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Report on
Groundwater Nutrient Transport Modelling

Central Dune Sand Deposit
Great Keppel Island Revitalisation Plan

Prepared for
GKI Resorts Pty Ltd

Project 74586.02
September 2011

Douglas Partners
Geotechnics / Environment / Groundwater

Document History

Document details

Project No.	74586.02	Document No.	1
Document title	Report on Groundwater Nutrient Transport Modelling		
Site address	Central Dune Sand Deposit, Great Keppel Island Revitalisation Plan		
Report prepared for	Tower Holdings Pty Ltd		
File name	P:\Groundwater Projects\74586.02_Additonal Groundwater Assessmt for EIS, GKI\Docs\74586.02 Nutrient Modelling REPORT_Final.doc		

Document status and review

Revision	Prepared by	Reviewed by	Date issued
0	Carl Deegan	Iain Hair	7 September 2011

Distribution of copies

Revision	Electronic	Paper	Issued to
0	1	0	GKI Resorts Pty Ltd, CQ Consulting Group, Opus.

The undersigned, on behalf of Douglas Partners Pty Ltd, confirm that this document and all attached drawings, logs and test results have been checked and reviewed for errors, omissions and inaccuracies.

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1. Introduction

Douglas Partners Pty Ltd (DP) was commissioned by GKI Resorts Pty Ltd to conduct groundwater numerical modelling of nutrients within the central dune sand deposit on Great Keppel Island. The groundwater modelling was carried out as part of an Environmental Impact Statement (EIS) for the Great Keppel Island (GKI) Revitalisation Plan (the "Project"). The objective of the modelling was to assess the nutrient levels within the groundwater discharging into Leeke's wetland as a result of effluent irrigation over the proposed golf course.

Previous geotechnical and groundwater investigations (DP 2011a, 2011c) confirmed a more extensive dune sand deposit present within the central region of GKI than that previously mapped by DNRMW (2006). The investigations also identified a groundwater resource (or aquifer) within the western portion of the dune sand deposit, which discharges groundwater into Leeke's Beach and the tidal wetland. It is understood that the "Project" proposes to irrigate treated effluent over the golf course area which overlays parts of the central dune sand aquifer.

This report describes the numerical transport model developed for the central dune sand aquifer, the predictive modelling simulations carried out to assess the transport of nutrients (nitrogen and phosphorous) within the aquifer, and the modelling results. The purpose of the transport modelling was to assess the maximum allowable nutrient levels entering the groundwater from the irrigation, that would not significantly impact upon the wetland ecosystem.

2. Previous Groundwater Investigations

Three previous investigations into the groundwater resources on GKI were carried out by DP, two in 2007 and one in 2011. Results of the investigations are detailed in DP (2007a), DP (2007b) and DP (2011b). These investigations and results are summarised in the following sub-sections.

2.1 Douglas Partners Pty Ltd (2007a)

Hydrogeological investigations were carried out to identify potential groundwater resources on GKI in 2006 and 2007 for major redevelopments of the island that were proposed at the time. The investigations comprised reviewing existing information, mapping of dune sand deposits, an electromagnetic geophysical survey, drilling of 11 test bores and installation of 10 monitoring bores, groundwater quality testing, development of conceptual hydrogeological models, and groundwater modelling to assess their sustainable yield.

The hydrogeological investigations identified potential groundwater resources (aquifers) located within the north-eastern and south-western dune sand deposits on GKI. The south-western dune sand aquifer was considered to consist of two distinct aquifer areas divided by shallow bedrock beneath the southern end of the air strip. These two distinct aquifer areas were referred to as the “Resort aquifer” draining to Putney Beach and Fisherman’s Beach, and the “Long Beach aquifer” draining to Long Beach. It was recommended that the Resort aquifer not be considered as a potential water resource due to its poor water quality from salt water intrusion.

The investigation identified the Long Beach aquifer and the Northeast aquifer as the viable groundwater resources capable of being used for a water supply. Field and laboratory water quality testing indicated the groundwater was fresh and suitable for a potable water supply, with the exception of a low pH. Salt water intrusion into the Long Beach aquifer due to historic over-pumping from bores which deceased the quality of the groundwater was also reported.

Groundwater modelling was conducted using Visual MODFLOW for the north-eastern aquifer and the Long Beach aquifer to assess the sustainable aquifer yields and borefield design. A sustainable yield of approximately 100 kL/day (50 kL/day in each bore) was determined for two production bores in the Long Beach aquifer, and a sustainable yield of approximately 270 kL/day was determined for three production bores in the north-eastern aquifer.

2.2 Douglas Partners Pty Ltd (2007b)

Based on the results and recommendations of DP (2007a), two production bores were installed within the Long Beach aquifer on GKI in 2007. The bores were installed to supplement the existing resort water supply. Most of this aquifer had been affected by salt water intrusion, so the location of each bore and the long-term pumping rates would be critical to the sustainability of the supply.

Test pumping and analysis was carried out to assess the hydraulic parameters of the Long Beach aquifer and to confirm the maximum long term yields of each production bore. Analysis of the test pumping data confirmed that the aquifer is unconfined, has a transmissivity of approximately 220 m^2/day and a hydraulic conductivity of 20 m/day.

Recommendations for the long-term protection and management of the aquifer were provided. These included the decommissioning of nine existing water supply bores in the Long Beach aquifer, maintaining two monitoring bores for future monitoring purposes, installation of an additional monitoring bore, installation of protective covers and fencing around each production bore, regulation and monitoring of flow rates, and exclusion of any potential contaminating activities over the surface of the aquifer.

2.3 Douglas Partners Pty Ltd (2011b)

Geotechnical investigations in 2010 (DP 2011a) identified a sand deposit in the central area of GKI Island more extensive than that previously mapped by DNRMW (2006) indicating it had a potential to provide a sustainable groundwater resource. Additional groundwater investigations were carried out in 2011 to determine whether a potential groundwater resource exists within the central dune sand deposit and to assess its long term sustainable yield. The investigation included a review of existing information, mapping of the extent of the dune sand deposit, drilling and installation of five groundwater monitoring bores (MB12-MB16), groundwater quality sampling and analysis, development of the conceptual hydrogeological model, and groundwater modelling to assess the sustainable yield.

The investigations identified a viable aquifer (or groundwater resource) within the central dune sand which extends from Leeke's Beach to approximately half way along the central valley towards Clam Bay. It is an unconfined (or water table) aquifer and is relatively thin in parts, varying between 3 m and 10 m in thickness.

Groundwater quality was found to be generally fresh at Bores MB12, MB14, and MB16, and found to be slightly brackish and non-potable at Bore MB13. The groundwater is acidic indicating it would require treatment (pH correction) prior to being used as a potable water supply. Levels of chloride exceeded the ADWG aesthetic guideline in the three samples tested and hardness exceeded the ADWG aesthetic guideline in MB13. None of the heavy metals tested reported levels which exceeded the drinking water guidelines, with the exception of nickel in MB13. It was concluded that if the groundwater resource was to be used as a water supply, then additional water quality testing would be required to confirm its suitability as a potable water source.

Groundwater modelling conducted using Visual MODFLOW indicated a long term sustainable yield of approximately 90 kL/day was possible using two production bores in the central dune sand aquifer. The sustainable yield was limited by the thin aquifer thickness and relatively low permeability of the dune sand. The sustainable yield was reported to be dependent on the location of the production bores within the aquifer and the flow rates extracted from each bore. Recommendations were provided for the location and construction requirements of production bores (water bores), as well as for ongoing monitoring of groundwater levels and quality.

3. Site Information

3.1 Great Keppel Island

Great Keppel Island is the largest island in the Keppel group of islands, and is located approximately 19 km east of Yeppoon off the Central Queensland coastline. It is located within the Mackay/ Capricorn region of the Great Barrier Reef Marine Park (GMRMP).

The former Great Keppel Island Resort is located on a dune sand deposit on the western side of the island between Fisherman's Beach and Long Beach. The main resort facilities are situated near Fisherman's Beach with some elevated villas on a hill immediately east of the main former resort area. A sealed landing strip is located to the east of the former resort area aligned approximately north-west to south-east. Residential houses, some retail properties and accommodation facilities including the Keppel Haven Resort, and Keppel Island Village are also located on this dune sand deposit between Fisherman's Beach and Putney Beach.

3.2 Site Location & Description

According to the proposed revitalisation plans provided by GKI Resorts Pty Ltd, three precincts of the island will be developed as follows:

- *Marina Precinct*: Proposed marina area, northern section of Putney Beach and off-shore area;

- *Fisherman's Beach Precinct*: Proposed resort redevelopment area, footprint of existing resort, air strip, and vegetated areas east of the airstrip; and

- *Clam Bay Precinct:* Proposed golf course area, north of Clam Bay from the eastern base of Mount Wyndham and Wyndham Cove north to the historical Homestead, and east to the base of the mountain.

The **"site"** for this report and groundwater modelling is limited to the central dune sand aquifer as shown on Drawing 1 and includes the western parts of the Clam Bay Precinct. The GKI revitalisation plans are provided in Appendix A.

3.3 Geology

According to the published geological map for the Rockhampton region (DNRMW 2006), the central area of the island is primarily underlain by the Carboniferous aged Shoalwater Formation comprising metamorphic quartzose and lithic sandstones, with minor mudstone and schist. This Carboniferous sequence is mapped as being overlain by Quaternary alluvial deposits of clay, silt, sand, gravel, and flood-plain alluvium in the northern section of the site.

DP (2011a and 2011b) confirmed the presence of an extensive dune sand deposit within the central region of GKI which contains the Clam Bay Precinct. The general profile of the sand deposit comprises light grey, fine to medium grained sand underlain by light orange/brown or brown fine to medium grained sand with some silt, which inturn is underlain by light orange/brown silty sand. No shell layers or indurated sand layers (or coffee rock) were evident in the drilling of the monitoring bores. The dune sand was underlain by residual silty clay/clayey sand weathered from the Shoalwater Formation.

The revised geological plan for GKI and the geology for the central region (or "site") is shown on Drawing 2.

4. Conceptual Hydrogeological Model – Central Dune Sand Aquifer

The Conceptual Hydrogeological Model (CHM) for central dune sand aquifer was based on a review of the geological and topographic maps, existing information sourced from DERM, and the results of drilling carried out as part of the central sand dune deposit groundwater investigation in 2011 (DP, 201b).

The CHM was described in DP (2011b) and is summarised in the following sections. The major components of the CHM are illustrated on the hydrogeological cross section reproduced for convenience in this report as Drawing 3

4.1 Geological Setting

The central dune sand aquifer is composed of Quaternary dune beach sand. The sand deposit is a relatively poorly-sorted fine to medium grained sand and grades into a silty sand in some areas. The general profile of the sand deposit comprises fine to medium grained sand underlain by fine to medium grained sand with some silt, which inturn is underlain by silty sand.

The basement of the aquifer is comprised of residual silty clay/clayey sand which overlies the metamorphic sandstones of the Carboniferous Shoal-water Formation. The dune sand deposit is bounded to the north, east and south by outcrop of the Shoalwater Formation.

4.2 Hydrogeology

The Great Keppel Island central dune sand aquifer is an unconfined (or water table) aquifer which extends from Leeke's beach to approximately half way along the valley to Clam Bay, as shown on Drawing 1. The western boundary coincides with the tidal wetlands and Leeke's Beach where the groundwater will discharge. The aquifer is bounded by outcrop of the Shoalwater Formation to the north and south. The basement of the aquifer is composed of the same formation.

Aquifer recharge occurs through the direct infiltration of rainfall over its entire natural ground surface. It would also receive additional recharge through the infiltration of rainfall into the unsaturated sand deposit between the aquifer's eastern boundary and Clam Bay.

Permeability estimates based on PSD tests were derived for MB12, MB13, MB14 and MB16, indicating an average hydraulic conductivity of 5 m/day for the boreholes, a value which is characteristic of fine grained sands. The saturated thickness of the aquifer is relatively thin in parts and varies between 3.0 m at MB13 up to 10 m at MB16.

Monitoring data in 2011 indicated the average hydraulic gradient between MB12 and MB16 is calculated to be 0.01 (DP 2011b), which is a relatively high gradient for a coastal sand aquifer and probably a reflection of the low permeability and high basement gradient.

4.3 Groundwater Flow Patterns

In shallow coastal aquifers the groundwater table is generally a subdued reflection of the surface topography. The monitoring data recorded in February 2011 indicated the groundwater generally flows to the northwest through the aquifer towards the tidal wetland and Leeke's Beach. Groundwater within the aquifer will discharge directly into surface water associated with the wetland. During wet climatic periods, when groundwater levels are high, groundwater may also discharge into Blackall Creek and Leeke's Creek.

5. Groundwater Model

The groundwater numerical flow model was developed using the pre-processor or graphical interface program *Visual MODFLOW* and was based on the CHM described in Section 4. Model simulations were conducted using *MODFLOW* (McDonald & Harbaugh, 1988), a three-dimensional groundwater head and flow model developed by the United States Geological Survey. Prior to any predictive simulations, the model predictions were confirmed as reasonable by calibrating the model to observed groundwater levels and flow patterns.

The initial purpose of developing the flow model was to aid in the assessment of the sustainable yield of the aquifer. A full description of the model geometry, boundary conditions, hydraulic parameters and calibration is provided in DP 2011b.

5.1 Nutrient Transport Model

The MT3DMS (Mass Transport in 3-Dimensions Multi-Species) numerical code (Zheng and Wang, 1998) was used for the nutrient transport simulations as it allows for more than one compound to be modelled, given the interest in both Total Nitrogen (TN) and Total Phosphorus (TP) migration. MT3DMS can be used to simulate changes in concentrations of miscible contaminants in groundwater considering *advection* (movement at the same velocity as groundwater), *dispersion* (spreading of concentration caused by microscale deviations in velocity from the prevailing groundwater velocity), diffusion (molecular-level movement driven by concentration gradients) and some basic *chemical reactions* (sorption, radioactive decay etc). Various types of boundary conditions (e.g. coastal margins) and external sources (e.g. irrigation) or sinks (e.g. wetlands) can be included. It should be noted that while multiple species are accommodated, they are treated separately and not intermixed. The transport model was developed as an extension of the already-developed MODFLOW flow model and the predictive simulations run using the *Visual MODFLOW* software.

The transport model was developed to assess the levels of TN and TP, discharging within the groundwater into the tidal wetland. The nutrients will enter the aquifer through the deep drainage occurring below the root zone from the irrigation of treated effluent over the golf course. Consequently, the purpose of the transport modelling was to assess the maximum allowable levels of nutrients within the deep drainage which would not significantly impact upon the wetland, based on conservative assumptions, which are described in the following sections. For the transport predictive simulations, if the nutrient levels within the groundwater discharging into the wetland were below the relevant 2009 Queensland Water Quality Guidelines (QWQG), refer Section 6.1, then no significant impact to the wetland was assumed.

5.2 Aquifer Hydraulic & Transport Parameters

The transport model used the same aquifer parameters used for the previous groundwater flow modelling (DP, 2011b). For a single layer numerical flow model these included the following horizontal hydraulic conductivity value and rainfall recharge coefficient adopted following completion of the steady state calibration:

- Hydraulic conductivity = 8 m/day.
- Recharge = 40% average rainfall.

For transport simulations of nutrients estimates of the specific yield, porosity, and dispersion are also required. Porosity and specific yield affect the transport solutes as they determine the seepage velocity, which controls the advection, and also the pore volume available for storage of a solute (Zheng & Bennett, 1995). Dispersion can result from the process of dilution when a contaminant mixes with uncontaminated water as it moves through the porous aquifer matrix. The mixing occurring along the groundwater flow direction is known as longitudinal dispersion (Fetter, 2001).

The following estimates of these parameters were obtained from published ranges for a fine to medium grained sand (Fetter, 2001) and applied to the model for the transport simulations:

- Porosity = 0.30
- Specific yield (effective porosity) = 0.15
- Dispersion (longitudinal dispersivity) = 15 m

To be conservative, no sorption reactions were applied to the nitrogen or phosphorous species during the transport simulations. Sorption refers to the mass transfer process between the solute dissolved in groundwater (aqueous phase) and the solute sorbed on the porous medium (solid phase). This process effectively retards the progress of the miscible solute as it "binds" with the aquifer material. Sorption tends to be significant for clay minerals or aquifers with a high clay content (Fetter, 2001) and so was not applied to this dune sand aquifer.

5.3 Effluent Irrigation Recharge Volume

Aquifer recharge is applied to the top of the model as 40% of the rainfall over the entire surface area of the aquifer. The actual rainfall recorded between January 1992 to December 2006 for the region, multiplied by 40%, was applied to the model for the 15 year transport simulation. Additional recharge was applied to the area of the golf course to take into account the deep drainage entering the aquifer from the effluent irrigation. The volume of recharge was provided by Opus International Consultants (PCA) Pty Ltd following completion of their MEDLI (Model for Effluent Disposal using Land Irrigation) (Gardner et al., 1996) modelling study. To assess different sewerage flows, treatment, and irrigation options, the following volumes were used:

- Irrigation Scenario 1: 257.6 m^3/day over 25 ha (or 376 mm/year) for predictive model Runs 1 to 4; and
- Irrigation Scenario 2: 378.6 m^3/day over 31 ha (or 446 mm/year) for predictive model Runs 5 to 7.

This additional recharge was uniformly applied to the model over parts of the aquifer which are below the proposed golf course extent.

5.4 Nutrient Levels in Effluent Irrigation

The nutrient concentration levels of Nitrogen (N) and Phosphorous (P) in effluent (applied as a constant source with time) were estimated from the MEDLI modelling of the effluent irrigation by Opus International Consultants (PCA) Pty Ltd. To assess different fertiliser application rates on the golf course and sewerage treatment options, two sets of source concentrations were provided:

- Irrigation Scenario 1: N = 6.3 mg/L and P = 0.2 mg/L, with recharge volume of 376 mm/year (Runs 1 to 4); and
- Irrigation Scenario 2: N = 0.5 mg/L and P = 0.0 mg/L, with recharge volume of 446 mm/year (Runs 5 to 7).

To assess the maximum N and P levels could be within the deep drainage without impacting on the wetland, the following levels were used for the transport model runs (or simulations) as constant concentration levels applied to the golf course over time:

- Run 1 – N = 6.30 mg/L and P = 0.20 mg/L
- Run 2 – N = 2.10 mg/L and P = 0.067 mg/L (1/3 of Run 1 levels)
- Run 3 – N = 1.05 mg/L and P = 0.033 mg/L (1/6 of Run 1 levels)
- Run 4 – N = 0.79 mg/L and P = 0.025 mg/L (1/8 of Run 1 levels)
- Run 5 – N = 0.70 mg/L and P = 0.06 mg/L
- Run 6 – N = 0.55 mg/L and P = 0.03 mg/L
- Run 7 – N = 0.65 mg/L and P = 0.05 mg/L

The concentration levels were uniformly applied to the model over the golf course effluent irrigation area. The initial concentration of nutrients in the aquifer system prior to effluent irrigation were assumed to be zero. Therefore the aim of the predictive modelling was to focus only on the relative impact of different effluent irrigation management options.

6. Predictive Nutrient Transport Modelling

To evaluate the impact of effluent irrigation over the golf course and the potential nutrient levels entering the wetland, the transport model was run for various transient simulations with different starting levels of nutrients within the deep drainage water from the effluent irrigation entering the aquifer. The long-term predictive simulations were run over a 15 year period (January 1992 to December 2006) which contained one of the driest periods on record between 1991 and 2007.

Hydraulic heads obtained from the calibrated steady state simulation (DP 2011b) were incorporated into the transient model as the initial heads. The simulations comprised 180 monthly stress periods to allow for changes in the monthly rainfall to be simulated.

6.1 Maximum Nutrient Criteria For The Wetland

For the transport predictive simulations, the criteria used to assess if nutrient levels within the groundwater discharging into the wetland would cause a detrimental impact were the 2009

Queensland Water Quality Guidelines (QWQG), based on Mid-estuarine waters, central coast waters, which are slightly to moderately disturbed systems. The relevant guideline levels for the nutrients are:

- Total Nitrogen = 0.3 mg/L
- Total Phosphorous = 0.025 mg/L

The above guidelines then were used as the target criteria along the edge of the wetland for the transport simulations. If the groundwater discharging into the wetland contained nutrient levels below these guidelines, then it was considered that the irrigation of effluent would not impact upon the water quality within the wetland. To assess the levels within the groundwater discharging into the wetland efficiently, three hypothetical monitoring bores were located within the model along the boundary between the wetland and the aquifer. These were labelled CB1, CB2, and CB3 and the levels of Nitrogen and Phosphorous were monitored throughout each transport simulation.

To be conservative, the specific criteria adopted to assess if the effluent irrigation over the golf course would impact upon the wetland was if:

- Total Nitrogen levels exceeded 0.3 mg/L in model monitoring bores CB1 to CB3 at any time throughout the 15 year simulation; and
- Total Phosphorous levels exceeded 0.025 mg/L in model monitoring bores CB1 to CB3 at any time throughout the 15 year simulation.

This is considered a conservative approach as it does not take into account the dilution that would occur when the groundwater discharges into and mixes with the tidal surface water within the wetland.

6.2 Predictive Modelling Results

The following predictive scenarios were run under transient conditions using the historical set of monthly rainfall from January 1992 to December 2006:

<u>Model Runs 1 to 4:</u>
Results of predictive Runs 1 to 4 are shown as concentration versus time graphs in Appendix B for the levels within the groundwater passing through the three monitoring bores CB1 to CB3. These graphs also show the guideline value for ease of comparison. Plan views of the aquifer showing the concentration contour plots for N and P at the end of the 15 year simulation are provided on Drawings 4 to 11. Location of bores CB1 to CB3 are also shown on Drawings 4 to 11.

Model Run 1 results indicated the levels of N of 6.3 mg/L and P of 0.2 mg/L within the deep drainage from the golf course would impact significantly on the wetland water quality. The graph for CB1, CB2, and CB3 for Run 1 in Appendix B show the levels of N and P significantly exceed the guideline values. To assess what levels within the deep drainage would not exceed the guideline values in CB1 to CB3, along the wetland, the starting levels were reduced for Runs 2 to 4 until an acceptable level which did not cause the levels in CB1 to CB3 to exceed the guideline values.

Model Run 4 results show the N concentration did not exceed the guideline value (0.3 mg/L) throughout the entire simulation. This indicates that using this scenario for effluent irrigation, a level of

N of 0.79 mg/L or less within the deep drainage would not impact upon the water quality within the wetland.

Model Run 2 results show the P concentration did not exceed the guideline value (0.025 mg/L) throughout the entire simulation. This indicates that using this scenario for effluent irrigation, a level of P of 0.067 mg/L or less within the deep drainage would not impact upon the water quality within the wetland.

Model Runs 5-7:

Results of predictive Runs 1 to 4 are shown as concentration versus time graphs in Appendix C for the levels within the groundwater passing through the three monitoring bores CB1 to CB3. Plan views of the aquifer showing the concentration contour plots for N and P at the end of the 15 year simulation are provided on Drawings 12 to 17.

Model Run 5 results indicated the levels of N of 0.7 mg/L and P of 0.2 mg/L within the deep drainage from the golf course was likely to impact on the wetland water quality. The graphs for CB2 for Run 5 in Appendix B show the levels of N and P exceed the guideline values. Runs 6 and 7 were then carried out to assess the maximum levels within the deep drainage which would not cause these levels to exceed guideline levels.

Model Run 6 results show the N concentration did not exceed the guideline value (0.3 mg/L) throughout the entire simulation. This indicates that using this scenario for effluent irrigation, a level of N of 0.65 mg/L or less within the deep drainage would not impact upon water quality in the wetland.

Model Run 7 results show the P concentration did not exceed the guideline value (0.025 mg/L) throughout the entire simulation. This indicates that using this scenario for effluent irrigation, a level of P of 0.05 mg/L or less within the deep drainage would not impact upon the water quality within the wetland.

7. Conclusions

To asses the impact of effluent irrigation over the proposed golf course, located within the Clam Bay Precinct, the central dune sand aquifer numerical flow model was used to simulate the transport of nutrients N and P through the aquifer over a 15 year period. The transport modelling assessed the levels of N and P within the groundwater discharging into the tidal wetland from different treated effluent irrigation strategies. The purpose was to assess the maximum allowable nutrient levels entering the groundwater from the irrigation, which would not significantly impact upon the wetland ecosystem.

The predictive transport modelling results indicated the following:

- For Irrigation Scenario 1 – with a deep drainage recharge volume of 257.6 m^3/day over 25 ha (or 376 mm/year), the maximum levels of N and P entering the aquifer which would not cause a significant impact upon the water quality of the wetland are:
    - Nitrogen = 0.79 mg/L or less; and
    - Phosphorous = 0.07 mg/L.

- For Irrigation Scenario 2 – with a deep drainage recharge volume of 378.6 m^3/day over 31 ha (or 446 mm/year), the maximum levels of N and P entering the aquifer which would not cause a significant impact upon the water quality of the wetland are:
  - Nitrogen = 0.65 mg/L or less; and
  - Phosphorous = 0.05 mg/L.

7.1 Recommendations

To allow future monitoring and management of nutrient levels within the groundwater discharging into the wetland, it is recommended that monitoring bores are installed at the locations shown as CB1, CB2, and CB3 on Drawings 4-17.

8. References

ANZECC, 2000: *Australian and New Zealand Guidelines for Fresh and Marine Water Quality, Volume 1: The Guidelines*. Canberra.

Department of Environment and Resource Management (DERM), 2009: *Queensland Water Quality Guidelines (QWQG) 2009*, Version 3. Brisbane.

Department of Natural Resources, Mines and Water (DNRMW), 2006: *Australia 1:100,000 Geological Series, Rockhampton, Queensland*, *Sheet 9051*. Brisbane.

Douglas Partners Pty Ltd., 2007a: *Report on Groundwater Supply Investigation, Great Keppel Island*. Project 33976. Dated February 2011. Brisbane.

Douglas Partners Pty Ltd., 2007b: *Report on Production Bore Installation and Testing, Long Beach Aquifer, Great Keppel Island*. Project No. 33976A. Dated November 2007. Brisbane.

Douglas Partners Pty Ltd., 2011a: *Report on Preliminary Geotechnical Assessment, Proposed Great Keppel Island Resort, Great Keppel Island*. Project 74586.00. Dated April 2011Brisbane.

Douglas Partners Pty Ltd., 2011b: *Report on Additional Groundwater Investigation, Central Dune Sand Deposit, Great Keppel Island*. Project 74586.01. Dated April 2011. Brisbane.

Fetter, C.W., 2001: *Applied Hydrogeology, Fourth Edition.* Prentice Hall, New Jersey.

Gardner, T., Atzeni, M., & McGahan, E., 1996: *A computer model to help resolve commercial conflict in intensive rural industries*. Paper presented at the Resolving Environmental Conflict, Institution of Engineers, Brisbane, Australia

McDonald, M.G., & Harbaugh, A.W., 1988: A modular three-dimensional finite-difference ground-water flow model. USGS Techniques of Water Resources Investigations, Book 6, Chapter A1. Washington DC.

Zheng, C. & Bennett, D., 1995: *Applied Contaminant Transport Modeling, Theory and Practice.* S.S Papadopulos & Associates Inc, Maryland.

9. Limitations of this Report

Douglas Partners (DP) has prepared this report for this project on Great Keppel Island in accordance with DP's proposal BNE100871dated 10 December 2010 dated 3 February 2011 and acceptance received from Mr. Anthony Aiossa of Tower Holdings Pty Ltd on 11 January. This report is provided for the exclusive use of Tower Holdings Pty Ltd for the specific project and purpose as described in the report. It should not be used by or relied upon for other projects or purposes on the same or other site or by a third party.

This report must be read in conjunction with any attached explanatory notes and should be kept in its entirety without separation of individual pages or sections. DP cannot be held responsible for interpretations or conclusions from review by others of this report or test data, which are not otherwise supported by an expressed statement, interpretation, outcome or conclusion stated in this report. In preparing this report DP has necessarily relied upon information provided by the client and/or their agents.

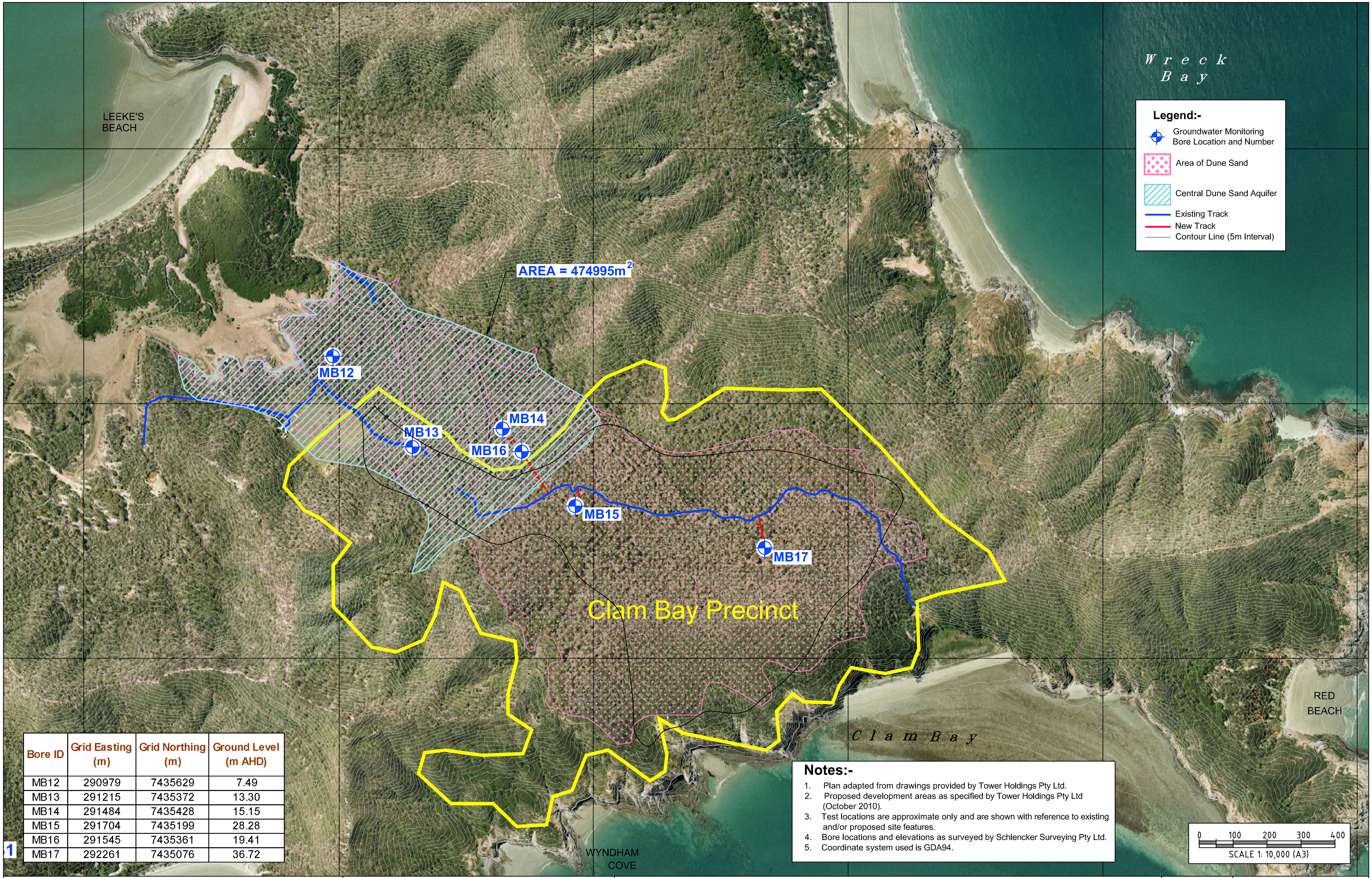
The results provided in the report are indicative of the sub-surface conditions only at the specific sampling or testing locations, and then only to the depths investigated and at the time the work was carried out. Sub-surface conditions can change abruptly due to variable geological processes and also as a result of anthropogenic influences. Such changes may occur after DP's field testing has been completed.

DP's advice is based upon the conditions encountered during this investigation. The accuracy of the advice provided by DP in this report may be limited by undetected variations in ground conditions between sampling locations. The advice may also be limited by budget constraints imposed by others or by site accessibility.

This report, or sections from this report, should not be used as part of a specification for a project, without review and agreement by DP. This is because this report has been written as advice and opinion rather than instructions for construction.

Douglas Partners Pty Ltd

Drawings



Bore ID	Grid Easting (m)	Grid Northing (m)	Ground Level (m AHD)
MB12	290979	7435629	7.49
MB13	291215	7435372	13.30
MB14	291484	7435428	15.15
MB15	291704	7435199	28.28
MB16	291545	7435361	19.41
MB17	292261	7435076	36.72

Notes:-

1. Plan adapted from drawings provided by Tower Holdings Pty Ltd.
2. Proposed development areas as specified by Tower Holdings Pty Ltd (October 2010).
3. Test locations are approximate only and are shown with reference to existing and/or proposed site features.
4. Bore locations and elevations as surveyed by Schlencker Surveying Pty Ltd.
5. Coordinate system used is GDA94.

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CLIENT: GKI Resort Pty Ltd		TITLE:	**Central Dune Sand Aquifer Location Plan**
OFFICE: Brisbane	DRAWN BY: JT		**Groundwater Nutrient Transport Modelling**
SCALE: As shown	DATE: 5 September 2011		**Central Dune Sand Deposit, Great Keppel Island Revitalisation Plan**

PROJECT No:	74586.02
DRAWING No:	1
REVISION:	0

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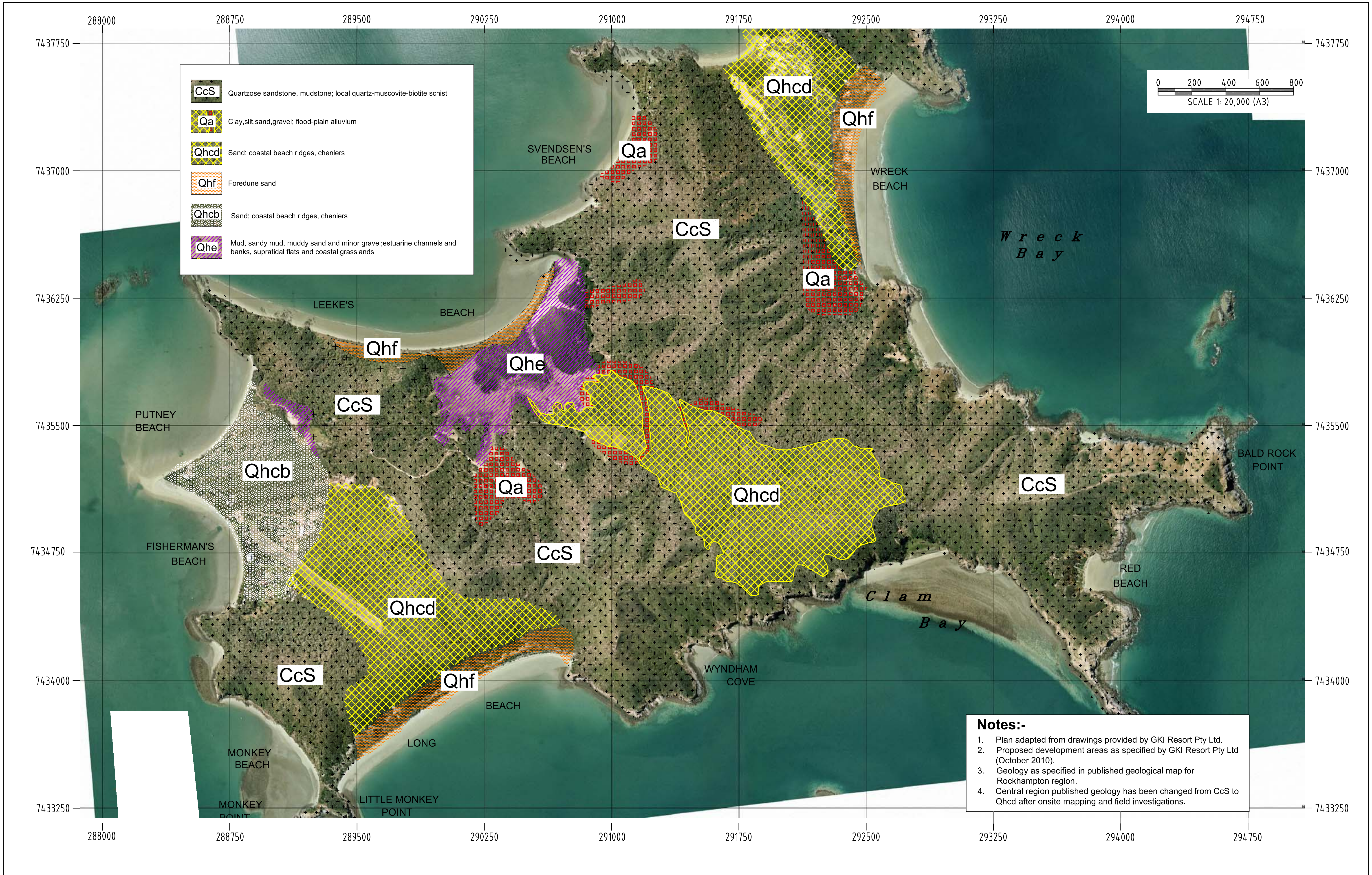

Notes:-

1. Plan adapted from drawings provided by GKI Resort Pty Ltd.
2. Proposed development areas as specified by GKI Resort Pty Ltd (October 2010).
3. Geology as specified in published geological map for Rockhampton region.
4. Central region published geology has been changed from CcS to Qhcd after onsite mapping and field investigations.

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resort Pty Ltd		TITLE: **Great Keppel Island Revised Geological Map** **Groundwater Nutrient Transport Modelling** **Central Dune Sand Deposit, Great Keppel Island Revitalisation Plan**
	OFFICE: Brisbane	DRAWN BY: JT	
	SCALE: As shown	DATE: 5 September 2011	

PROJECT No:	74586.02
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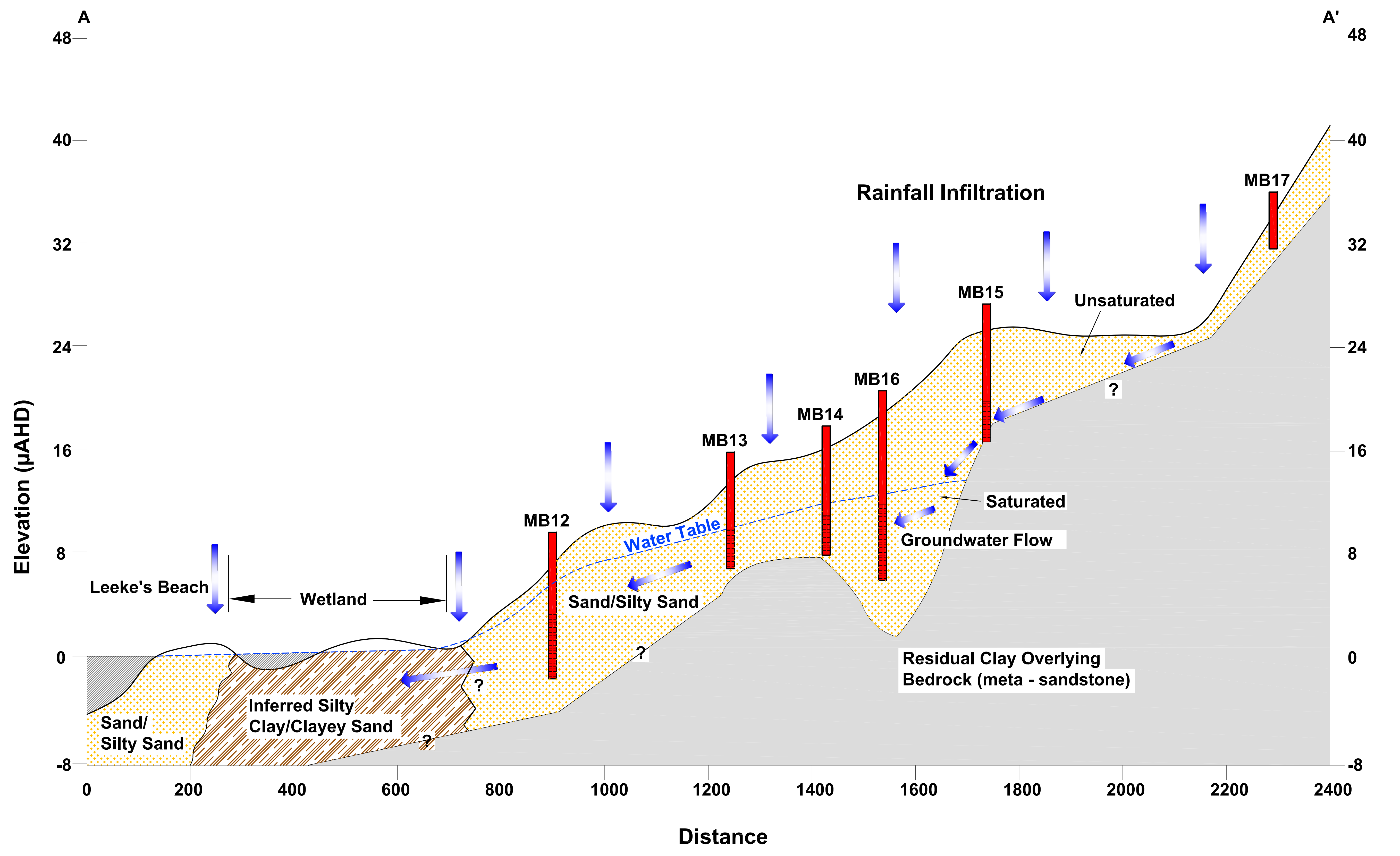

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	OFFICE: Brisbane	DRAWN BY: JT		DRAWING No: 3
	SCALE: As shown	DATE: 1 September 2011		REVISION: 0

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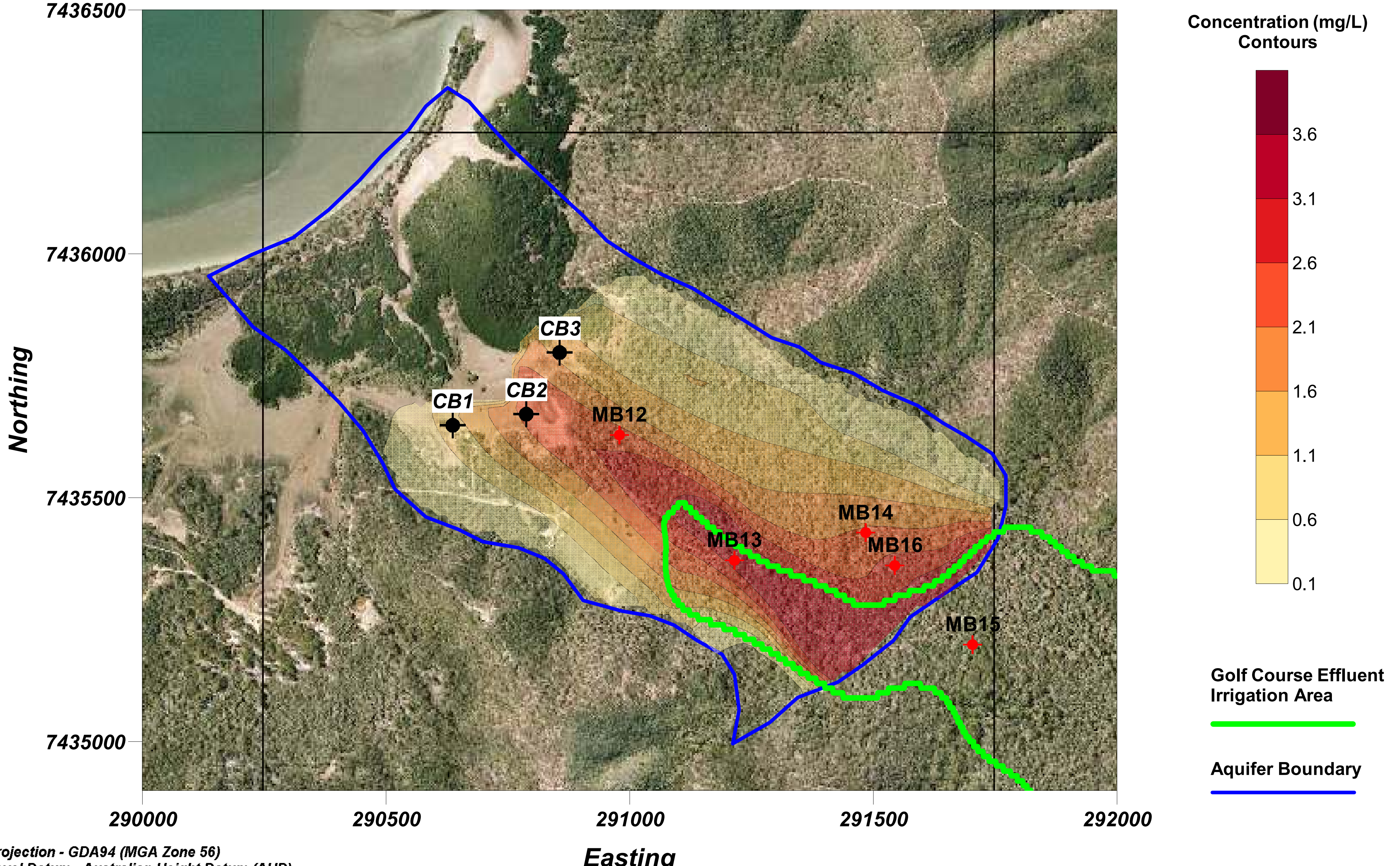

Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd		TITLE Run 1 Simulated Nitrogen Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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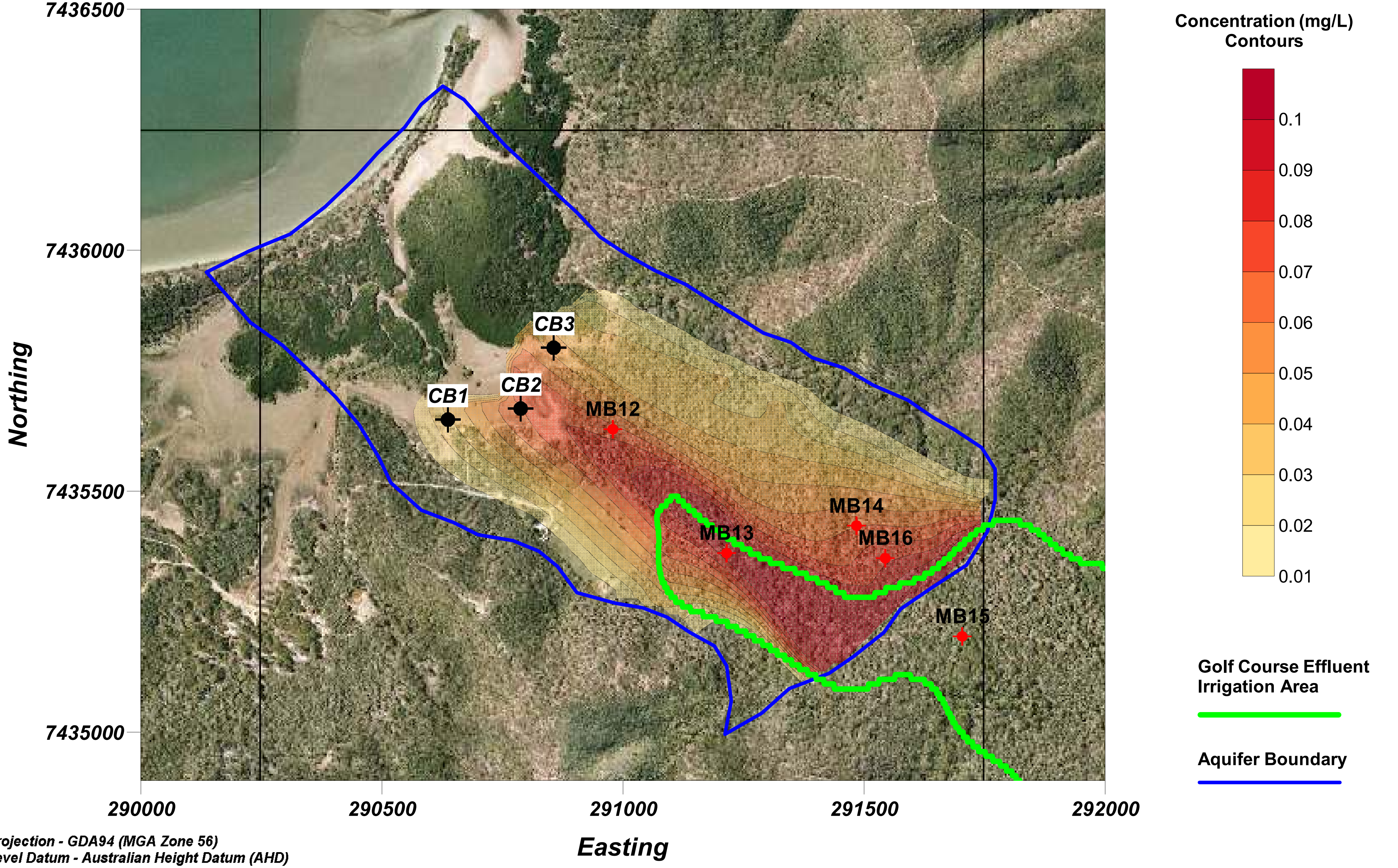
	SCALE: 1:15 000	DATE: Sep 2011		REVISION: A



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Level Datum - Australian Height Datum (AHD)

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CLIENT: GKI Resorts Pty Ltd		TITLE: Run 1 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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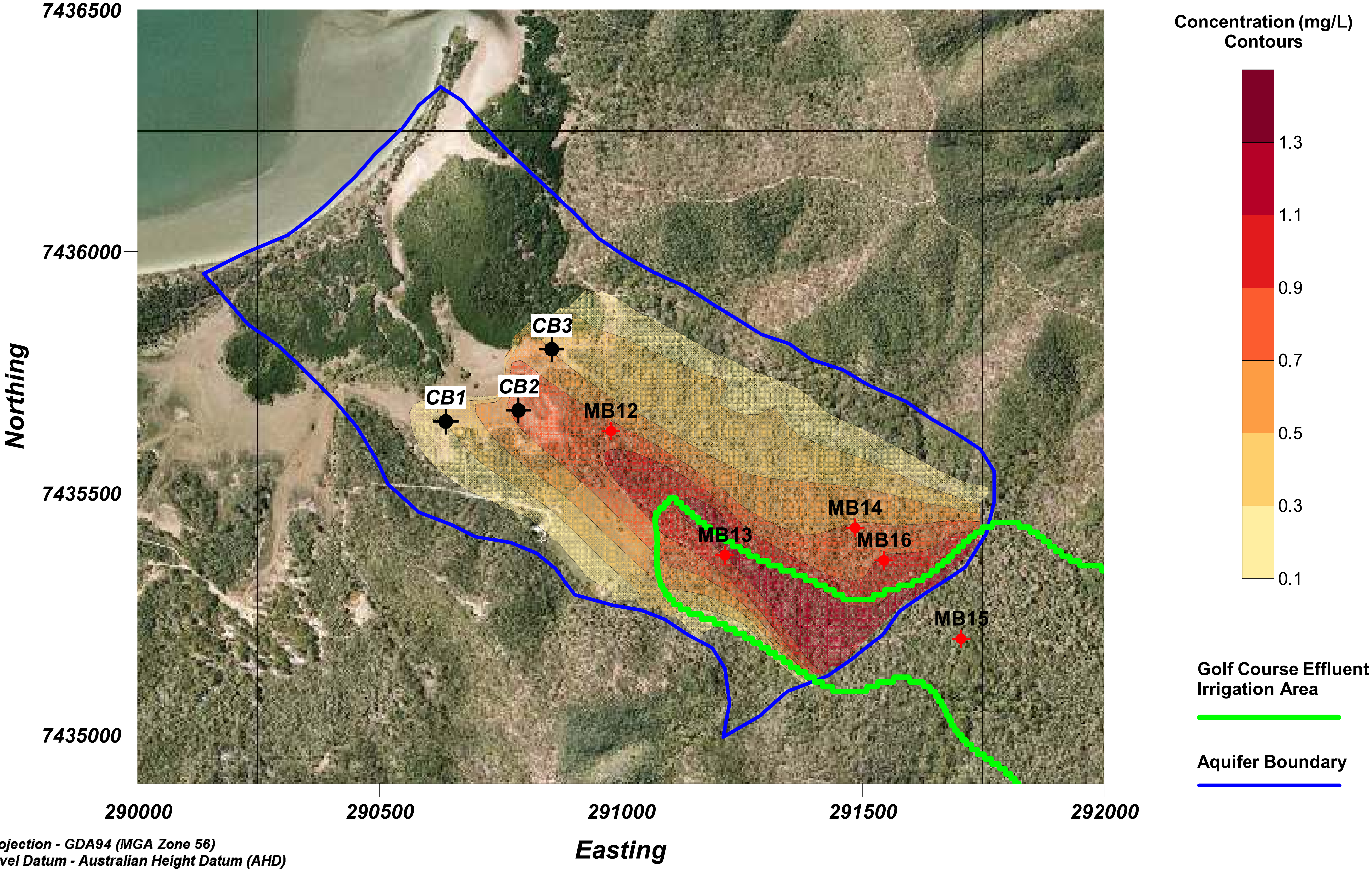

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Level Datum - Australian Height Datum (AHD)

Douglas Partners
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CLIENT: GKI Resorts Pty Ltd		
OFFICE: Brisbane	DRAWN BY: CD	
SCALE: 1:15 000	DATE: Sep 2011	

TITLE
Run 2 Simulated Nitrogen Levels (After 15 yrs)
Groundwater Nutrient Transport Modelling
Central Dune Sand Deposit, GKI Revitalisation Plan

PROJECT No:	74586.02
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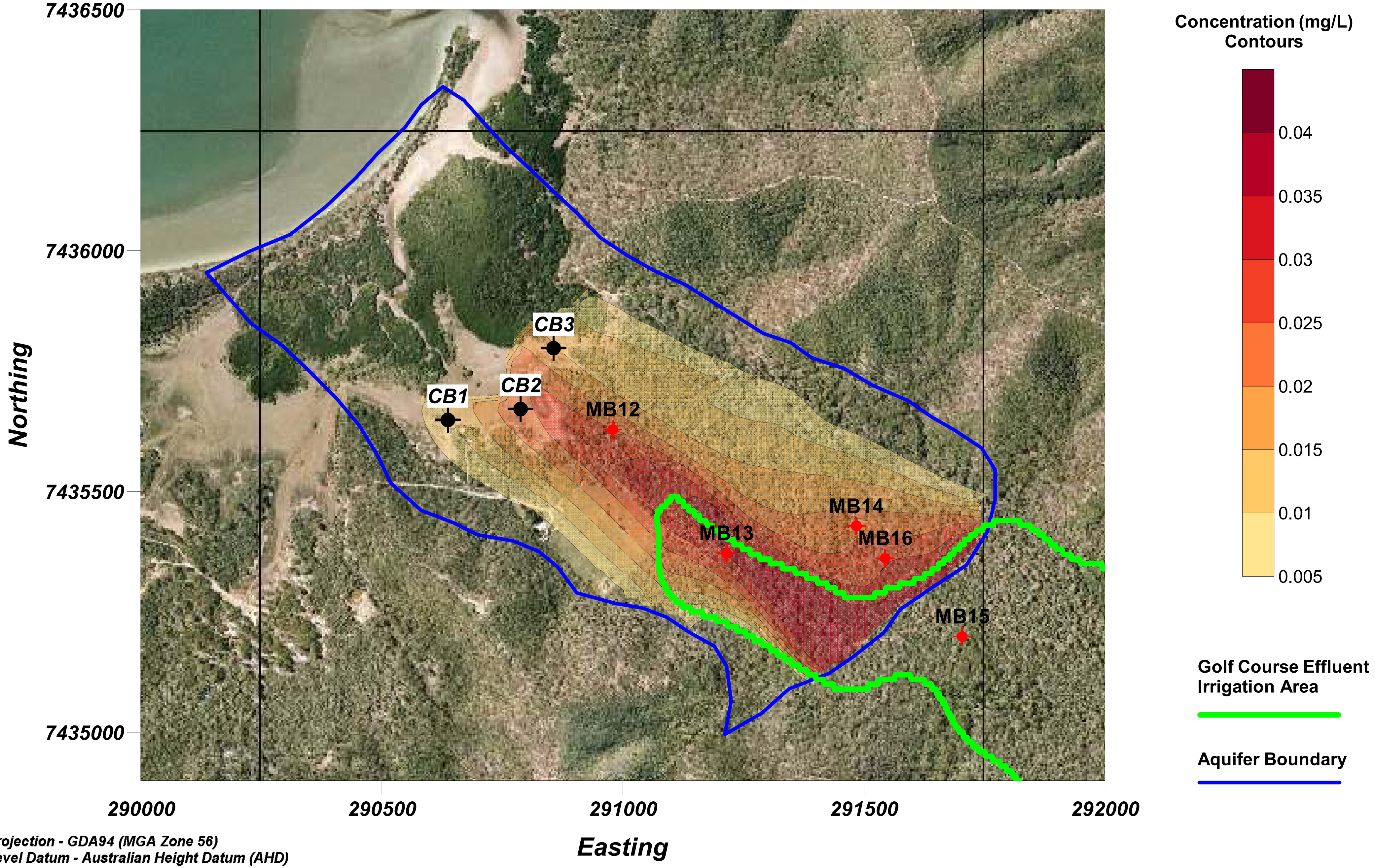

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd	TITLE Run 2 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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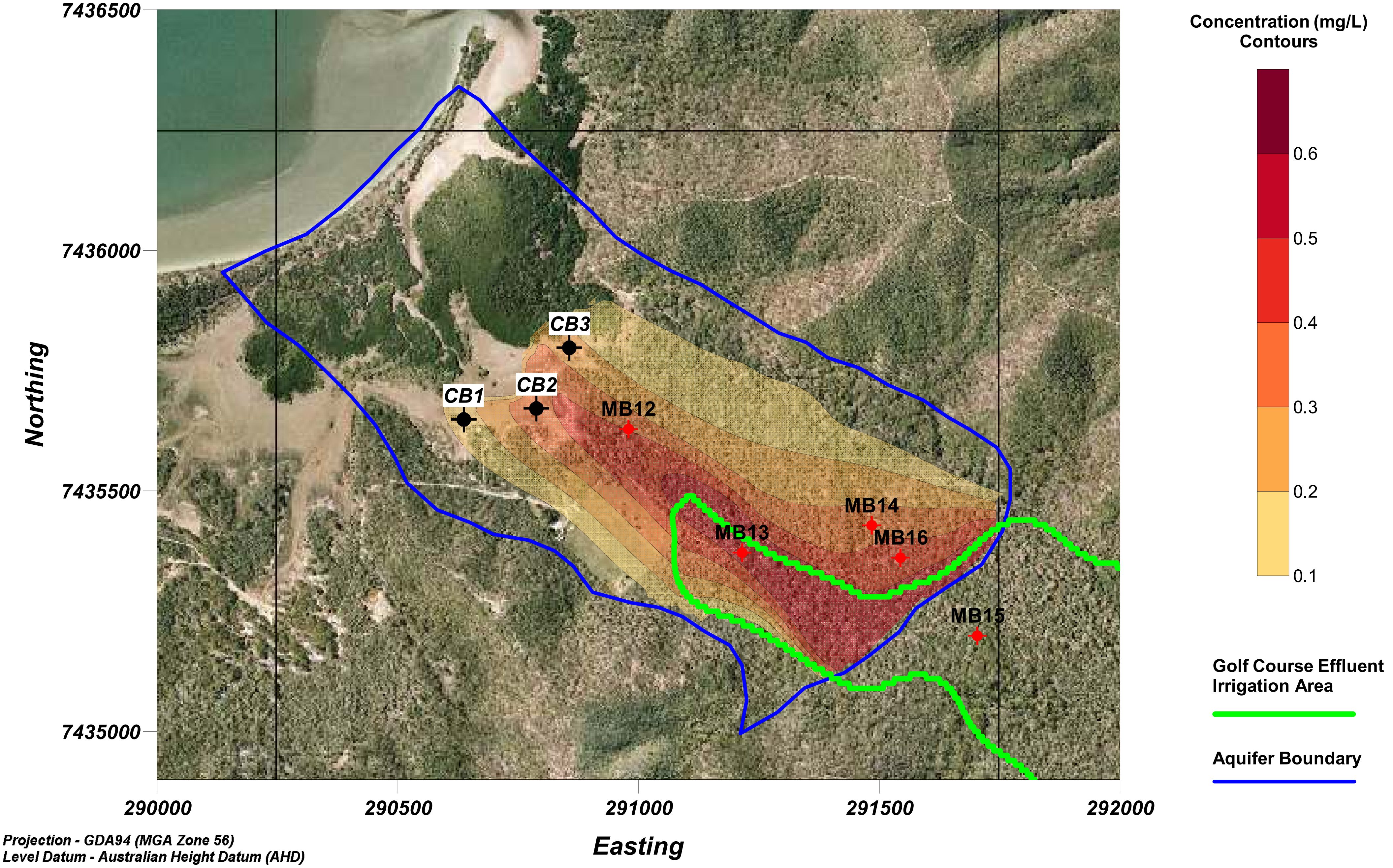

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Level Datum - Australian Height Datum (AHD)

Douglas Partners
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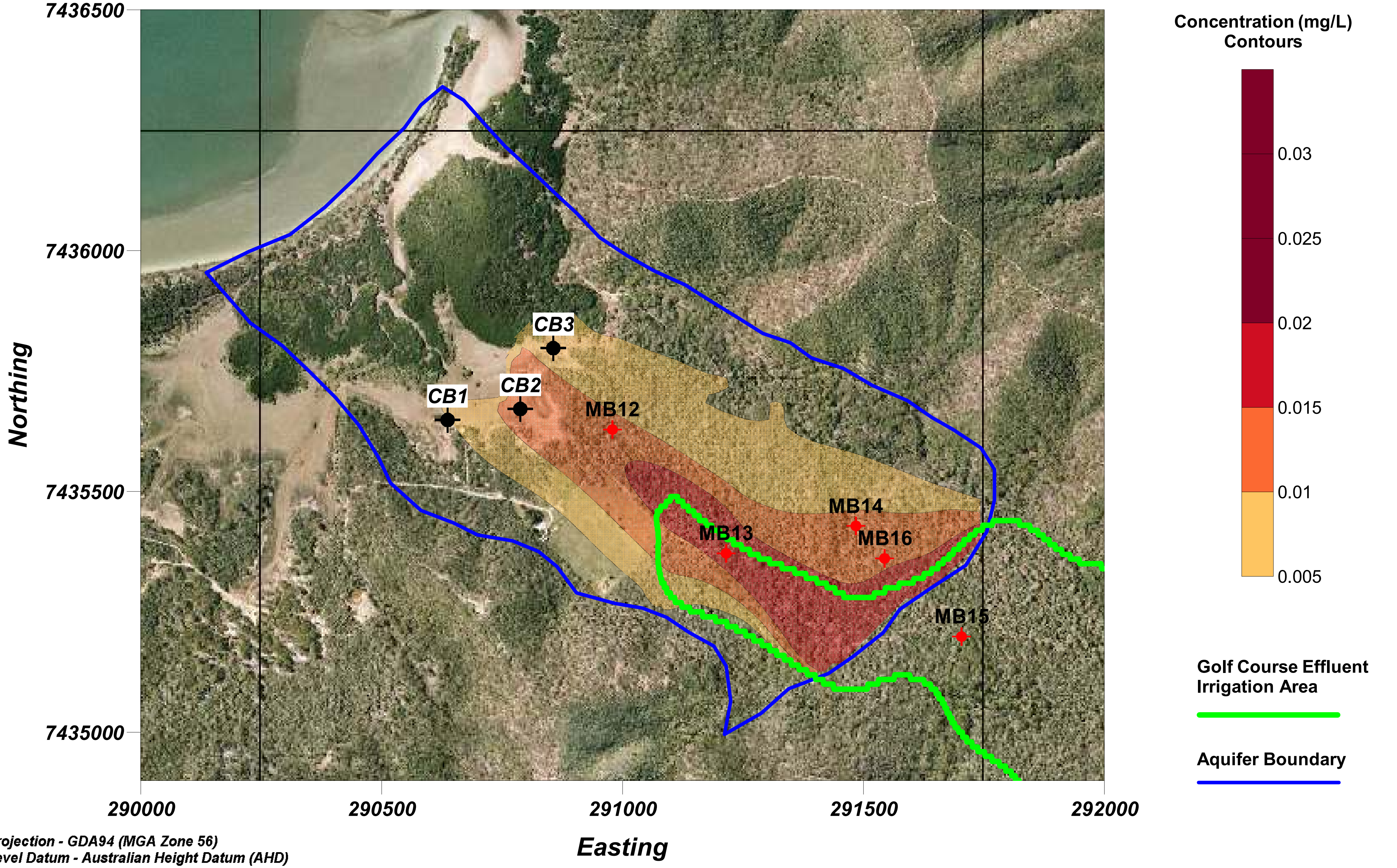
CLIENT: GKI Resorts Pty Ltd		
OFFICE: Brisbane	DRAWN BY: CD	
SCALE: 1:15 000	DATE: Sep 2011	

TITLE
Run 3 Simulated Nitrogen Levels (After 15 yrs)
Groundwater Nutrient Transport Modelling
Central Dune Sand Deposit, GKI Revitalisation Plan

N

PROJECT No:	74586.02
DRAWING No:	8
REVISION:	A



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Level Datum - Australian Height Datum (AHD)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd		TITLE Run 3 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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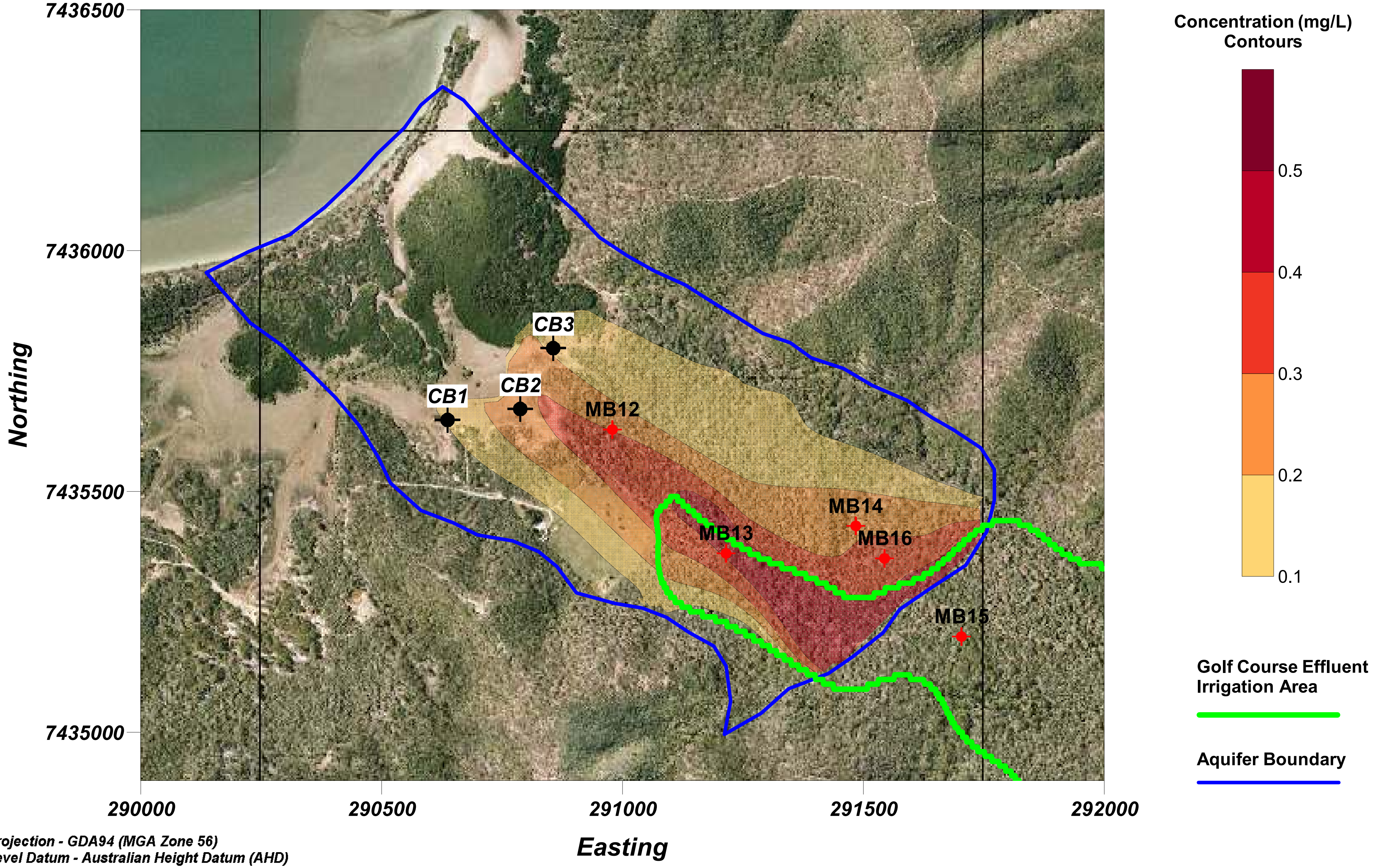

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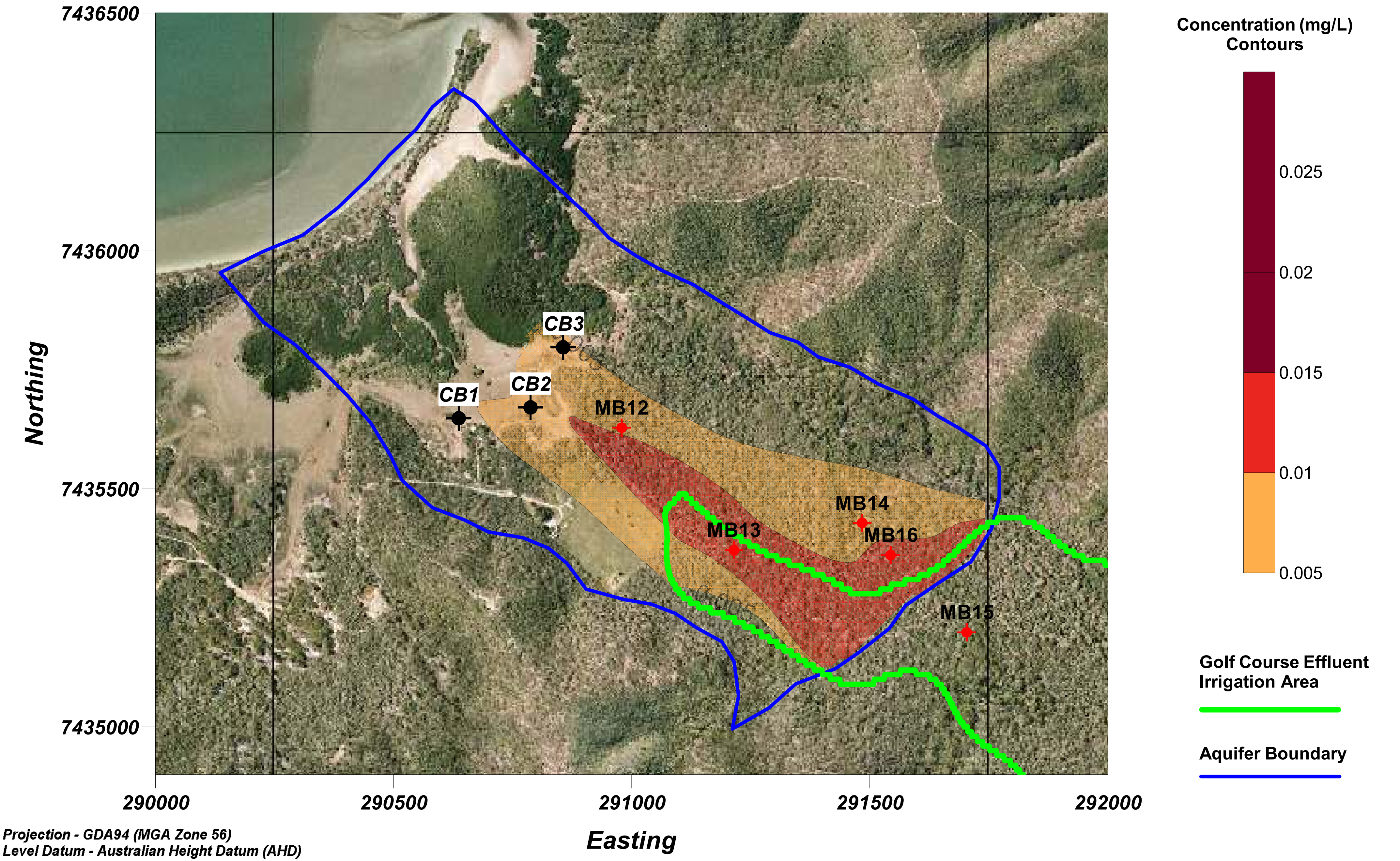
Level Datum - Australian Height Datum (AHD)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd	TITLE Run 4 Simulated Nitrogen Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
	OFFICE: Brisbane / DRAWN BY: CD		DRAWING No: 10
	SCALE: 1:15 000 / DATE: Sep 2011		REVISION: A



Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd		TITLE Run 4 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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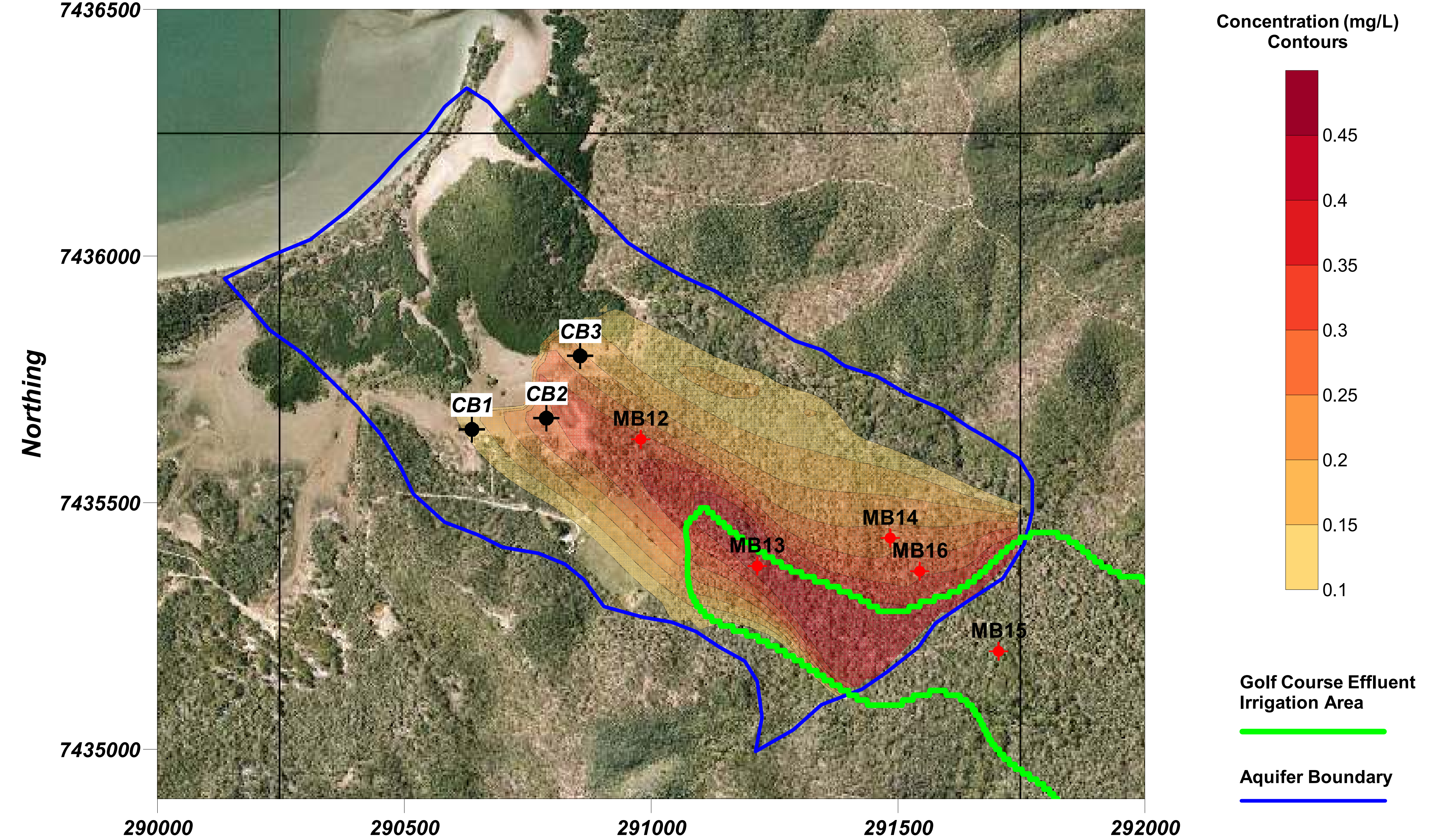
	SCALE: 1:15 000	DATE: Sep 2011		REVISION: A



Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

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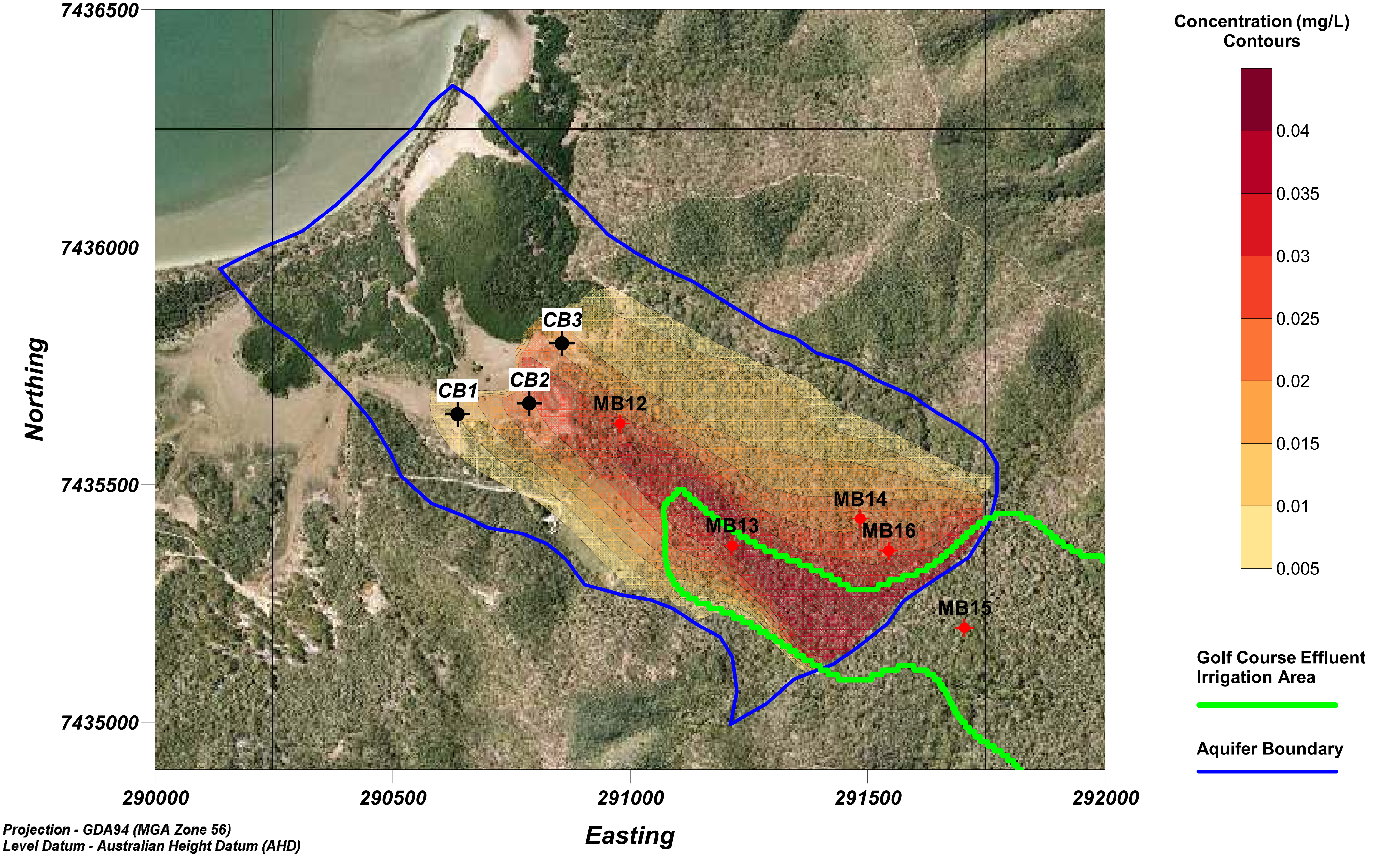

Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

Douglas Partners
Geotechnics | Environment | Groundwater

CLIENT: GKI Resorts Pty Ltd		TITLE: Run 5 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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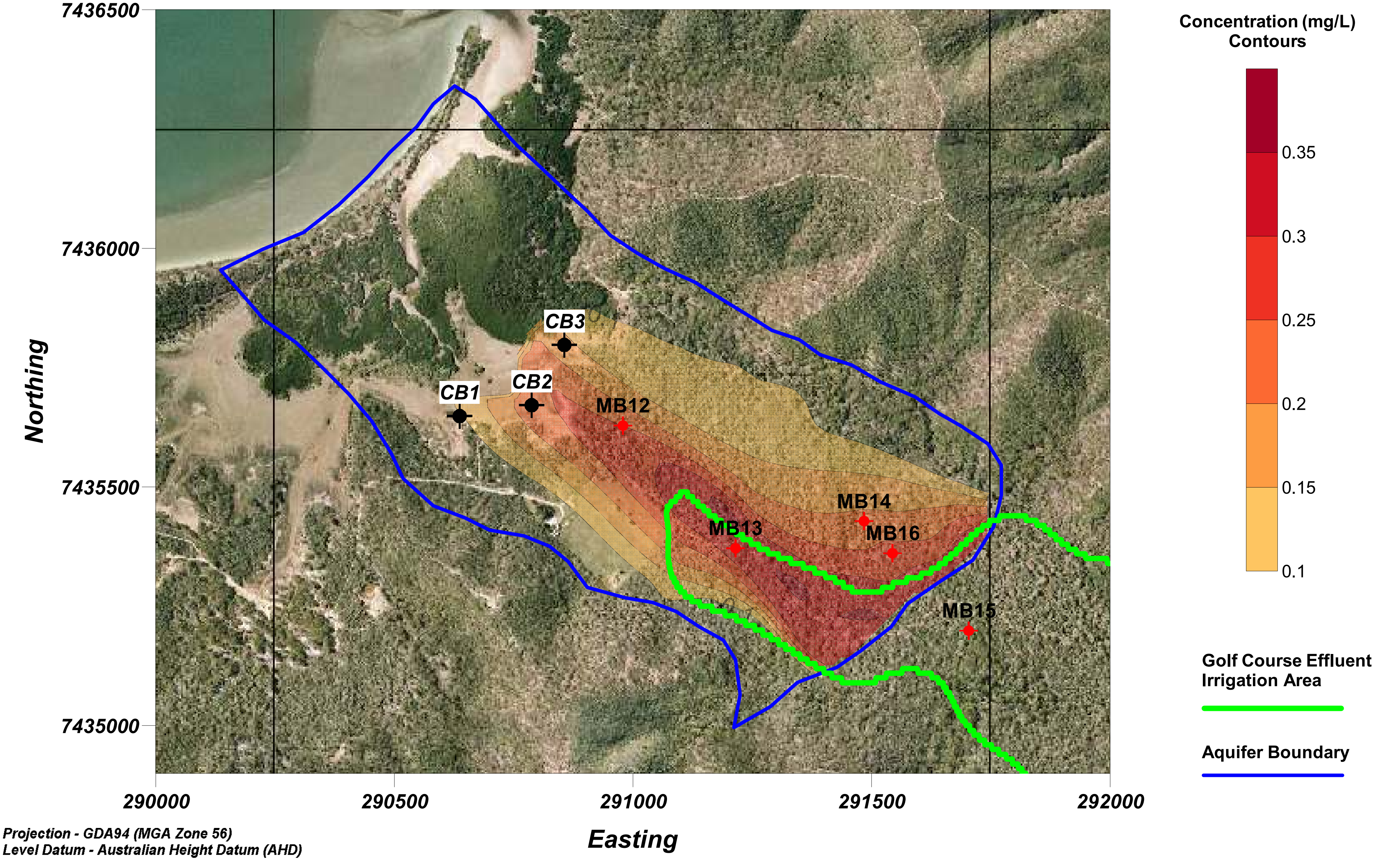


Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

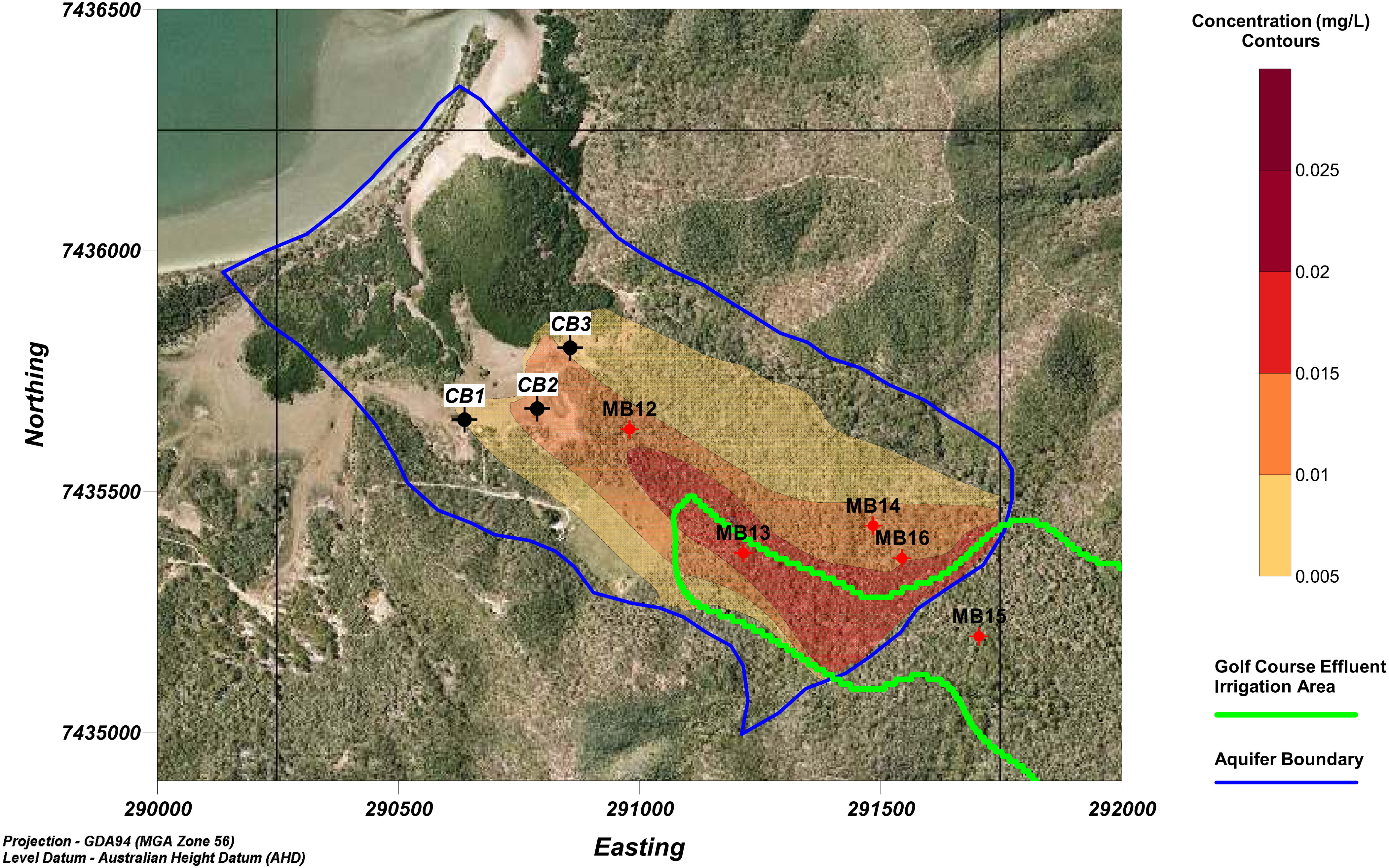
Douglas Partners
Geotechnics | Environment | Groundwater

CLIENT: GKI Resorts Pty Ltd		
OFFICE: Brisbane	DRAWN BY: CD	
SCALE: 1:15 000	DATE: Sep 2011	

TITLE
Run 6 Simulated Nitrogen Levels (After 15 yrs)
Groundwater Nutrient Transport Modelling
Central Dune Sand Deposit, GKI Revitalisation Plan

N

PROJECT No: 74586.02
DRAWING No: 14
REVISION: A



Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

Douglas Partners
Geotechnics | Environment | Groundwater

CLIENT: GKI Resorts Pty Ltd		TITLE: Run 6 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
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SCALE: 1:15 000	DATE: Sep 2011		REVISION: A

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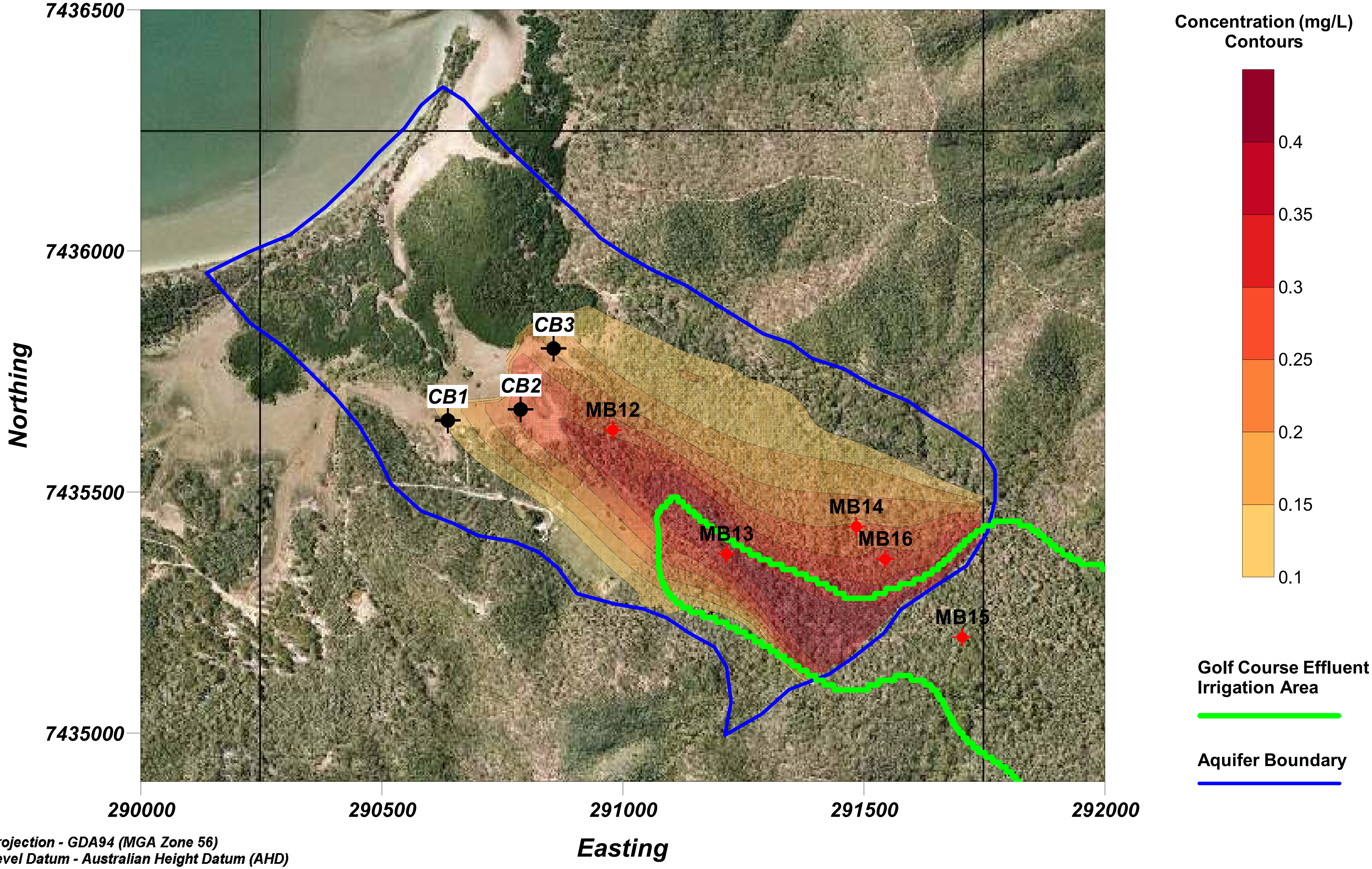

Projection - GDA94 (MGA Zone 56)
Level Datum - Australian Height Datum (AHD)

Douglas Partners Geotechnics / Environment / Groundwater	CLIENT: GKI Resorts Pty Ltd		TITLE Run 7 Simulated Nitrogen Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	N	PROJECT No: 74586.02
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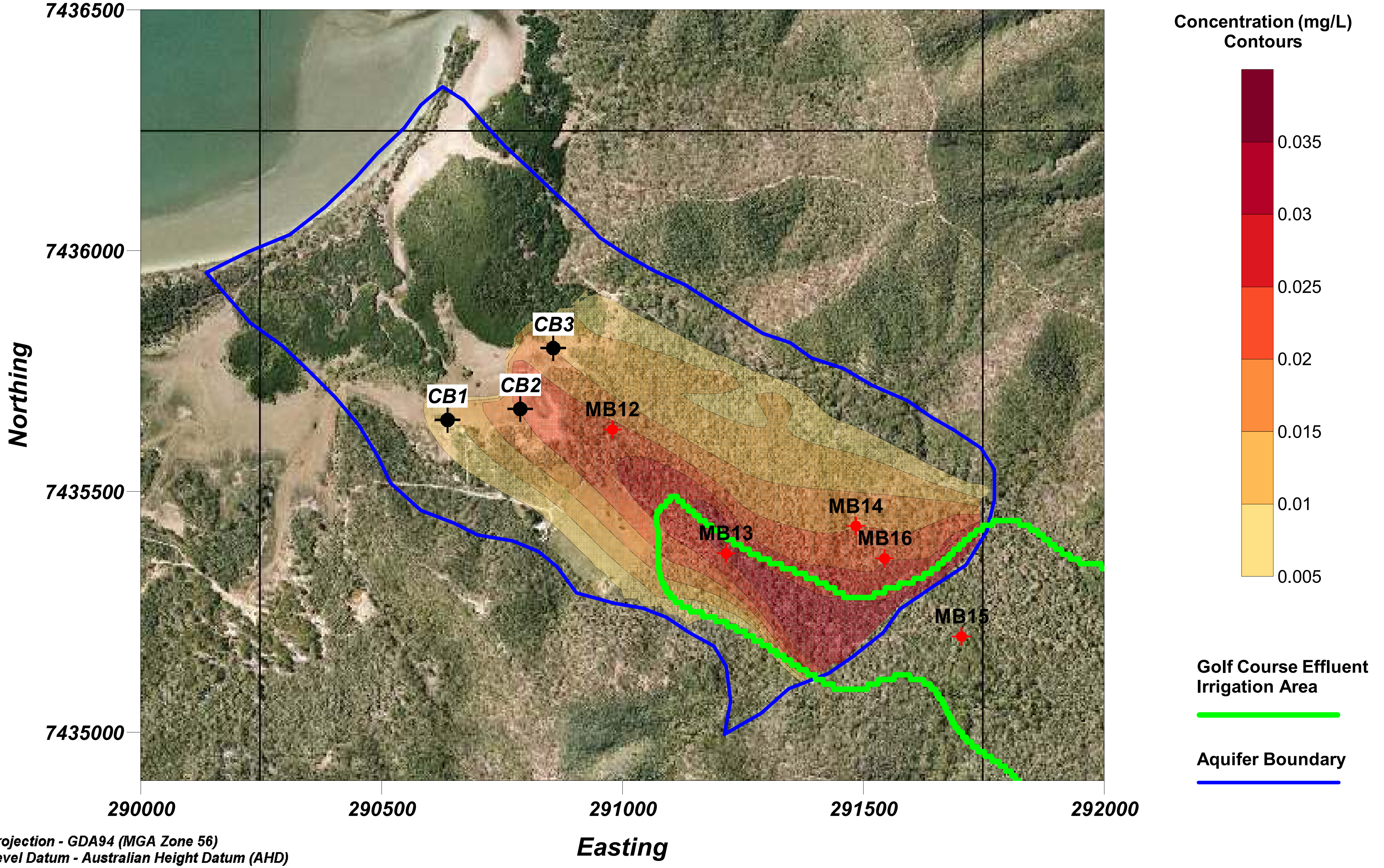

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Level Datum - Australian Height Datum (AHD)

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CLIENT: GKI Resorts Pty Ltd		TITLE: Run 7 Simulated Phosphorous Levels (After 15 yrs) Groundwater Nutrient Transport Modelling Central Dune Sand Deposit, GKI Revitalisation Plan	PROJECT No: 74586.02
OFFICE: Brisbane	DRAWN BY: CD		DRAWING No: 17
SCALE: 1:15 000	DATE: Sep 2011		REVISION: A

Appendix A

Appendix A – Explanatory Notes About This Report

About this Report

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Introduction

These notes have been provided to amplify DP's report in regard to classification methods, field procedures and the comments section. Not all are necessarily relevant to all reports.

DP's reports are based on information gained from limited subsurface excavations and sampling, supplemented by knowledge of local geology and experience. For this reason, they must be regarded as interpretive rather than factual documents, limited to some extent by the scope of information on which they rely.

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This report is the property of Douglas Partners Pty Ltd. The report may only be used for the purpose for which it was commissioned and in accordance with the Conditions of Engagement for the commission supplied at the time of proposal. Unauthorised use of this report in any form whatsoever is prohibited.

Borehole and Test Pit Logs

The borehole and test pit logs presented in this report are an engineering and/or geological interpretation of the subsurface conditions, and their reliability will depend to some extent on frequency of sampling and the method of drilling or excavation. Ideally, continuous undisturbed sampling or core drilling will provide the most reliable assessment, but this is not always practicable or possible to justify on economic grounds. In any case the boreholes and test pits represent only a very small sample of the total subsurface profile.

Interpretation of the information and its application to design and construction should therefore take into account the spacing of boreholes or pits, the frequency of sampling, and the possibility of other than 'straight line' variations between the test locations.

Groundwater

Where groundwater levels are measured in boreholes there are several potential problems, namely:

- In low permeability soils groundwater may enter the hole very slowly or perhaps not at all during the time the hole is left open;
- A localised, perched water table may lead to an erroneous indication of the true water table;
- Water table levels will vary from time to time with seasons or recent weather changes. They may not be the same at the time of construction as are indicated in the report; and
- The use of water or mud as a drilling fluid will mask any groundwater inflow. Water has to be blown out of the hole and drilling mud must first be washed out of the hole if water measurements are to be made.

More reliable measurements can be made by installing standpipes which are read at intervals over several days, or perhaps weeks for low permeability soils. Piezometers, sealed in a particular stratum, may be advisable in low permeability soils or where there may be interference from a perched water table.

Reports

The report has been prepared by qualified personnel, is based on the information obtained from field and laboratory testing, and has been undertaken to current engineering standards of interpretation and analysis. Where the report has been prepared for a specific design proposal, the information and interpretation may not be relevant if the design proposal is changed. If this happens, DP will be pleased to review the report and the sufficiency of the investigation work.

Every care is taken with the report as it relates to interpretation of subsurface conditions, discussion of geotechnical and environmental aspects, and recommendations or suggestions for design and construction. However, DP cannot always anticipate or assume responsibility for:

- Unexpected variations in ground conditions. The potential for this will depend partly on borehole or pit spacing and sampling frequency;
- Changes in policy or interpretations of policy by statutory authorities; or
- The actions of contractors responding to commercial pressures.

If these occur, DP will be pleased to assist with investigations or advice to resolve the matter.

About this Report

Site Anomalies

In the event that conditions encountered on site during construction appear to vary from those which were expected from the information contained in the report, DP requests that it be immediately notified. Most problems are much more readily resolved when conditions are exposed rather than at some later stage, well after the event.

Information for Contractual Purposes

Where information obtained from this report is provided for tendering purposes, it is recommended that all information, including the written report and discussion, be made available. In circumstances where the discussion or comments section is not relevant to the contractual situation, it may be appropriate to prepare a specially edited document. DP would be pleased to assist in this regard and/or to make additional report copies available for contract purposes at a nominal charge.

Site Inspection

The company will always be pleased to provide engineering inspection services for geotechnical and environmental aspects of work to which this report is related. This could range from a site visit to confirm that conditions exposed are as expected, to full time engineering presence on site.

Soil Descriptions

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Description and Classification Methods

The methods of description and classification of soils and rocks used in this report are based on Australian Standard AS 1726, Geotechnical Site Investigations Code. In general, the descriptions include strength or density, colour, structure, soil or rock type and inclusions.

Soil Types

Soil types are described according to the predominant particle size, qualified by the grading of other particles present:

Type	Particle size (mm)
Boulder	>200
Cobble	63 - 200
Gravel	2.36 - 63
Sand	0.075 - 2.36
Silt	0.002 - 0.075
Clay	<0.002

The sand and gravel sizes can be further subdivided as follows:

Type	Particle size (mm)
Coarse gravel	20 - 63
Medium gravel	6 - 20
Fine gravel	2.36 - 6
Coarse sand	0.6 - 2.36
Medium sand	0.2 - 0.6
Fine sand	0.075 - 0.2

The proportions of secondary constituents of soils are described as:

Term	Proportion	Example
And	Specify	Clay (60%) and Sand (40%)
Adjective	20 - 35%	Sandy Clay
Slightly	12 - 20%	Slightly Sandy Clay
With some	5 - 12%	Clay with some sand
With a trace of	0 - 5%	Clay with a trace of sand

Definitions of grading terms used are:

- Well graded - a good representation of all particle sizes
- Poorly graded - an excess or deficiency of particular sizes within the specified range
- Uniformly graded - an excess of a particular particle size
- Gap graded - a deficiency of a particular particle size with the range

Cohesive Soils

Cohesive soils, such as clays, are classified on the basis of undrained shear strength. The strength may be measured by laboratory testing, or estimated by field tests or engineering examination. The strength terms are defined as follows:

Description	Abbreviation	Undrained shear strength (kPa)
Very soft	vs	<12
Soft	s	12 - 25
Firm	f	25 - 50
Stiff	st	50 - 100
Very stiff	vst	100 - 200
Hard	h	>200

Cohesionless Soils

Cohesionless soils, such as clean sands, are classified on the basis of relative density, generally from the results of standard penetration tests (SPT), cone penetration tests (CPT) or dynamic penetrometers (PSP). The relative density terms are given below:

Relative Density	Abbreviation	SPT N value	CPT qc value (MPa)
Very loose	vl	<4	<2
Loose	l	4 - 10	2 -5
Medium dense	md	10 - 30	5 - 15
Dense	d	30 - 50	15 - 25
Very dense	vd	>50	>25

Soil Descriptions

Soil Origin

It is often difficult to accurately determine the origin of a soil. Soils can generally be classified as:

- Residual soil - derived from in-situ weathering of the underlying rock;
- Transported soils - formed somewhere else and transported by nature to the site; or
- Filling - moved by man.

Transported soils may be further subdivided into:

- Alluvium - river deposits
- Lacustrine - lake deposits
- Aeolian - wind deposits
- Littoral - beach deposits
- Estuarine - tidal river deposits
- Talus - scree or coarse colluvium
- Slopewash or Colluvium - transported downslope by gravity assisted by water. Often includes angular rock fragments and boulders.

Appendix B

Appendix B – Great Keppel Island Revitalisation Plans

GREAT KEPPEL ISLAND RESORT ~ REVITALISATION PLAN

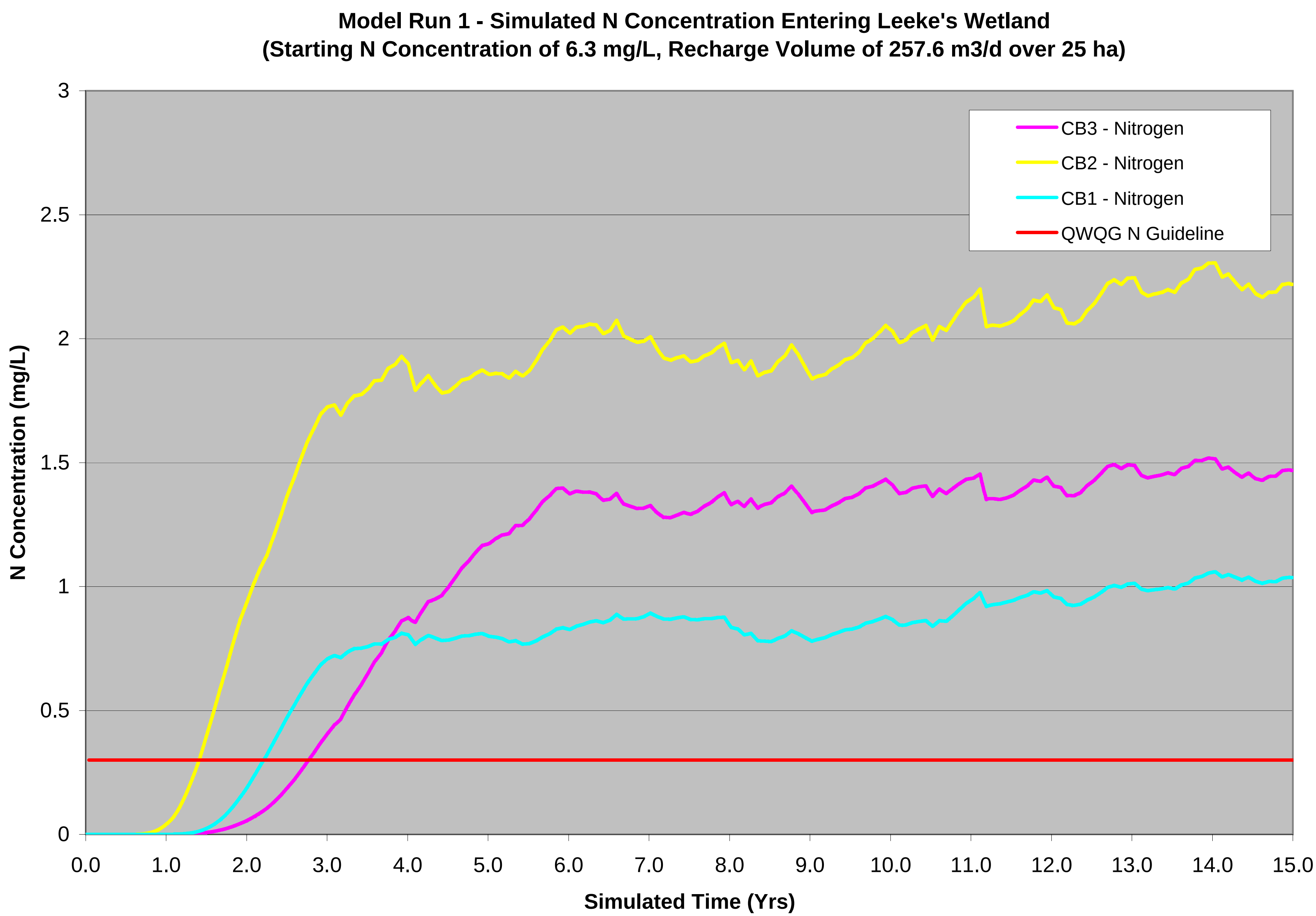
REVITALISATION PLAN 2011

PROJECT #: 093024

08 JULY 2011

Appendix C

Appendix C - Model Runs 1 to 4 N & P Concentration Versus Time Graphs



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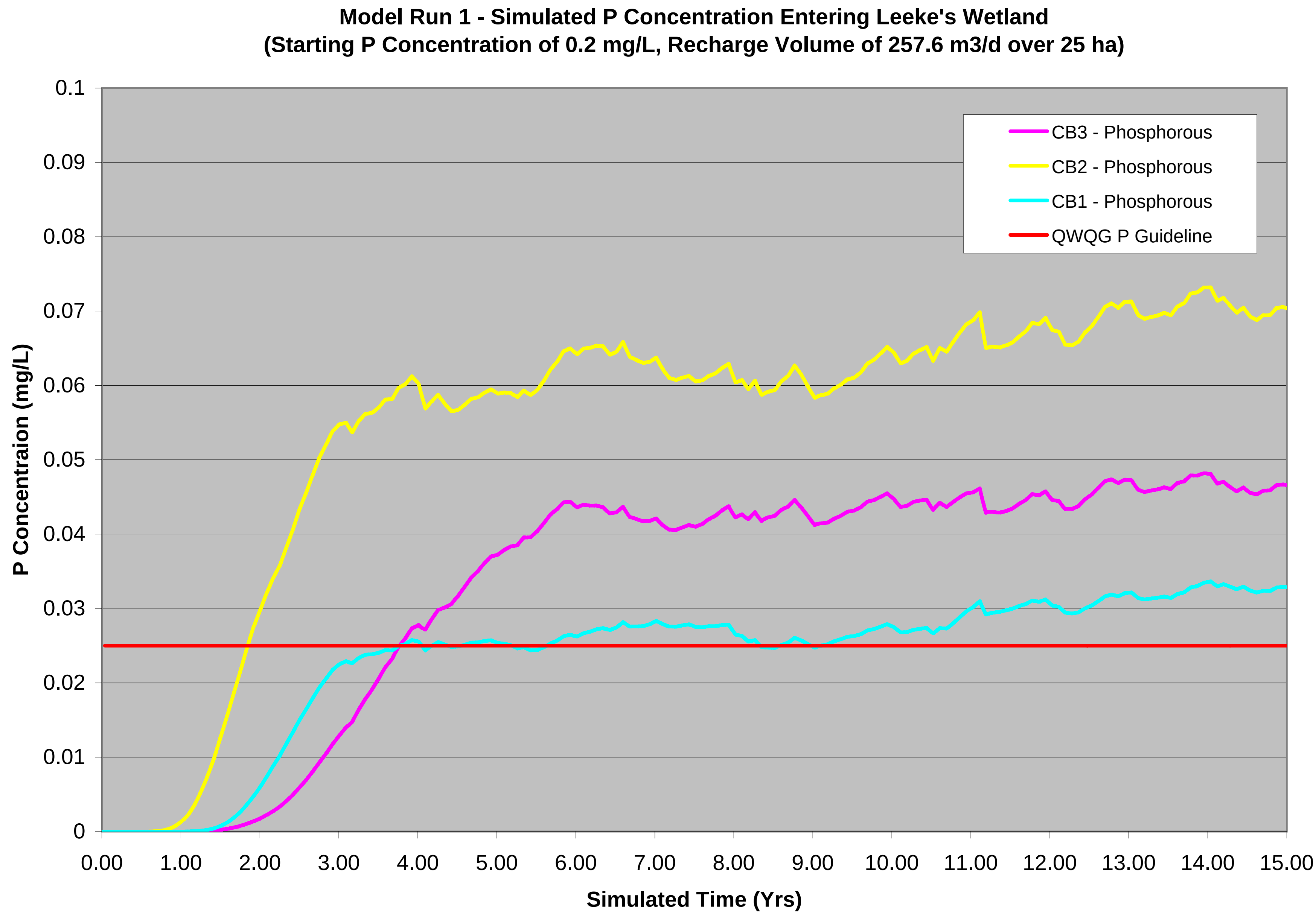

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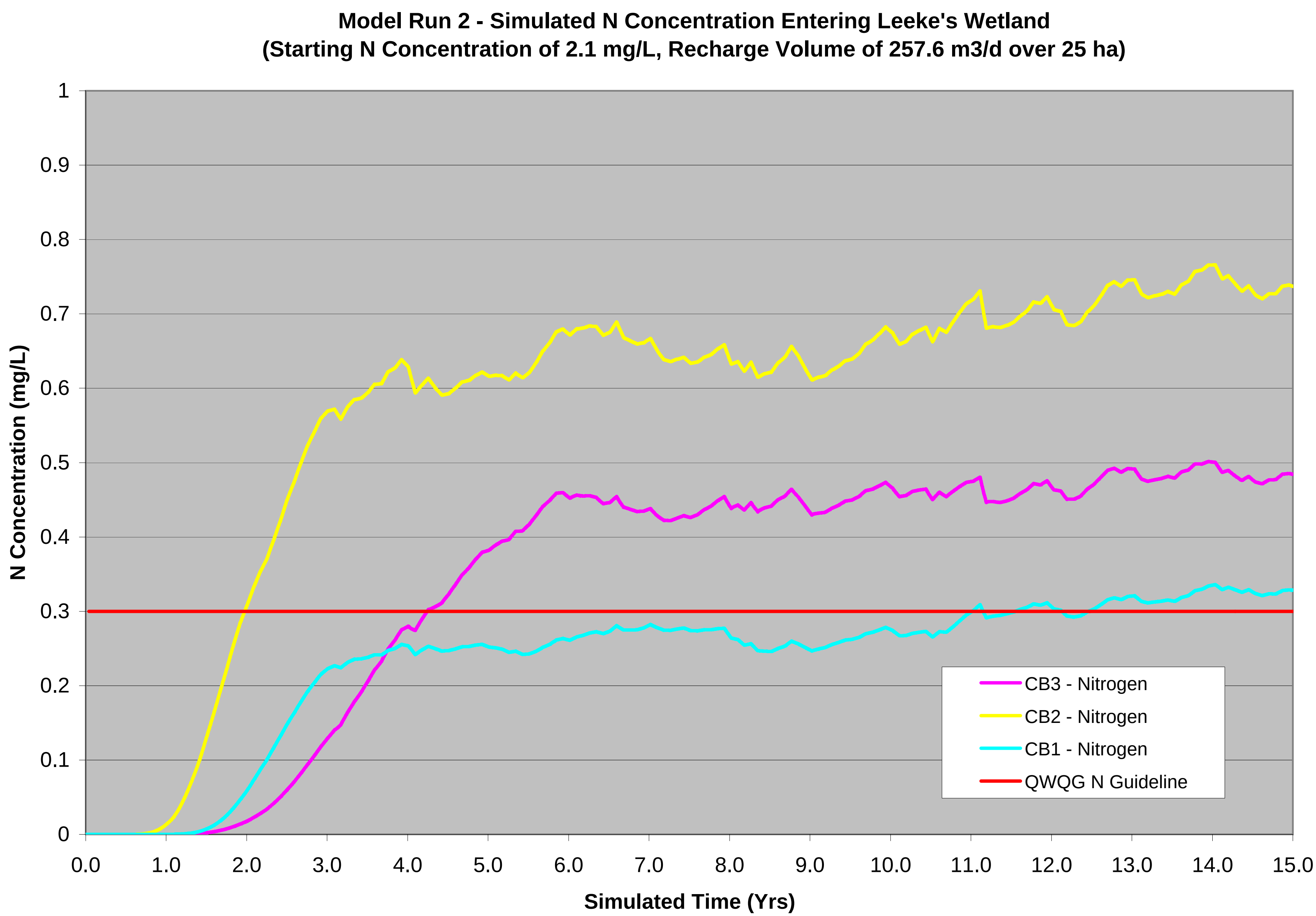

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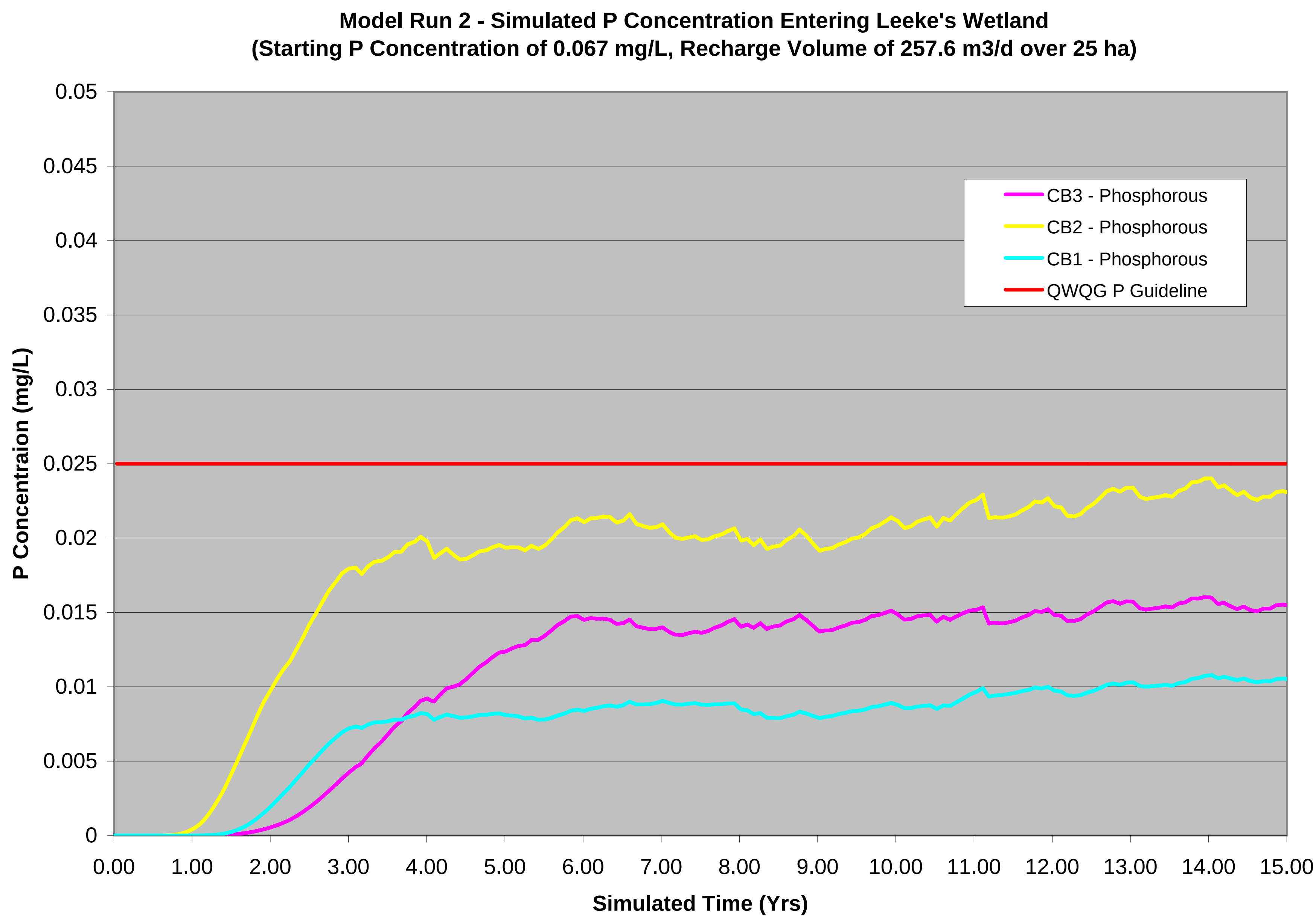

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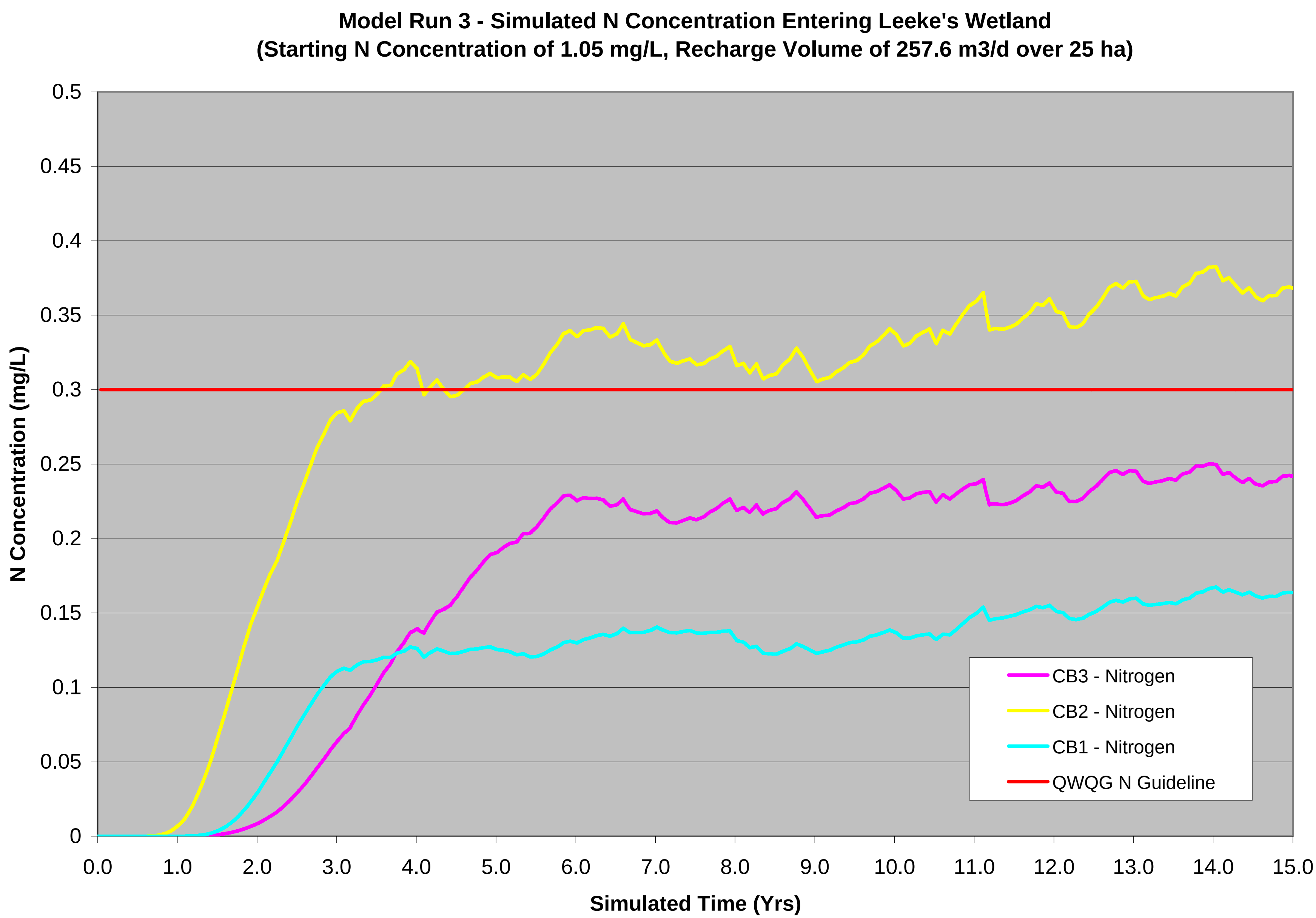

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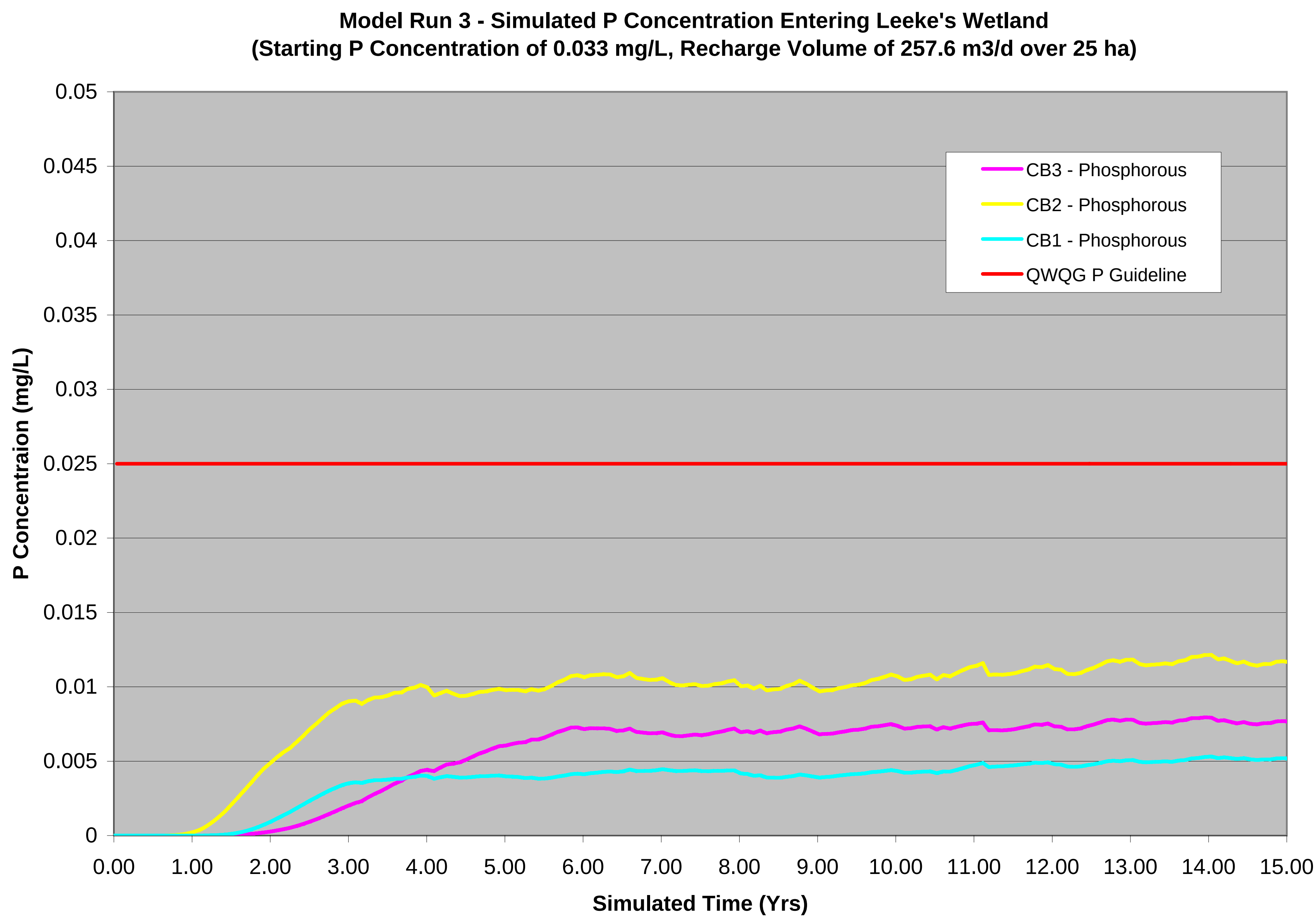

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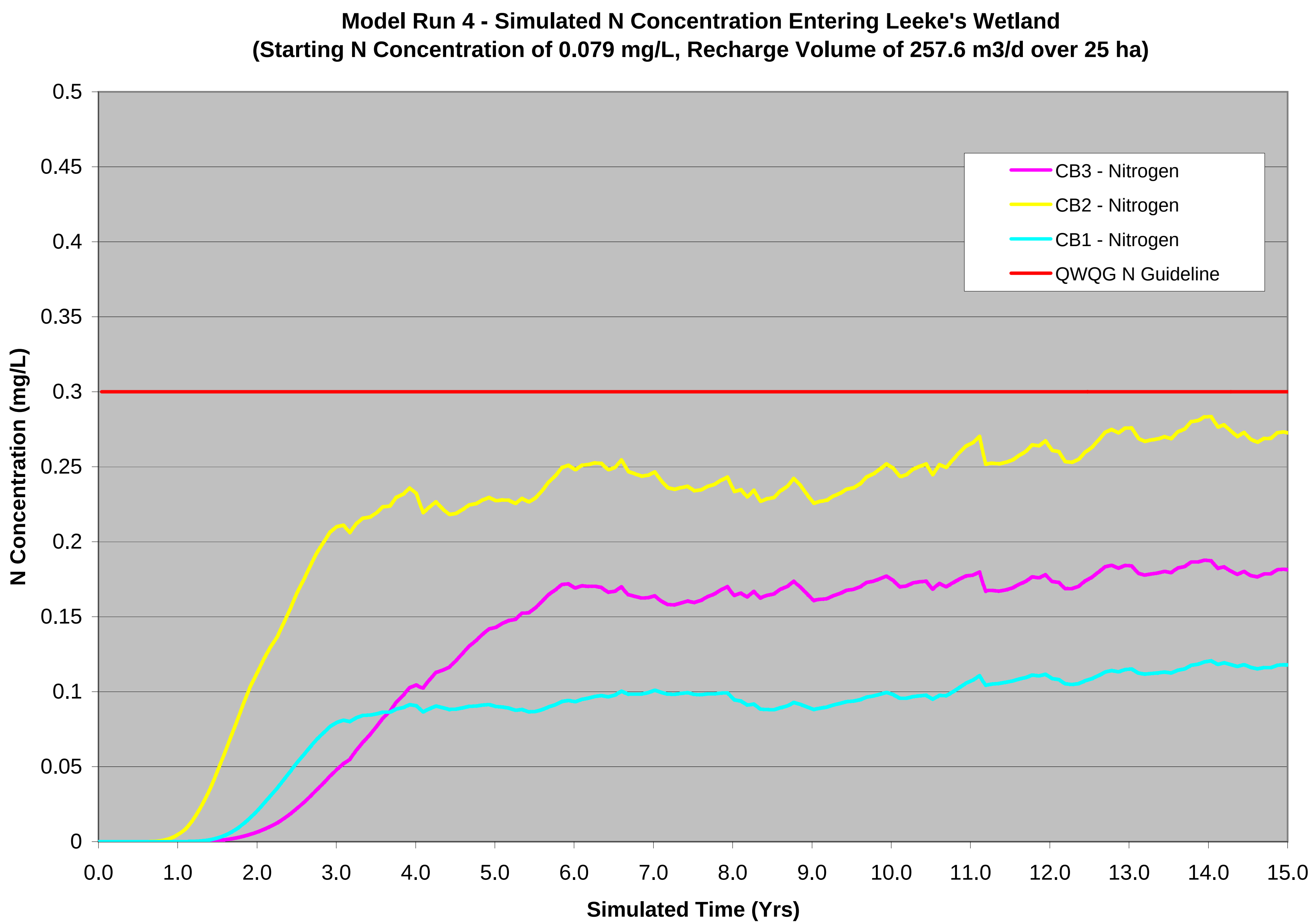

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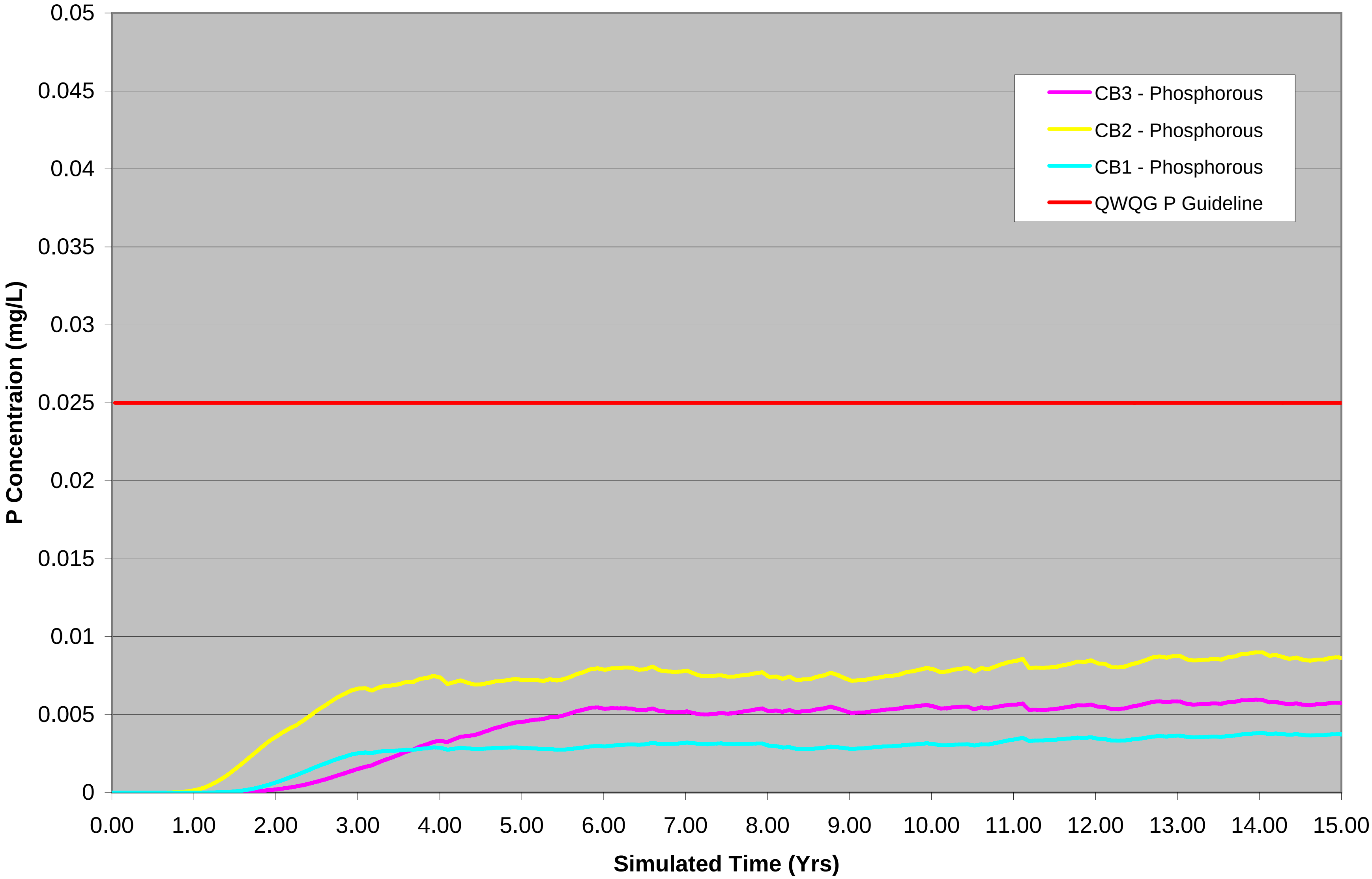
Model Run 4 - Simulated P Concentration Entering Leeke's Wetland
(Starting P Concentration of 0.025 mg/L, Recharge Volume of 257.6 m3/d over 25 ha)



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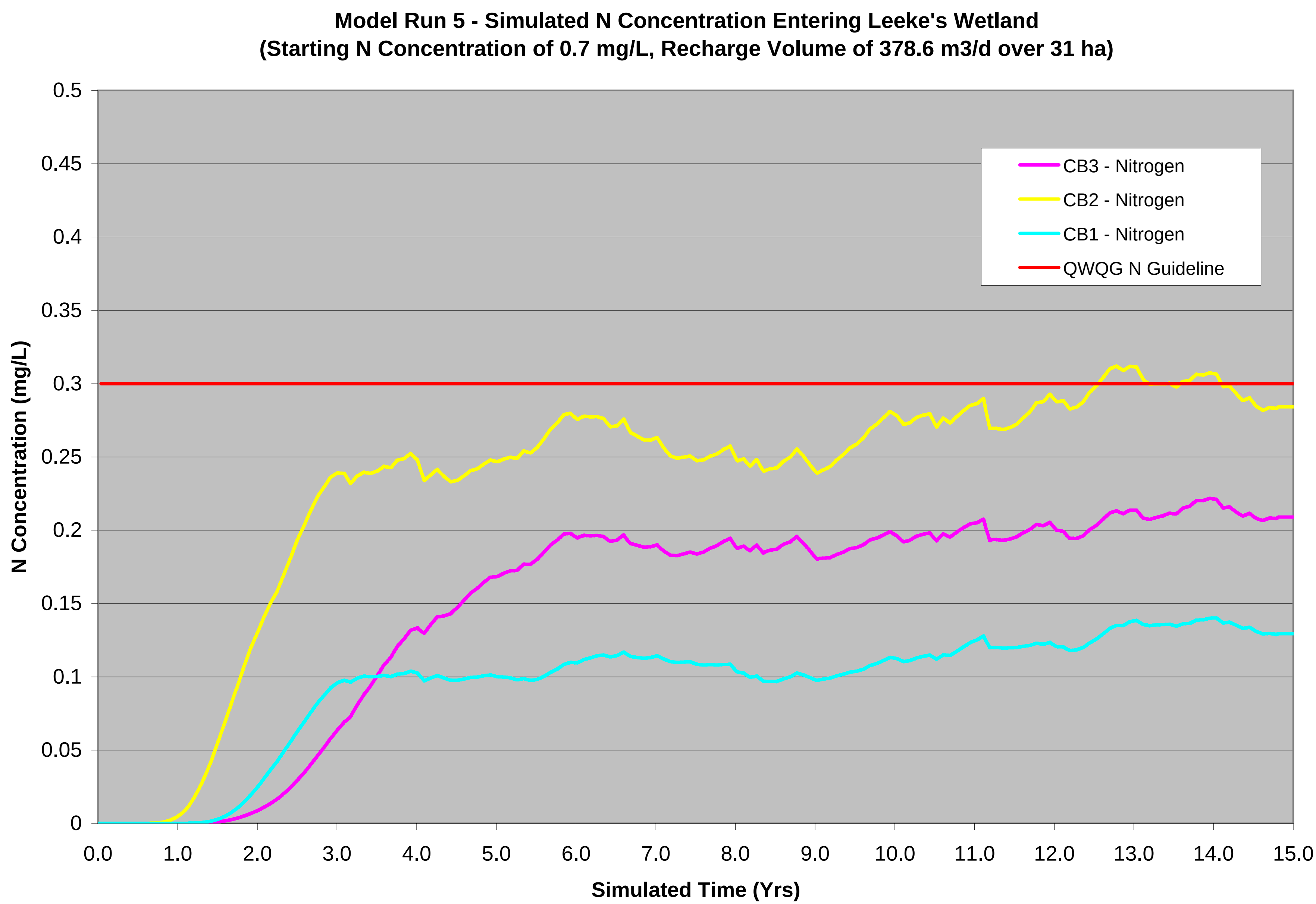
Appendix D

Appendix D - Model Runs 5 to 7 N & P Concentration Versus Time Graphs



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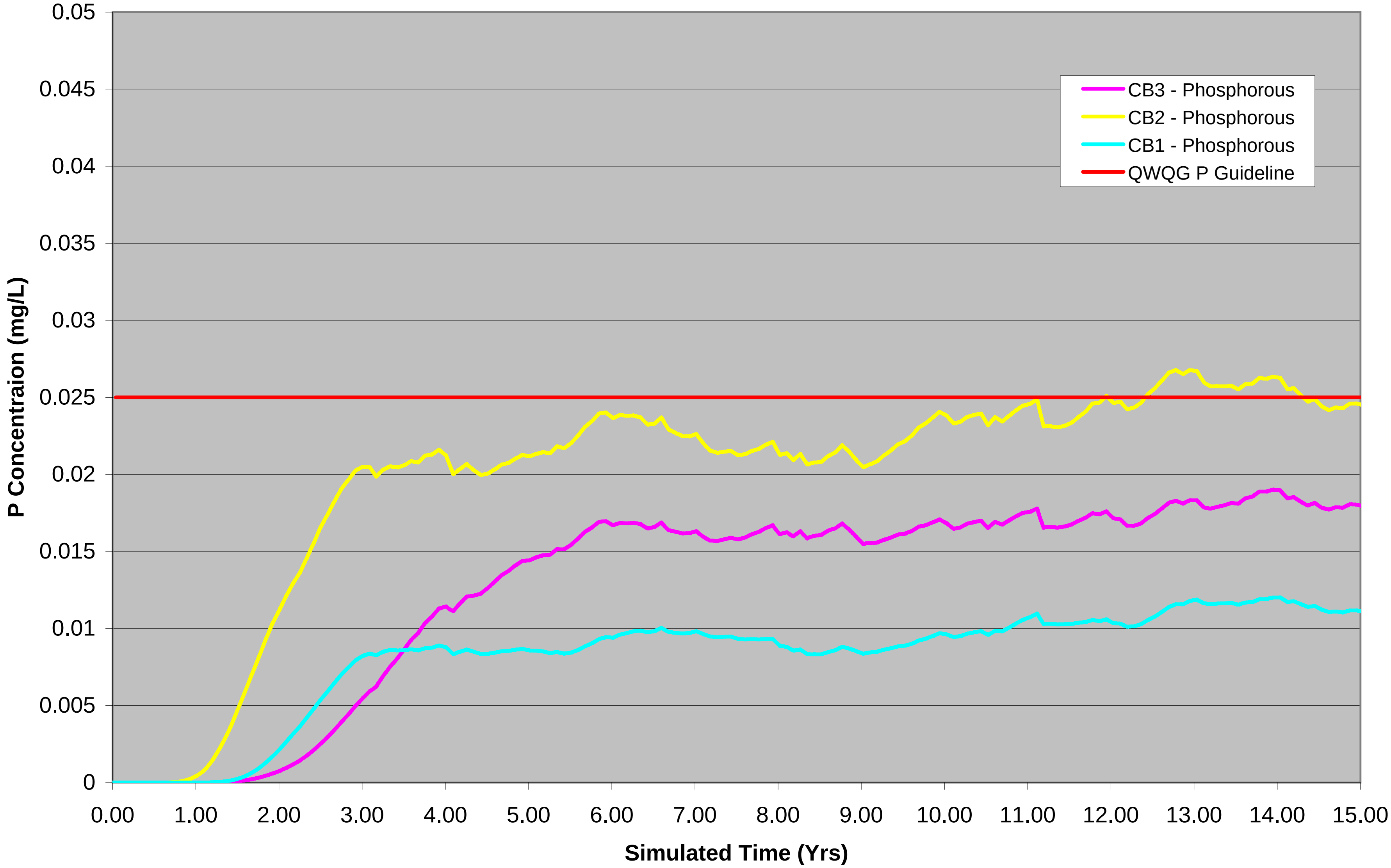
Model Run 5 - Simulated P Concentration Entering Leeke's Wetland
(Starting P Concentration of 0.06 mg/L, Recharge Volume of 378.6 m3/d over 31 ha)



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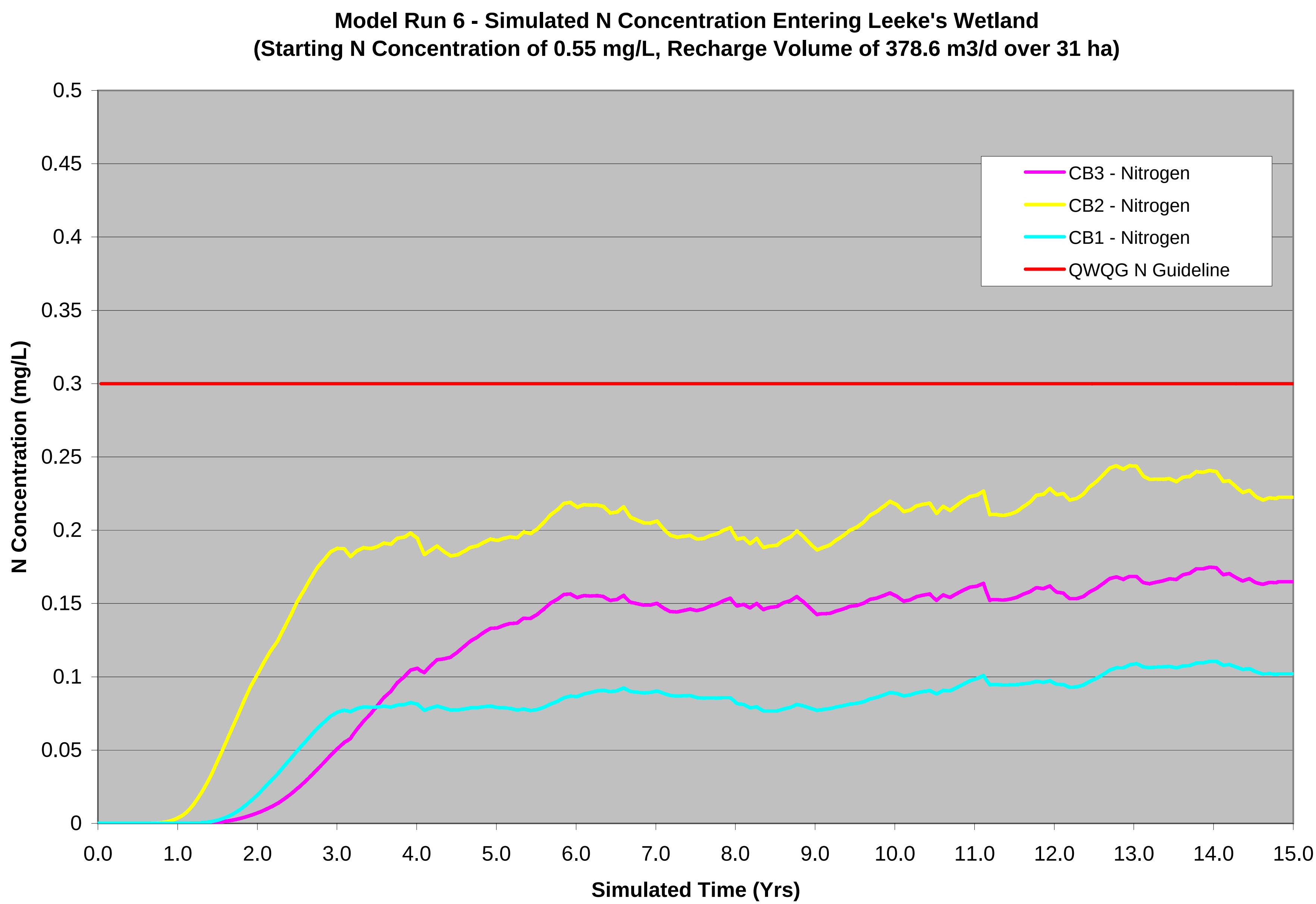

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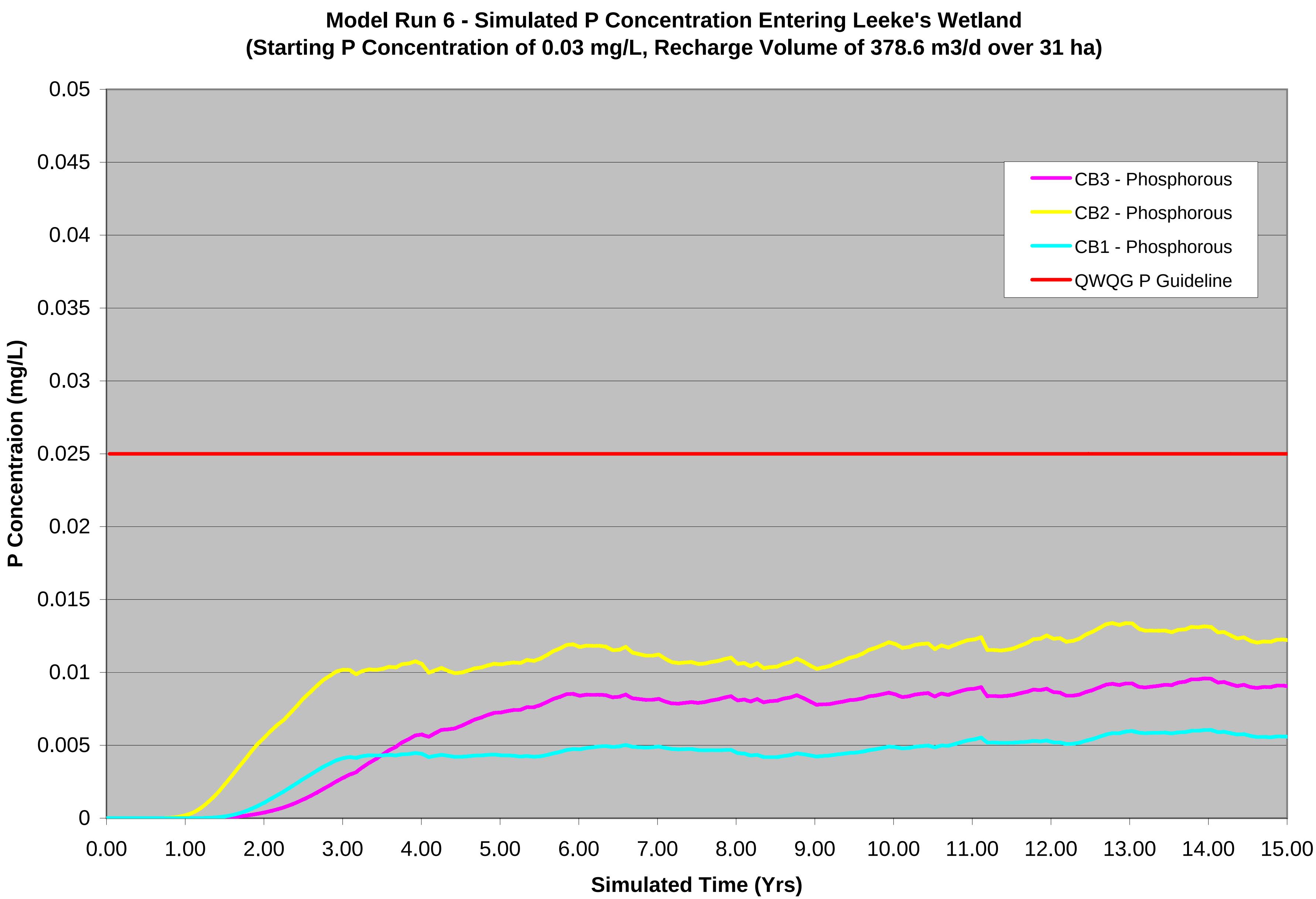
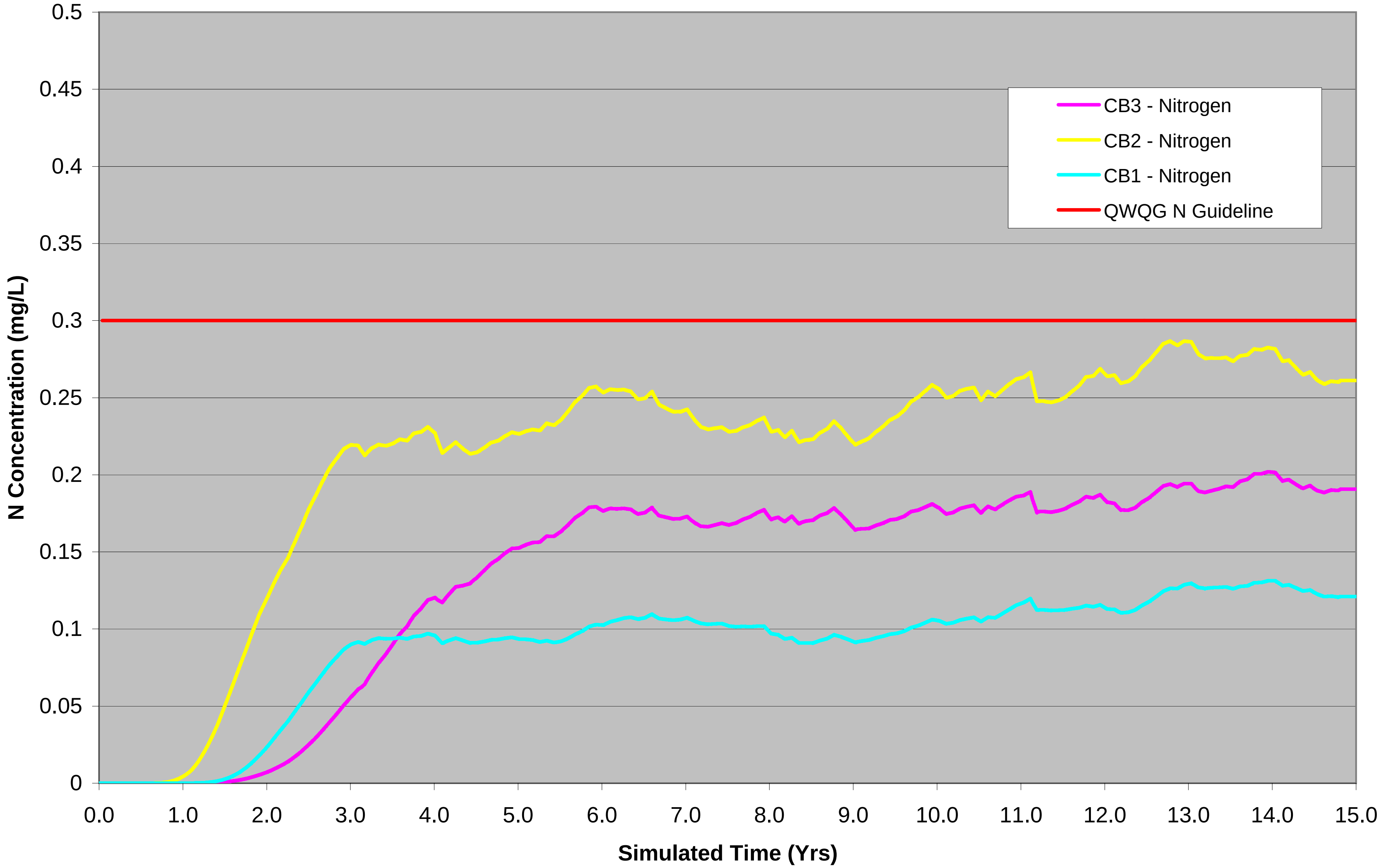


Douglas Partners
Geotechnics | Environment | Groundwater

Model Run 7 - Simulated N Concentration Entering Leeke's Wetland
(Starting N Concentration of 0.65 mg/L, Recharge Volume of 378.6 m3/d over 31 ha)



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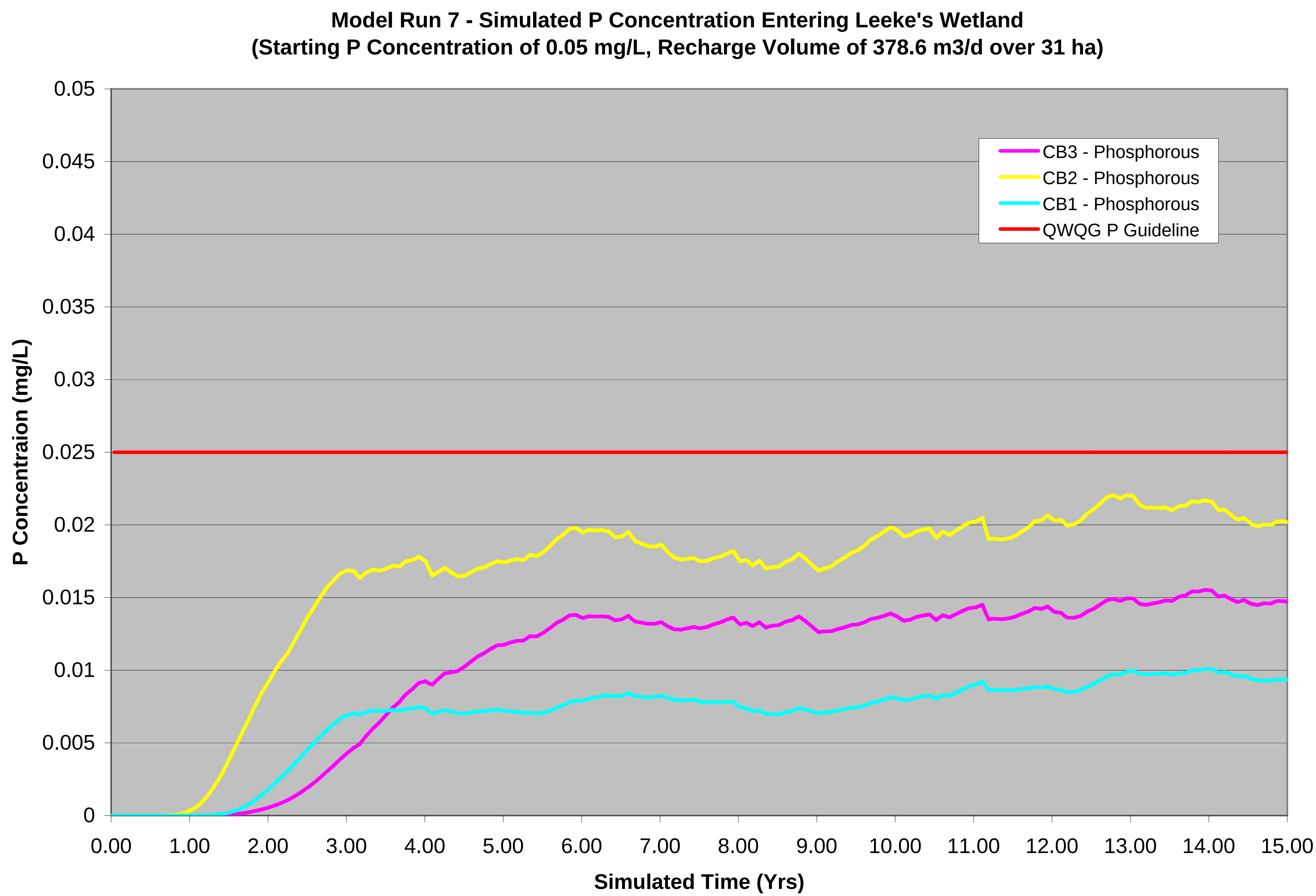

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