Fortescue Metals Group Ltd

Peer review and model appraisal

Hydrogeological Assessment for the Christmas Creek Water Management Scheme

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1. Introduction

This report provides peer review of the hydrogeological assessment and groundwater model for the Christmas Creek Water Management Scheme. The Christmas Creek iron-ore mine is located in the Pilbara region of Western Australia. The model has been developed in-house by hydrogeologists and groundwater modellers within Fortescue Metals Group Ltd (Fortescue).

The groundwater model will support internal planning of pit dewatering and excess water management for the future development of the Christmas Creek mine site. The model outcomes will contribute to an improved Public Environmental Review document that will be communicated and submitted to the EPA as part of environmental approvals. The purposes of the modelling are to assess potential impacts of the proposed water management approach on local aquifers and environment (most importantly, the Fortescue Marsh), and to facilitate design of dewatering and injection infrastructure required for operational water management.

2. Scope

HydroConcept was approached to undertake a peer review of the hydrogeological conceptual and numerical groundwater models relating to Christmas Creek Water Management Scheme. The primary tasks involved being:

- Read and comment on the technical report detailing a hydrogeological assessment of the Christmas Creek Water Management Scheme compiled by Fortescue;
- Review and verify the conceptual hydrogeology including an assessment of technical robustness, rigour and level of confidence in the interpretations and analyses that support the developed numerical groundwater model;
- Review the model as documented against the Murray-Darling Basin Commission (MDBC) Groundwater Modelling Guidelines; and
- Provide the review in the form of a written report.

3. Review Guidelines

The review has been structured according to checklists in the Groundwater Flow Modelling Guideline (MDBC, 2001). This guide, sponsored by the Murray-Darling Basin Commission, is considered the Australian standard for assessing numerical groundwater flow models.

There are no recognised guidelines for reviewing conceptual hydrogeology and the suitability of the conceptual model for the purposes of numerical modelling. As such, the reviewer has used elements from within the Conceptualisation table – Model Review (MDBC, 2001) and provided additional comments where required.

The modelling has been reviewed according to the two-page Model Appraisal Checklist in MDBC (2001). The checklist has a series of standard questions relating to the (1) Report; (2) Data Analysis; (3) Conceptualisation; (4) Model Design; (5) Calibration; (6) Verification; (7) Prediction; (8) Sensitivity Analysis; and (9) Uncertainty Analysis. This checklist is considered appropriate for the review of density-coupled groundwater flow models, as per that developed by Fortescue.

All efforts have been made to follow the MDBC guidelines and make the required assessment based on the report and information provided by Fortescue. The reviewer has had no involvement in development in the groundwater model, as recommended within the guidelines, and this model appraisal has been undertaken at the completion of the modelling process.

4. Reviewed Documentation

The reviewer was provided a large complement of technical reports to enable a thorough and comprehensive review of the conceptual hydrogeology and groundwater model. These supplementary reports ensured the reviewer had all the background information to facilitate a prompt and accurate review.

The primary documentation on which this review is based was:

1. Fortescue, 2010, Hydrogeological assessment for the Christmas Creek Water Management Scheme, CC-RP-HY-0004, 30 September 2010.

The following documentation relating to the Christmas Creek operations were reviewed in conjunction with Document #1 (the aforementioned report):

2. Fortescue, 2009, Bore Completion Report – Christmas Creek Stage 1, CC-RP-HY-0001, 5 June 2009.
3. Fortescue, 2010, Bore Completion Report, CC-RP-HY-0007, June 2010.

In addition, the following documents were reviewed and inspected which relate to other Fortescue operations and the Hancock Prospecting proposal for Roy Hill:

4. Fortescue, 2010, Cloudbreak Hydrogeological Assessment, CB-PL-HY-0001, 20 April 2009.
5. Hancock Prospecting Pty Ltd, 2009, Roy Hill 1 Iron Ore Project Stage 1, Public Environmental Review Document, June 2009.

A draft version of Document #1 was evaluated by the reviewer in mid September with a number of recommendations and improvements for Fortescue to incorporate and ensure it was a standalone document. Fortescue have since made these changes and the final version of Document #1 is reviewed and discussed below.

5. Peer Review

There are two components to the peer review of the hydrogeological assessment of the Christmas Creek Water Management Scheme. It comprises (1) a review of the conceptual hydrogeology and its appropriateness for incorporating into the numerical groundwater model, and (2) a model appraisal against the MDBC modelling guidelines.

5.1 Conceptualisation

The conceptual hydrogeology has been reviewed for its technical rigour, robustness and appropriateness for developing the numerical groundwater model. The format of this review is somewhat based on the Model Review questioning template in MDBC (2001) for lack of a formal standard.

5.1.1 Consistency with prior knowledge

Prior to the development of the Christmas Creek and Cloudbreak projects, there was a poor regional understanding of the hydrogeology and groundwater resources in this part of the Pilbara. There had been no regional groundwater investigations by State Government; hence no background knowledge of groundwater resources, which required Fortescue to develop its own understanding.

Since 2004, Fortescue has undertaken several phases of hydrogeological investigation and assessment that have substantially improved knowledge and understanding of the hydrogeology both at a regional and local scale. This continual improvement is a requirement of responsible and best practice resource development. As a result, all conceptualisation is original and any regional understanding of groundwater resources can be directly attributable to those studies completed by Fortescue.

5.1.2 Consistency with required model complexity

In order to assess impacts to groundwater resources and the environment related to Christmas Creek, a groundwater model has been developed to evaluate a number of different development scenarios. Fortescue recognised that a coupled-density flow model would be required to adequately represent groundwater flow and salinity distribution.

There has been focused effort to understand groundwater resources in terms of both hydraulics (groundwater flow) and hydrochemical distribution. This approach has enabled Fortescue to develop a conceptual model that is consistent and meets the requirements of a density-coupled model.

5.1.3 Clear definition of conceptual model

The conceptual model is well described in Document #1 with respect to hydrostratigraphic units, water level trends, groundwater flow, recharge and discharge. The primary data sets used in developing the conceptual model are summarising in tabulation format. Table 7 provides a useful overarching description of the link between geology and hydrostratigraphy, which leads into the explanation of connectivity between units. The comparison with nearby mining operations (Cloudbreak and Roy Hill) is useful for provide regional context.

Chapter 5 outlines Fortescue's understanding of the Fortescue Marsh and most importantly its hydraulic functioning under different climatic and inundation conditions – this is best illustrated in Figure 16. Section 5.2 provides the rationale and approach for representing components of the conceptual model into the numerical model.

5.1.4 Graphical representation

Figure 3 provides a hydrogeological cross section illustrating the conceptual hydrogeology with respect to (1) hydrostratigraphy and groundwater flow; and (2) groundwater salinity distribution. It is considered an appropriate representation of groundwater flow and salinity distribution, in particular the concept of a transitional or mixing salinity zone.

The inclusion of Figure 16 illustrates the groundwater processes and interactions (recharge, discharge, groundwater flow) associated with the Fortescue Marsh. These diagrams highlight the changes in hydraulic processes and functioning, when the marsh is flooded, dry, and in an extended dry period.

5.1.5 Simple or complex conceptual model

The complexity of the conceptual model is more than adequate, and is not considered either too simple or overly complex. The decision to develop a density-coupled flow model is appropriate requiring the conceptual model to be sophisticated, and presents a robust understanding of groundwater flow dynamics and groundwater salinity distribution.

5.1.6 Limitations and uncertainties

Limitations and uncertainties within the conceptual and numerical model are described in Sections 5.2 and 6.7. There is adequate discussion to enable the reviewer to understand model constraints; determination of hydrostratigraphy; setting of model boundaries; assessing of hydraulic parameters; recharge, evapotranspiration and discharge considerations; and solute transport processes including diffusion and density estimations.

5.1.7 Appropriateness of the conceptual model

The conceptual model has been reviewed to assess its robustness and appropriateness for incorporating into the numerical groundwater model. The reviewer is satisfied with the interpretations used to develop the conceptual model.

Hydrostratigraphy

The understanding of the geological setting is considered the strongest element of the conceptual model. There is a good description of the stratigraphy for the major geological units, based on a large amount of mineral exploration and ongoing installation of production, injection and monitoring bores.

The hydrostratigraphical separation is logical and appropriate. The grouping of the seven hydrostratigraphic units is acceptable and considered representative of geological conditions in the vicinity of the Christmas Creek operations.

Fortescue have highlighted the limitation of no geological data beneath Fortescue Marsh. The company has endeavoured to undertake investigations as close to the Marsh (through installing bores) and from above (using airborne geophysics); but until approvals are granted, this is a recognised gap in understanding.

Connectivity between units

Section 3.6.3 provides a good discussion on hydraulic connectivity between the units and outlines the reasoning for hydrostratigraphic separation and hydraulic connection between units, particularly within the Tertiary detritals. This explanation of the shallow aquifer system is important for understanding the groundwater regime / potential connections with the Marsh and groundwater dependent ecosystems.

Hydrogeological processes

There is adequate description within the document on the functioning of the groundwater environment and its representation within the numerical model. Table 10 presents a summarised conceptual model (a handy reference) outlining the approach for representing hydrogeological processes, such as recharge, discharge and groundwater flow.

Recharge – The distribution of the four recharge zones is shown clearly in Figure 15 with the rationale for the separate zones detailed in Section 6.2.5.

Transient recharge / discharge related to Fortescue Marsh – Based on the drying and flooding of the Fortescue Marsh, the transient approach is conceptually valid. The approach and associated assumptions / formula with respect to net recharge are considered technically sound and robust. Table 16 assists with illustrating the conceptual and formulaic approach to resolve hydraulic functioning of the marsh under different flooding and drying conditions.

Hydraulic parameters

Section 3.6.2 presents testing methodology and results (including derived parameters) of numerous aquifer tests by Fortescue. The compiled hydraulic parameters used in the numerical model have considered the aquifer testing and are appropriate for the hydrostratigraphic units.

Groundwater flow

Baseline groundwater contours have been corrected for equivalent freshwater head, which is appropriate with respect to the saline / hypersaline groundwater near the Fortescue Marsh. The northward migration of groundwater in the deeper aquifer requires additional work to validate; but it doesn't impact on model integrity.

Functioning of the marsh

A conceptual model of the hydraulic functioning of the Marsh has been developed based on interpretations of surface hydrology, groundwater dynamics and hydrochemistry. Section 5.1 provides a good discussion on representing flooding and drying of the marsh within the numerical model. Figure 16 and Table 16 are useful for illustrating this concept.

Hydrochemistry

The conceptual model explaining groundwater salinity distribution in Figure 3 is sensible with a transitional or mixing zone between recharging groundwater from the Chichester Range and circulating hypersaline convection cell beneath the marsh. The reviewer considers the interpretation of a mixing / diffuse zone is important, based on data shown in the Durov diagram and results of the airborne AEM. There is further work required to demonstrate the magnitude and significance of northward migrating saline groundwater from the beneath the marsh.

Summary of the conceptual model review

Fortescue have produced a reasonable and robust interpretation of the hydrogeology, and valid conceptual model. The conceptual model has a strong foundation with respect to the hydrostratigraphy and connectivity between the units. The explanation of groundwater salinity distribution and hydraulic functioning of the marsh is innovative.

5.2 Model Appraisal

In terms of the modelling guidelines, the Christmas Creek model is best categorised as an Impact Assessment Model of medium complexity. The inclusion of density-coupling has increased model complexity; however, the primary intent of the model is to predict water level change and impact assessment.

This model appraisal was undertaken at the completion of the modelling process, after calibration, sensitivity analysis, prediction and final reporting. Table 1 follows the MDBC (2001) template for model appraisal.

5.2.1 The Report

To an external reader with no prior knowledge of the study, the Document #1 is considered a standalone document. Fortescue has completed extensive investigations, developed a robust conceptual model and numerical model. The report provides a sufficient description of the modelling process and modelling results, that is considered consistent with the MDBC guidelines for model report structure (Table 6.1.1 in MDBC, 2001).

5.2.2 Data Analysis

Fortescue has made considerable effort in collecting and analysing hydrogeological data in support of developing the conceptual understanding and groundwater model. The hydrostratigraphy is well understood with separation into representative model layers as well as hydraulic connectivity between layers. The hydraulic parameters for these model layers have been derived from aquifer test data and learnings at the nearby Cloudbreak operations.

There is a good understanding of groundwater flow within the different model layers due to the construction of discrete interval monitoring bores. The groundwater contours have also been corrected to equivalent fresh water head, in recognition of variations in groundwater salinity.

Despite the lack of field data, the reviewer acknowledges the efforts in developing the conceptual model for Fortescue Marsh. The methodology for resolving water balance and understanding the cyclic recharge / discharge function in the marsh is innovative and technically valid. The transient calibration shown in Figure 26 highlights the success of this approach.

Table 1. Model appraisal (Part 1) – Christmas Creek

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0,3,5)	COMMENT
1.0	***THE REPORT***								
1.1	Is there a clear statement of project objectives in the modelling report?		Missing	Deficient	Adequate	Very Good			Model objectives are clearly stated.
1.2	Is the level of model complexity clear or acknowledged?		Missing	No	Yes				Impact assessment model of medium complexity
1.3	Is a water or mass balance reported?		Missing	Deficient	Adequate	Very Good			A broad water balance has been presented in terms of major components
1.4	Has the modelling study satisfied project objectives?		Missing	Deficient	Adequate	Very Good			The model has largely satisfied project objectives
1.5	Are the model results of any practical use?			No	Maybe	Yes			Modelling results will support water management planning needs
2.0	***DATA ANALYSIS***								
2.1	Has hydrogeology data been collected and analysed?		Missing	Deficient	Adequate	Very Good			There has been considerable effort in compilation and interpretation
2.2	Are groundwater contours or flow directions presented?		Missing	Deficient	Adequate	Very Good			Contours are presented for each aquifer including equivalent fresh water head correction
2.3	Have all potential recharge data been collected and analysed? (rainfall, streamflow, irrigation, floods, etc.)		Missing	Deficient	Adequate	Very Good			Recharge zones have been characterised
2.4	Have all potential discharge data been collected and analysed? (abstraction, evapotranspiration, drainage, springflow, etc.)		Missing	Deficient	Adequate	Very Good			Considerable effort has been spent of determining recharge / discharge relationships at the marsh
2.5	Have the recharge and discharge datasets been analysed for their groundwater response?		Missing	Deficient	Adequate	Very Good			
2.6	Are groundwater hydrographs used for calibration?			No	Maybe	Yes			Hydrographs have been used to support calibration; however calibration is hindered by the lack of a significant wet period. Excellent transient calibration for the marsh.
2.7	Have consistent data units and standard geometrical datums been used?			No	Yes				

Table 1. (cont.) Model appraisal (Part 1) – Christmas Creek

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0,3,5)	COMMENT
3.0	***CONCEPTUALISATION***								
3.1	Is the conceptual model consistent with project objectives and the required model complexity?		Unknown	No	Maybe	Yes			The conceptual model is robust and appropriate for the model complexity.
3.2	Is there a clear description of the conceptual model?		Missing	Deficient	Adequate	Very Good			There is a good description of the conceptual model
3.3	Is there a graphical representation of the modeller's conceptualisation?		Missing	Deficient	Adequate	Very Good			Graphical illustrations are very good.
3.4	Is the conceptual model unnecessarily simple or unnecessarily complex?			Yes	No				Good balance in model complexity
4.0	***MODEL DESIGN***								
4.1	Is the spatial extent of the model appropriate?			No	Maybe	Yes			The model extent is adequate and ensures that there are no boundary effects within the model.
4.2	Are the applied boundary conditions plausible and unrestrictive?		Missing	Deficient	Adequate	Very Good			The applied boundaries are appropriate and related to hydrogeological reasoning.
4.3	Is the software appropriate for the objectives of the study?			No	Maybe	Yes			FEFLOW - density-coupled flow.

Table 1. (cont.) Model appraisal (Part 1) – Christmas Creek

Q.	QUESTION	Not Applicable or Unknown	Score 0	Score 1	Score 3	Score 5	Score	Max. Score (0,3,5)	COMMENT
5.0	***CALIBRATION***								
5.1	Is there sufficient evidence provided for model calibration?		Missing	Deficient	Adequate	Very Good			Multiple lines of evidence; scattergram, comparison to real contours.
5.2	Is the model sufficiently calibrated against spatial		Missing	Deficient	Adequate	Very Good			Good calibration to groundwater contours and salinity distribution.
5.3	Is the model sufficiently calibrated against temporal observations?		Missing	Deficient	Adequate	Very Good			Transient calibration is excellent particularly with respect to the marsh; however there is still to check against a real wet rain season.
5.4	Are calibrated parameter distributions and ranges plausible?		Missing	No	Maybe	Yes			All parameters are considered appropriate and representative.
5.5	Does the calibration statistic satisfy agreed performance criteria?		Missing	Deficient	Adequate	Very Good			Normalised RMS is 10%
5.6	Are there good reasons for not meeting agreed performance criteria?		Missing	Deficient	Adequate	Very Good			No agreed criteria but model has met objectives
6.0	***VERIFICA TION***								
6.1	Is there sufficient evidence provided for model verification?		Missing	Deficient	Adequate	Very Good			Comparison of simulated and observed water level and salinity appear realistic.
6.2	Does the reserved dataset include stresses consistent with the prediction scenarios?	N/A	Unknown	No	Maybe	Yes			
6.3	Are there good reasons for an unsatisfactory verification?	N/A	Missing	Deficient	Adequate	Very Good			

Table 1. (cont.) Model appraisal (Part 1) – Christmas Creek

7.0	***PREDICTION***								
7.1	Have multiple scenarios been run for climate variability?		Missing	Deficient	Adequate	Very Good			Synthetic rainfall pattern developed to consider wet and dry seasons / scenarios.
7.2	Have multiple scenarios been run for operational management alternatives?		Missing	Deficient	Adequate	Very Good			Multiple dewatering and injection scenarios have been completed for the mine plan.
7.3	Is the time horizon for prediction comparable with the length of the calibration / verification period?		Missing	No	Maybe	Yes			Synthetic rainfall scenarios back to 1973. Limited calibration data but only 5 year prediction
7.4	Are the model predictions plausible?			No	Maybe	Yes			The model provides reasonable estimations of dewatering and injection considerations for mine water planning.
8.0	***SENSITIVITY ANALYSIS***								
8.1	Is the sensitivity analysis sufficiently intensive for key parameters?		Missing	Deficient	Adequate	Very Good			Sensitivity analysis undertaken during modelling process. Sensitive parameters are documented.
8.2	Are sensitivity results used to qualify the reliability of model calibration?		Missing	Deficient	Adequate	Very Good			Modeller has reviewed parameter sensitivity and optimised accordingly.
8.3	Are sensitivity results used to qualify the accuracy of model prediction?		Missing	Deficient	Adequate	Very Good			Table 24 shows change in dewatering volumes relative to sensitive parameters of K and Ss.
9.0	***UNCERTAINTY ANALYSIS***								
9.1	If required by the project brief, is uncertainty quantified in anyway?		Missing	No	Maybe	Yes			Uncertainty analysis undertaken and documented.
	TOTAL SCORE								**PERFORMANCE:**

5.2.3 Conceptualisation

The conceptual model is considered a reasonable and robust interpretation of the hydrogeology. It has a strong foundation with respect to the hydrostratigraphy and connectivity between the units.

The hydrogeological cross section (Figure 3) provides a good graphical representation of the conceptual hydrogeology with respect to (1) hydrostratigraphy and groundwater flow; and (2) groundwater salinity distribution.

Figure 16 describes and graphically illustrates the groundwater processes and interactions (recharge, discharge, groundwater flow) associated with the Fortescue Marsh. This illustration, when the marsh bed is inundated versus dry, assists in explaining the water level methodology and formula in Section 6.2.5.

5.2.4 Model Design

The model has been built using FEFLOW finite-element code, version 5.412. This model approach allows for discretisation of the model domain, and the project need for density-coupled flow modelling.

Model discretisation is appropriate with mesh refinement in the vicinity of mining operations related to the position of dewatering and injection bores. Model layering is consistent with the conceptual model. Figure 18 shows a section of model layering to illustrate the success at representing the hydrostratigraphy within the numerical model.

The no-flow model boundaries are appropriate and are located at a reasonable distance away from the dewatering and injection, as to not interfere with model outputs. This is confirmed as all drawdown and injection impacts are clearly within model boundaries.

Section 6.2.4 provides a good description of the solute transport processes and parameters used in the model. The parameters are valid.

5.2.5 Calibration

The numerical model has been calibrated for steady state using initial head and salinity distribution derived from a long-term simulation; and transient relative to monitoring bore records and marsh flooding records.

The modelled head and salinity distribution at steady-state calibration produced an RMS of 0.74 m and normalised RMS of 10.2%. These results are considered adequate for the moderate complexity of the numerical model.

Rainfall data from Newman station was used as the primary time-varying model parameter for marsh-flood / transient calibration. Figure 24 shows a good correlation of modelled Fortescue Marsh recharge and observed flood levels.

Transient calibration is hindered by the lack of a long-term record of water levels at the site. Two years of water level monitoring data and an interpretation of marsh flooding from satellite imagery have been used to facilitate and enable calibration. There is a good fit between observed and modelled water levels related to the extended dry season that the region has experienced. Data for a ‘wet’ season will enable further refinement of calibration.

Salinity distribution has been well replicated by the model. This suggests that the model is calibrated with respect to the mass / solute transport component and provides some reliability for use in predictive assessment. The reviewer feels that the model is calibrated and can be reliably used for predictive modelling and scenario runs.

5.2.6 Prediction

Section 6.4 provides a good description of the water management assumptions used in the modelling scenarios. The three simulation approach to assess and incorporate dewatering and injection is appropriate, as it provides a meaningful distribution of groundwater drawdown and mounding enabling an assessment of impacts.

The approach to backfill is conservative and valid considering the lack of data on the hydraulic functioning and parameters, which will slightly over-predict modelled dewatering volumes.

The explanation and representation of the mine plan in Section 4.8 is logical. The methodology for incorporating the water management strategy (in terms of abstraction and injection) into the model scenarios is robust.

Injection volume is calculated as a product of dewatering volumes minus amounts used for water usage. The injection has been modelled via a series of brackish and saline injection borefields.

The natural groundwater regime within the Chichester Range and Fortescue Marsh is well represented by the model.

The predictive results for dewatering and injection are illustrated in Figures 37 to 38 and show distinctive water level responses. A mound is developed to the west of the mining operations and drawdown from the mining operations appears to be mitigated by the injection barrier. All predictive changes in water level are confined to the model domain, highlighting that the model boundaries are appropriate.

Section 6.5.5 presents a useful interpretation of potential cumulative impacts to nearby mining operations, relative to the Christmas Creek Water Management Scheme. The predictions appear sensible and highlight the localised impact of the Christmas Creek when considering the regional context. This sub-regional approach will support Government authorities in making their assessment and evaluation of cumulative impacts, which is well illustrated in Figure 43.

5.2.7 Sensitivity and uncertainty analysis

Model sensitivity related to key parameters, particularly those likely to impact dewatering and the Fortescue Marsh, were assessed during numerical simulation. The model was found to be most sensitive to hydraulic conductivity of the ore body with a range of uncertainty in dewatering rates. While, the climate scenario was assessed to have negligible impact on dewatering volumes,

Fortescue tested a wide range of sensitivities using likely end-member values to observe changes in dewatering volumes. Following this analysis, an upper limit for dewatering at 50GL/yr was estimated.

There is an adequate discussion on model limitations as well as recommendations for improving hydrogeological understanding.

6. Conclusions

The groundwater model of the Christmas Creek Water Management Scheme has been developed competently. It provides a robust and meaningful representation of the hydrogeology, as Fortescue has utilised all available information and made appropriate estimations where required.

There has been a significant improvement in the understanding of the hydrogeology and groundwater resources around the Christmas Creek operations. The reviewer considers the report and model outputs are considered satisfactory for internal mine planning and supporting the environmental approvals process.

7. References

MDBC (2001) Groundwater flow modelling guideline, Murray-Darling Basin Commission.