seepage i.e. _____KLD / _____KLY and rainwater accumulation i.e. _____ is in sync with the actual dewatering data i.e. _____ KLD / _____KLY from the sump pit of all mine pits.

Date:

Place: (Authorized signatory)
Designation

Company stamp

*****

Note:

1. Please strike out the conditions which are not applicable.
2. Do not change or delete the words. However, additional information shall be provided, if required.
3. The said undertaking shall be attached as a part of IAR/GWM report

Annexure II B

Letter head of Company/Firm/Project Proponent /Consultant

File no: Date:

LETTER OF UNDERTAKING (LUT)

(*applicable for Applications in **INDUSTRY** Category*)

It is to certify that I, _____ (name) _____, _____ (designation) _____, _____ (office) _____, have applied for new/renewal of NOC for groundwater withdrawal vide Application No. _____; Project Name:_____ for the quantity of _____ KLD/ _____/ KLY. The previous NOC for groundwater withdrawal was issued for the quantity _____/ KLD, _____/ KLY vide NOC No. _____ dated _____.

Further, it is to undertake:

1. that, the aquifer parameters, recharge, abstraction, stress period set up, initial head etc., used in the ground water modeling are same as the data presented during _____Internal EAC/External EAC meeting dated _____and they are in tune with the field hydrogeological conditions.
2. that, it is certified that the aquifer parameter(s) i.e., _____, ____, and _____ optimized using PEST/Auto calibration, are in the range of realistic aquifer parameters as per the site-specific hydrogeological conditions.

Date:

Place: (Authorized signatory)
Designation

Company stamp

*****

***Note**:*

1. Please strike out the conditions which are not applicable.
2. Do not change or delete the words. However, additional information shall be provided, if required.
3. The said undertaking shall be attached as a part of IAR/GWM report