North Tuncurry Urban Release Area

Stormwater Management System Review

FINAL Review
Project No 4383853

12 July 2021

Prepared for NSW Department of Planning, Industry and Environment

The expert in **WATER ENVIRONMENTS**

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Final Report
Project No 43803853

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1 Summary

An independent technical review was undertaken of the following documents:

- North Tuncurry Development Project Integrated Water Cycle Management Strategy
- North Tuncurry Development Project Groundwater Modelling Technical Report
- North Tuncurry Development Project Water Assessment Addendum Report

It is the opinion of the reviewers that the concept design has been undertaken will the care and skill of a design engineer that usually undertakes surface and groundwater engineering design and that the level of detail in the reports is considered sufficient for a concept design as part of a re-zoning study. There are elements that would need further consideration and design work but these are generally completed during detailed design stages.

The review has identified several risks to successful project implementation. Acceptance and ownership of these risks should either be clearly stated within documentation or acceptance of these risks delayed until detailed design stages when more information can be made available.

A table of these identified key risks and proposed actions for resolution can be found in Table 1.1.

The proposed design addresses potential flooding impacts, under various scenarios, at the concept design level and the agreement to proceed could be given with minor amendments to the documentation. This agreement to proceed would not be final approval and final approval of a risk-based approach to water management at the site would not be given until such time as sufficient evidence can be produced (detailed design) but for the purposes of concept design the risks have been clearly articulated and it is reasonable from a flooding perspective for the proposal to progress with certain caveats.

Table 1.1 Summary of Key Risks Identified

Design Element	Comments	Risk	Designer's Mitigation	Residual Risk	Proposed Action to Resolve
Gravity Pipe	Operation of this gravity pipe is critical to the proposed operation of the surface water system	The gravity pipe will be prone to blockage over the life of the asset and may not function as intended – increased risk of flooding impacts	The designer has included mention of some elements (inlet and outlet configurations) and notes that the concept will be further investigated at detailed design but the burden of responsibility under the current concept will fall with the maintainer of this asset.	Regular and comprehensive maintenance of the gravity pipe concept must be undertaken in perpetuity. It is not clear who the responsible party will be and if appropriately skilled and funded resources will be available.	The final authority of this asset needs to be made clear and this party must accept responsibility. A workshop is proposed to be held with relevant parties to identify options to mitigate risks, improve the design and functionality of the gravity pipe solution and to ensure that parties are clear on responsibilities/commitments.
Basin Top Water Level	The design top water level of the basins appears to be fixed at 4.2m AHD - golf basin and 4.4m AHD - Northern basins for the 1% AEP event	The design top water level of the basins may be underestimated – higher incidence of flooding impacts	The designer has undertaken sensitivity analysis that builds a good understanding of changes to certain assumptions in the analysis	The wording of the addendum leads to the conclusion that these basin top water levels are fixed and that future design phases will not allow for a higher top water level.	The reports are amended to recognise the current basin top water levels are indicative/at the concept stage only. There are elements of the design analysis that may alter in future phases and the ability to alter design surface levels should be retained.
Groundwater Top Water Levels	Significant uncertainty in the groundwater model predictions	Groundwater levels are underestimated and the freeboard requirements will not be met over the life of the development – higher incidence of flooding impacts	Designer has noted localised groundwater 'mounding' will be examined at detailed design using a risk framework. Noted the uncertainty analysis was outside the scope of the designer's work.	Groundwater levels in the GWMR are adopted for development and future phases will not be revised or reconsidered at detailed design stages.	The reports are amended to recognise the current groundwater top water levels are indicative/at the concept stage only. Uncertainty analysis would be undertaken, minor adjustments to the numerical model and incorporation of more recent monitoring data can be allowed for during detailed design. A revision of the groundwater 1% AEP levels needs to be allowed for during future stages
Future Phases	There is limited information in these documents about the phasing and requirements of future work packages.	Relevant approving authorities may not be clear on where and when acceptance of the design occurs, if/when further review comments can be given during later project development and if acceptance is delayed past this proposal.	The designer has noted in several locations where items will be considered further in detailed design and may be revised. The design is considered to an appropriate level of detail for concept design but would not be sufficient for construction nor for a maintenance party to accept responsibility.	Revisions and design changes are likely (guaranteed) to occur during design progression but relevant parties may not have a clear understanding about where and at which point the approval is given to proceed.	A list of documents, at what point in the design progression they will be undertaken, which departments/authorities will be consulted and when approval must be sought could be provided (e.g. Surface Water Management Plan, Gravity Pipe Maintenance Plan, Evacuation Plan). This is not considered strictly necessary but would be informative.

It is the reviewer's opinion that the information provided within the documentation (ICWMS, GWMR and Addendum) is sufficient for concept design as part of a rezoning proposal. Furthermore, there is considered limited risk for amendment of the extent of the proposed rezoning during further design stages and any new information ascertained at detailed design can be incorporated into the development through alterations to the detailed design of drainage system, or raising surface and finished floor levels, to mitigate flood risk.

Prior to approval to proceed the following amendments are suggested within the documentation (ICWMS, GWMR and Addendum):

1. The Gravity Drainage system concept is noted that the final asset owner and maintainer is not yet identified, and the concept design does not have approval for adoption.
2. Progression of this gravity drainage outlet option requires a design and risk workshop with relevant parties. A commitment that this workshop is held at the earliest opportunity and prior to detailed design should be clearly stated. This workshop would need to commit to examining the cost-benefit of designing out risks and incorporate planned redundancy as far as practicable within the design. This would include examination raising flood planning levels to above the modelled top water levels under various scenarios to allow for flood protection in the event of system failure. The outcome must be in-principal approval from all parties for the final option to progress to detailed design.
3. Flood Planning Levels for the 1% AEP groundwater level and 1%AEP basin water level are amended to explicitly state these are indicative at the concept level only - It is anticipated that detailed design may yield differing top water levels and the design should allow for flexibility.
4. A commitment is made to deliver the following documentation (as a minimum) during detailed design stages. These documents will need to be approved prior to construction commencement and may be provided as part of a Development Application.
    a. Maintenance Plan which clearly articulates responsibility and contains costing of the proposed long-term maintenance regime.
    b. Construction Management Plan with consideration to groundwater constraints at the site.
    c. Water Management Plan which contains detailed surface water modelling including design events, application of conservative groundwater levels, uncertainty analysis and risk appropriate freeboards applied for determination of road surface levels and finished floor levels.
    d. Evacuation Plan which considers the evacuation procedures of the lowest lying areas, nearby developments, as well as regional evacuation plans.
    e. Detailed design drawings and reports with road and lot levels and details of infiltration and bioretention devices and consideration for any lot level interventions that may be required for subdivision.
5. A commitment is made to deliver future phases of design with consideration of, and adherence to, the updated flood prone land package (https://www.planningportal.nsw.gov.au/flood-prone-land-package).

2 Scope and Objectives

The scope of this this report was to review the documents listed in Table 2.1.

Table 2.1 Documents for Review

Document Ref. No.	Revision No.	Title/Description	Referred to in this document as:
30011196	5	North Tuncurry Development Project Integrated Water Cycle Management Strategy, SMEC (April 2019)	IWCMS
30011196	B	North Tuncurry Development Project Groundwater Modelling Technical Report, SMEC (2014)	GWMR
H200596 RP#5	V4 Final	North Tuncurry Development Project Water Assessment Addendum Report (EMM, 2021)	Addendum

These documents have been reviewed with consideration of concurrent events, probable maximum flood extent, evacuation assessment and surface/groundwater modelling:

a) The flood mitigation approach and proposed infrastructure which includes internal drainage, open basins and a gravity drainage system to the Wallis Lake entrance channel. The review considers system functionality, constructability and long-term maintenance risks, at an appropriate level of detail for a rezoning study.
b) The modelling undertaken to inform design flood levels and assessment of risks and impacts.
c) The potential for the project to result in offsite flood impacts.
d) The potential impacts of flooding in the event of system failure

No other documents or models were reviewed as part of the scope of this assessment. As no models were provided the 'review' was limited to the information that is contained within the reports only.

Reviews are targeted towards groundwater and surface water management strategies, conveyance, outfalls, constructability, maintainability and flooding risks. Review of sewer, potable water, reticulation and water quality elements was not undertaken.

In the interest of not reviewing design elements that may have been addressed as part of the Integrated Water Cycle Management Strategy (IWCMS) Addendum (North Tuncurry Development Project Water assessment addendum report (EMM, 2021)), the addendum document has been reviewed as a priority and supplementary information from the other reports utilised where appropriate. The IWCMS Addendum is hereon referred to as Addendum.

Review comments are limited to risks that DHI believe should be considered further prior to acceptance of the re-zoning study.

3 Design Development

The following table summarises the expected design definition and maturity level expected for the various stages of design and project development:

Table 3.1 Design Definition and Maturity Level

Design Definition	Maturity Level (expressed as % of complete definition)	Expected Cost Accuracy Level	Indicative Components
Preliminary Design	1 - 15%	-30% to +50%	Sufficient for design as part of a rezoning study. e.g. Strategic documents and high-level proof of concept designs.
Concept Design	10 – 40%	-20% to +30%	
Detailed Design (early)	30 – 60%	-15% to +20%	Included as part of a DA process but may not yet have final detail for approval of some elements. Workshop for optioneering of critical/high risk/high cost elements e.g. gravity drainage system. Consultation with, and Approval 'in-principal' sought from, relevant authorities.
Detailed Design (latter)	60 – 80%	-10% to +15%	Sufficient for design as part of a Development Application Approved option progressed through detailed design. Final documents available for review and approval by Council e.g. Maintenance Plan, Construction Management Plan etc.
For Construction	80 – 100%	-5% to +10%	Revision and approval from Detailed Design. Final product is documentation required for construction.

4 Regulatory Context

The Department of Planning, Industry and Environment has finalised a new flood-prone land package (https://www.planningportal.nsw.gov.au/flood-prone-land-package), which provides advice to councils on considering flooding in land-use planning. The finalised package will commence on 14 July 2021.

The revised flood-prone land package allows a more contemporary approach to better manage flood risk beyond the 1% AEP, including building greater resilience to the effects of climate change. The update package addresses the key concerns over the safety of people, the management of potential damage to property and infrastructure, and the management of the cumulative impacts of development, particularly on evacuation capacity

It is noted that information contained within this package aligns closely with the Floodplain Development Manual (2005) which has been available for several years and is considered good practice and is a standard requirement in many developments.

Of particular relevance is the following text:

Section 9.1(2) of the Environmental Planning and Assessment Act 1979

A planning proposal must not contain provisions that:

6 (g) are likely to result in a significantly increased requirement for government spending on emergency management services, and flood mitigation and emergency response measures, which can include but not limited to road infrastructure, flood mitigation infrastructure and utilities

5 Surface Water

5.1 Gravity Drainage Pipe

The addendum provides a revised “proof-of-concept” (Figure 2.1 Gravity drain concept page 4) surcharged pit outfall arrangement. Proof of concept is considered to be to an appropriate level of detail for a re-zoning study and the solution presented could be accepted if the risks may be accepted by the appropriate entities.

There are several risks that should be considered prior to approving the outfall arrangement for construction. These risks have been considered to an appropriate level of skill and care to be expected of the design engineer at the concept stage. Risks have been mitigated where possible but the residual risks (and costs) will be transferred to the construction, owner and maintenance entities.

5.1.1 Constructability

The limited gradient, 2km length of pipe, presence of groundwater, aeolian sands and potentially aggressive soil conditions, all present risks and/or costs for construction of this asset by an appropriately qualified contractor.

5.1.2 Operations

There is limited discussion on groundwater and seawater ingress into the pipe system. This is likely to occur over the life of the asset. The potential presence of acid sulfate soils would influence the longer-term risks related to this asset. Detailed design will need to include consideration of the behaviour of the water in the pipe. It will be a mixture of seawater, groundwater and freshwater. There is the potential for odour related issues at the surcharge point or other considerations related to water quality.

Figure 2.1 Gravity drain concept has a conceptual error with the sea-level rise applied of 0.91m. The figure shows the base of the tidal flap -0.8m AHD (approx.) (Indian Spring Low Water ISLW). With the sea level rise of 0.91m, this becomes 0.11m AHD. This is not reflected in the flushing outlet – essentially meaning that if constructed as indicated the flushing outlet will be permanently submerged in the longer term and may not act as intended. This would come with operations and maintenance issues and would need to be considered in detailed design. Raising this flushing outlet to have a base of 0.11m AHD such that it allows manual opening at low tide will further reduce the hydraulic grade of the pipe, below the current <0.2% indicated. It is noted that the 0.91m sea level rise applied is at the conservative end of the 0.18m-0.91m range suggested by IPCC, CSIRO and NSW DECC.

5.1.3 Maintainability

There is a risk of blockage in the gravity pipe which is exacerbated by the length of pipe, proposed gradient, surcharged outlet, and limits of construction tolerances. This has clearly been considered by the Designer through sensitivity analysis and the implementation of a surcharged pit outfall and proposed maintenance regime configuration - with a length of pipe available for debris/sediment and a maintenance arrangement. The Designer has also included consideration of self-cleansing velocities.

Sensitivity has been undertaken on the performance of the gravity drain (Table 3.4). This is good practice and Scenario 1 indicates that with only 50% functionality, road design surface levels and minimum habitable floor levels (minus the 500mm freeboard criterion) are only exceeded by 20mm. However, Scenario 5 clearly shows that with conservative initial conditions and a 100% blocked gravity drain then the basin top water level would be above the habitable floor level. This highlights the critical need for the gravity drain to be fully functional and properly maintained.

5.1.4 Risk Mitigation

It is considered that the concept design is at an appropriate level of detail for a re-zoning proposal (IWCMS), with the Addendum, but that the “next-steps” for resolution of outstanding issues between the concept level of detail and ensuring that the asset (and related development) is built to the appropriate level of service, and risks managed, is not well clearly communicated. Risks are considered in Table 2.3 of the Addendum but the pathway to managing these and the agency responsible for accepting responsibility and the residual risk is not clear. While this information may not necessarily need be contained within the Addendum, or associated reports, these risks need to be accepted by the appropriate agency and funding available for management of these risks. It is suggested that to ensure the risks of the outfall are appropriately managed a workshop is held between relevant parties. This would include (at a minimum):

a) Design Engineer
b) Independent Verifier (where appropriate)
c) Contractor(s) Representative
d) Final Asset Owner
e) Asset Maintainer
f) Local Council
g) Landcom

There are potentially other engineering solutions that may be more cost-benefit-risk appropriate when considering the risk profile of the various parties involved and the proposed cost/funding/responsibility arrangements. There is even the possibility that even after mitigation, any residual risks cannot be accepted. This may represent a fatal flaw in the implementation of the project (rather than the engineering design). Other configurations (pump out based system) should be explored with the final asset owner and maintainer as the CAPEX/OPEX/risk trade-off may mean this is a preferred option. Options have been considered by the Designer (rising mains, pumping, alternate gravity alignments, alternate materials etc) and there are potentially further options to be considered (e.g. ovoid/egg shaped pipe, tideflex/duckbill outfall etc) but until input is sought on the validity of these alternate options and the cost-benefit-risk ascertained then the ‘proof-of-concept’ cannot be adopted for construction. This is recognised by the Designer and proposed to be examined in detailed design.

5.1.5 Way Forward

Two potential avenues for resolution:

a) Accept with Caveats

As the re-zoning study is only at the concept level of detail, the proposal could be accepted, with the inclusion of necessary caveats, to ensure that the appropriate level of service is attained, and risks accepted to be managed during future detailed design phases. This should include ‘optioneering’ of the outfall configuration, with input by relevant parties. The caveats could include reference to design criteria to be achieved (1% AEP etc), documents to be provided (surface water flood risk and design reports/drawings), listing of deviations of engineering design standards and the authorities (DPIE, Council etc) that are required to endorse and accept residual risks, prior to construction.

b) Reject with Proposed Resolution

As the re-zoning study is only at the concept level of detail the risks/issues identified above can only be considered and resolved during future phases of design. There is the option to reject the proposal without more detail being provided to resolve these issues. While the level of detail is considered sufficient for concept design as part of a re-zoning proposal, the ability to reject is retained. If the proposal is rejected it is suggested that the proposed resolution is clearly indicated to the Designer (e.g.. ‘optioneering’ workshop with outcomes being accepted by all parties).

5.2 Design Storm Analysis

The Addendum provides information regarding the model and approach, rainfall inputs, hydrology assumptions, results and sensitivity analysis. While the modelling approach is generally consistent with common engineering design methods there are some assumptions that should be considered from a risk-based approach.

5.2.1 Antecedent Conditions

Median basin groundwater levels have been adopted for design storm analysis (1.8m).

Temporal Ensemble Pattern 6 has been used by the Designer (though the selection process of this pattern is slightly unclear and may not be the temporal pattern with representative/average impact) for the 144-hour storm, which was identified as critical. Temporal pattern 6 for this location has approximately 25% of rainfall landing in the first 3 days of the event before the peak of the event is during Day 4. Plate 5-10 - Empirical Groundwater Model Results [1963 Event] indicates that the catchment is responds quickly to rainfall events with peaks in groundwater and basin levels within a day or two after rainfall. It also shows the basin top water level at above 1.8m at the beginning of the event.

This combined with the below understanding of the pervious catchment contributions to the surface water model mean that there is the possibility of the initial rainfall within the 1% AEP 144-hour event would contribute to a higher basin level than the 1.8m adopted.

The Designer notes that combining the 1% AEP groundwater level and the 1% AEP storm event has a joint probability impact to the analysis which may give rise to an overly conservative outcome. This is acknowledged but when considering the responsiveness of the catchment, the adoption of a median antecedent basin level may result in an optimistic outcome without allowing for rainfall on pervious areas to contribute to the top water level (either directly through surface water or indirectly through groundwater).

This risk is acknowledged by the Designer, sensitivity analysis (Scenario 3) has been undertaken and additional freeboard of 160mm has been added to the Flood Planning Levels (Table 4.1 of the Addendum).

5.2.2 Hydrology Assumptions

It is noted by the Designer that assumptions regarding initial and continuing rainfall losses will mean that little or no runoff will be generated from pervious areas during most storm events. This would include the 1% AEP design event. The 144-hour duration storm event has been identified as critical which has an approximate storm depth of 580mm (Appendix C of the Addendum)

Initial losses for pervious areas of Zones D1 and D4 appear high (408mm and 1,088mm, respectively). This differs from commonly adopted values less than 100mm in NSW coastal catchments. The Designer has noted that the pre-development geology is primarily aeolian sands with a high infiltration rate and the surface water loss parameters have been derived from this information. This assumption relies on the pre-development surface geology being retained and/or the ability for surface runoff to infiltrate through the pre-development aeolian sands. The Addendum does not consider the post-development condition where addition and compaction of topsoil/growing media, fine sediment clogging surface layers over time, post-development vegetation and topographic gradients all may have an impact on runoff from pervious areas. The IWCM report notes that this has been considered but has been discounted. These risks may be mitigated during detailed design stages through infrastructure (e.g. infiltration devices) or management interventions but have not been considered in detail. The ability for runoff from nearby (golf course and other open areas in proximity to the basins) contributing to a rise in basin water levels is acknowledged by the Designer.

Approximately 150ha of the 254ha total development area is covered by pervious area. This large area combined with the loss parameters in the model represents a significant loss of rainfall from the design event (1% AEP) being conveyed to the basin storage areas. This may result in the basin top water level being under-estimated (and consequently the minimum habitable floor level and road surface levels) using the surface water design events and model. This risk is acknowledged by the Designer, sensitivity analysis has been undertaken and additional freeboard of 160mm has been added to the Flood Planning Levels (Table 4.1 of the Addendum).

Scenario 3 of the sensitivity analysis utilises limited initial condition losses of rainfall from pervious areas but utilises a continuing loss of 70mm/hr. This would still represent a significant loss of rainfall from pervious areas and may not be conservative for long duration events, particularly considering pervious areas in proximity to the basins which may contribute either directly via surface runoff or indirectly through groundwater recharge. Scenario 3 does, however, utilise an initial basin water level of 3m AHD which is considered conservative. Nevertheless, Scenario 3 indicates the basin top water level is sensitive to the initial condition parameters.

5.2.3 Risks

The combination of the above mean that there is a residual risk that the basin top water level is under-estimated. This would consequently impact the road surface levels and minimum habitable flood level design criteria of the development.

The groundwater models indicate a maximum top basin water level of 3.9m AHD and the design storm analysis indicates a top water level of 4.04m AHD. Designer has noted the Flood Planning Levels as the greater of the two and has added an additional freeboard to this. The design storm analysis has not allowed for the impact of much of the pervious catchment and the groundwater modelling does not allow for consideration of design storm events.

The Designer has undertaken sensitivity analysis and identifies risks to an expected level of detail from a concept design. However, the risk of the under-estimation of the basin top water level has been essentially accepted and the risks transferred to the final end users. If this design criteria is accepted as documented in the Addendum, the basin top water levels are accepted and the floor levels set at minimum 4.7m. There is a risk that future design phases will not undertake any further surface water investigation or that any additional surface water or basin top water level design information is not transferred to the road surface or minimum habitable floor levels.

As there is a freeboard allowance within the design along with a sensitivity analysis and an evacuation and PMF analysis, there is considered limited risk to safety. There is however a risk to serviceability of the system. Of particular relevance are the roads in proximity to the basins. If the road levels are set at the existing 1% AEP design event there is a risk that they will not be trafficable during this event or event at more frequent events. There is also a longer-term serviceability and maintenance consideration that if the basin water levels are more often higher, for longer durations, than anticipated then the serviceability of the road, and the related stormwater and subsurface drainage, and its design life may be impacted.

5.2.4 Way Forward

It is suggested that a requirement of acceptance of the re-zone proposal is contingent on the detailed design phase including re-evaluation of the basin top water level which may revise the road and floor levels of the development. This way the risk is not accepted at the concept stage, but acceptance delayed until detailed design allows for more detailed surface water analysis. This could easily be incorporated in Section 4 of the Addendum by allowing the basin top water levels to be indicative (at the concept stage) and may be revised during detailed design.

A way to account for both the groundwater, pervious areas and storm design events would be to develop an integrated water model. The Designer undertook this initially through the rechange and groundwater models but omitted the impact of design storm events. This level of detail is typically undertaken at the detailed design stage when a more developed understanding of the infrastructure is available (e.g. site, road and drainage gradients, distributed catchments etc.).

5.2.5 Anecdotal

There is anecdotal evidence that the basin and golf course have flooded for an extended period of time over the March 2021 rainfall events. This may indicate that the loss parameters have been under-estimated. This new data could be used to inform, validate and/or calibrate the models (both surface water and groundwater).

5.3 PMF and Evacuation

The PMF analysis will also be impacted by the loss parameter assumptions mentioned previously. The loss parameters have been modified, and the 3m AHD basin and groundwater initial condition has been applied, so any under-estimation would be less prevalent during the PMF.

It is not clear what tailwater condition has been utilised for the PMF but reference to the *Wallis Lake Flood Study Review* (WMA Water 2014) within Table 2.1 of the Addendum is noted. The WMA report utilises two scenarios to examine flood risk when considering coincident events of ocean/outlet levels and storm events. One is using the design ocean level combined with a moderate storm event, the other a moderate ocean event combined with a design storm event). This method could be utilised by the designer during detailed design to gain a better understanding of the PMF risks but is not considered necessary at the concept design stage.

The Designer has indicated the rate of water level rise along with duration of inundation for a variety of events demonstrating a thorough consideration.

The Designer has noted a shelter in place strategy would be appropriate during a short duration storm followed by an evacuation of impacted residents. Given the rate of rise of the short duration PMF is approximately 0.5m/hour it would be difficult to evacuate some residents at the onset of the storm. The dwellings closest to the basins which are accessed by roads adjacent to the basins would be most impacted. In these dwellings the road access may be cut-off (under 1.1m of water) within a short period of time (hours) and water levels do not recede to below road levels for over 1-week. In this scenario, specialist equipment would be needed to evacuate impacted properties.

The Designer has noted evacuation would be required for most dwellings under a longer duration PMF. While rate of rise is slower and water levels do not exceed the access road levels for over 24 hours the depth of water would be over 1.2m in the lowest lying properties. The slow rise would help facilitate safe evacuation.

Unfortunately, it is difficult to predict in advance if a potential PMF would more closely resemble a long or short duration PMF design event. As such an evacuation strategy for residents that are below the 6m AHD level would be a more conservative approach. Identification of evacuation routes and evacuation strategies is usually undertaken at detailed design when levels of shelters and access routes is better understood. The Designer has also noted there are potentially spill points in the developed landform which may lower the calculated PMF peak water level.

6 Groundwater

Groundwater and hydrogeology studies of the area, presented mostly in the GWMR report, have been undertaken to characterise the dynamics between rainfall, groundwater levels and recharge. Ultimately, findings from the study looked at groundwater related development constraints for the project, in particular groundwater levels (for design surface levels based on the 1% AEP event) and the aquifer capacity to receive water by infiltration (specific yield which is used for pervious runoff coefficients in the surface water analysis).

6.1 Methodology

The groundwater studies encompassed the collection of existing datasets, and site investigations aimed at acquiring additional data and fill potential data gaps. The data acquisition was followed by conceptualisation and application of quantitative methods with increasing level of complexity.

Relationships between rainfall events, groundwater recharge and groundwater levels have been established with the use of recharge models, which formed the basis for the more complex empirical and numerical modelling approaches.

These approaches were used to assess groundwater flooding likelihood, definition of flood planning levels and mitigation measures, as well as an overall assessment of the local groundwater system.

6.1.1 Site investigations and data collection

Data from several sources have been acquired for the hydrogeological studies. Data sources include climatic data, topographical data and hydrogeological data from previous investigations.

Climatic data from three weather stations from the Bureau of Meteorology (BoM) have been utilised. From the three stations, Forster (60013) provides representative site conditions, given its proximity to the study area (2km) and long monitoring coverage (1900-2013). Evaporation data was sourced from the Taree weather station (60141) and spatially distributed climate maps developed by the BoM.

Topographical data was sourced LiDAR surveys, which is ideal for the site geomorphological settings given the small variations in topography typical of coastal systems and accuracy needed for the design of the different drainage structures.

6.1.2 Groundwater monitoring data

Groundwater levels have been undertaken for the period of 2010 to 2013. Spatially, while the central and southern portions of development contain the majority of the monitoring boreholes, monitoring boreholes within the northern portion of the development are relatively sparse.

Groundwater levels were monitored using pressure sensors in three monitoring points as well as spot measurements in the remaining boreholes, providing a high-resolution data set and enabling the observation of groundwater level responses to rainfall events.

While the monitoring data set has an appropriate resolution for the 3-year period, it is relatively small considering the 114-year period simulated by the empirical model, and too distant to the model runs for the 1963 year aimed at simulation the required 1% AEP magnitude events. Furthermore, given the existence of other developments surrounding the area of interest, it is possible that additional groundwater level data could be obtained from these areas, which would be beneficial for both conceptualisation and quantification efforts. Implications of data coverage to model uncertainty is further discussed in the following sections.

6.1.3 Recharge modelling

SMEC developed a groundwater recharge model in order to estimate groundwater recharge characteristics for current and developed conditions of the site.

The formulation used in the recharge modelling seemed to be designed for this particular project, addressing recharge as a net balance of various vertical fluxes including rainfall, infiltration, interception and evapotranspiration losses. This approach provides a simple and yet robust approach for the simulation of recharge fluxes, however, it has not been reported whether this approach has been used and/or validated against other sites in similar settings.

The calibration of this model was undertaken using daily recharge depths derived from interpretation of the groundwater level hydrographs. Since this model was also utilised to estimate groundwater levels (in conjunction with the empirical model), it is unclear why calibration was not undertaken directly against groundwater levels, as this would eliminate subjectivity and potential errors from the hydrograph-based recharge estimates.

6.1.4 Empirical groundwater model

An empirical groundwater model was developed specifically for this site in order to estimate groundwater levels under a range of climatic conditions for both existing and proposed development conditions.

The model represents groundwater dynamics through a single-reservoir (box) approach for the development area, utilising recharge estimates from the recharge modelling, evapotranspiration and relationships between relationships between groundwater level, lateral flows and storage capacity. Similar to the recharge model, it is unclear whether this methodology has been benchmarked and/or validated against other modelling approaches and/or different sites.

In terms of calibration, it utilised data for the period of 25 March 2010 to 9 March 2012, with the remaining available data used for model validation purposes. It is unclear which monitoring borehole(s) have been used for calibration, as model results showed in Plates 4-4 and 4-5 show simulated results against observed levels for the three monitoring locations where continuous measurements were being undertaken (MB01, MB02 and MB05).

Following the calibration, the empirical model was developed to simulate the proposed development conditions. To that end, the model formulation was largely modified to accommodate the different hydrological settings of the proposed development.

6.1.5 Detailed groundwater model

A full three-dimensional groundwater model using MODFLOW-SURFACE has been undertaken for the area in order to estimate groundwater levels during the year 1963, where a significant rainfall event has occurred, as well as effects from potential sea level rise on groundwater levels.

The model encapsulated the dominant hydrogeological processes relevant to the estimation of groundwater levels, including rainfall recharge, horizontal flows, discharge to the seafloor and geometry of the main hydrogeological units.

The model domain and discretisation were appropriately designed to encompass the interactions between local groundwater system and surrounding environments, and also to provide sufficient numerical resolution for the simulation of groundwater levels. Vertically, the model was discretised in 4 layers to represent the different hydrogeological units in the area.

Aquifer properties have been defined for the model layers. Several parameter zones were assigned for the different layers likely to represent heterogeneity, although the basis for their definition is not clearly described in the report.

In terms of boundary conditions, dominant fluxes between the model domain and surrounding aquifer have been represented. Recharge boundaries have been implemented to introduce infiltration water, based on estimates from the empirical model. Outflow fluxes through the rivers, drains and ocean discharge have been reasonably represented in the model.

Evapotranspiration processes have been implemented using the evapotranspiration package from MODFLOW-SURFACT. The implementation of these boundaries raised a few questions as follows:

- As evapotranspiration rates are usually a function of vegetation and soil type, it is unclear why parameter zones were defined based on the spatial distribution of the aquifers, although the similar values obtained through the calibration may minimise this issue.
- It is unclear why evapotranspiration boundaries have been assigned to layers 2 and 3, since evapotranspiration occurs mostly within the shallow aquifer zones and assigning them to multiple layers might incur in its double accounting.
- Given that evapotranspiration was also accounted for in the recharge model, it is unclear as to whether evapotranspiration has been accounted for twice in the model (both recharge model and detailed groundwater model) and what is the impact of double-accounting (if present) on predictive estimates.

In terms of calibration, a preliminary steady-state calibration was conducted followed by a transient calibration. The assessment of calibration results raised several questions:

- Initial head conditions and their effect on calibration as not presented in report. Given its short period, it is expected that calibration results would be highly sensitive to the initial heads.
- The calibration period of 51 days does not seem reasonable, given that 3 years of monitoring data was available. While the justification was to narrow the calibration to a specifically wet period, there is no doubt that calibration would benefit from using the entire dataset.
- The calibration results show relatively low residuals (approximately 5%) when looked at the entire data set. While this may suggest that the models reasonably represent average groundwater level conditions, the predictions

of interest are more closely related to local level variations as a function of rainfall. To that end, normalised RMS values should have been calculated on a borehole basis as opposed to using maximum and minimum heads from the entire data set.

- Given that development design and feasibility can vary substantially depending on groundwater level differences of 20-30 cm, it is unclear whether the current calibration performance (+/- 30 cm) is sufficient to minimise predictive errors.

6.2 Model confidence and uncertainty

The confidence of the different models has been discussed in terms of model confidence level classification presented in the Australian Groundwater Modelling Guideline (Barnet et al., 2012). While these guidelines look at model generalities as ways to classify its confidence, it by no means establishes relations between model attributes and confidence of particular predictions of interest. To that end, while it has been mentioned that it was not part of the scope, quantitative predictive analysis is required to verify the uncertainty and confidence around the groundwater model results.

This is exacerbated by the fact that only three years of groundwater monitoring data was available while predictions of interest relate to 1 in 10 year or 1 in 100 year ARI events, and the fact that approaches used in the recharge and empirical groundwater models have not been benchmarked/validated against other model codes and/or sites.

The confidence of the different model attributes is possibly overstated in the report. For example, it claims that geological information can be considered to be a Class 3 due to the homogeneous nature of the geology within the project area. However, the fact that pump tests show remarkably different levels of fit between near and distant monitoring bores suggest that aquifer heterogeneity may be more pronounced than originally thought.

Furthermore, some of the predictive runs included substantial changes on the original calibrated models. In the empirical model for instance, while it is understandable that no site-specific calibration could be undertaken for the proposed conditions at the time of the study, the fact that no calibration, uncertainty analysis or performance assessment of the modified empirical model has been undertaken raises questions not only about the modified model ability to represent these conditions, but also reliability and uncertainty of predictive estimates.

The implications of these model deficiencies and impact on predictions of interest cannot be determined solely based on the work conducted to date, underlining the need for uncertainty quantification utilising modern highly-parameterised methods such as Nullspace Monte-Carlo or the Iterative Ensemble Smoother.

6.3 Assessment of groundwater flooding

The characteristics of groundwater flooding were assessed based on historical rainfall rates and results from empirical and numerical models. Groundwater levels were estimated for a period of 114 years (compared to 3 years of calibration data) to estimate the largest groundwater flooding events in during this period. Based on this analysis the year of 1963 was considered the largest flooding event, and it was utilised for further modelling using the empirical and numerical models.

The adopted Flood Planning levels were defined on the assumption that the 1963 is representative of a 100-year ARI event. While the proposed numbers are in line with the results of the different modelling approaches, they have not accounted for predictive uncertainty of these models (discussed in the previous section).

6.4 Recommendations

Overall, the scope and modelling approaches employed in the study provided reasonable results for historical and flooding groundwater levels, with the caveat that model uncertainty and its impact on the predictions of interest have not been addressed. This, as previously discussed, is exacerbated by the limited period of monitoring data (3 years total, 51 days used in the numerical model) compared to the different simulated periods. The assessment of calibration performance of the numerical models and pump test analyses indicate that the uncertainty on the hydrogeological settings may be more significant than implicitly stated in the report and model confidence levels.

The implications of model uncertainty in terms of model predictions and adopted flood planning levels cannot be assessed based on the modelling work conducted to date. To that end, the following actions are recommended with the understanding that uncertainty analysis often forms part of detailed design and may be delayed to a later date:

- Calibration-constrained uncertainty analysis of recharge and empirical models;
- Representation of aquifer heterogeneity in the numerical model by implementation of highly-parameterised approaches using pilot-points;
- Recalibration of all models with the entire dataset (as opposed to subsets used in each of the models) and utilise any new additional data that is available, including the pumping test data for the numerical model; and
- Calibration-constrained uncertainty analysis on numerical models.

In regards to the numerical model, the following measures are recommended:

- Given that the bottom 2 layers are aquitards, it is possible that they could be removed from the model, improving its performance in terms of running times while not having large impacts on the predictions;
- Verification of whether evapotranspiration has been double-accounted in the model, since it has been considered both in the recharge and numerical model (which uses the recharge model results as an input); and
- Re-parameterisation of evapotranspiration boundaries (in case they are not double accounting) to reflect vegetation and land use types, as opposed to the subcropping aquifers

7 Designing for Exceedance

There are opportunities for incorporating “right-side” failure risk management within the design. While this is not a necessary component of a concept design, future phases of detailed design could incorporate elements that mitigate the consequence of system failure. Of particular relevance is the reliance on the gravity pipe.

If the outlet is blocked another surcharge location could be incorporated into the design. If a location can be identified at the correct surface levels and with a safe overland flow path with does not export flood risk (e.g. Option 2 Ch 1900 - Beach Street) then if the outlet of the gravity pipe is blocked there is redundancy within the system.

The Designer has allowed for consideration of difference inlet configurations to mitigate the risk of blockage and has suggested a maintenance regime for further risk mitigation. Further considerations are generally for detailed design stages and the Designer has undertaken scenario analysis which considers risks of the gravity pipe being less than 100% functional. This demonstrates a competent designer implementing good practice.

The outfall configuration has allowed for future conditions with consideration of sea level rise. The adoption of this criterion needs further consideration at the detailed design stage to ensure that operation and maintenance of the outlet will be possible over the life of the asset or whether a submerged outlet is functionally adequate.

There are also potential opportunities for site and road grading to ensure that if design events are exceeded then the impact is limited to areas of low(er) consequence. This might include regrading parks and/or the golf course to allow flooding events to impact and be retained within these areas. The reconfigured golf course is noted by the Designer but was excluded for the purposes of earthworks modelling. There is a small section of the proposed development site to the south and within an infiltration zone that would discharge offsite. Conceptually this would drain to a nearby sports field which is offsite, and this is noted by the designer. These elements would need to be considered during detailed design.

It was noted that the design included use of rainwater tanks, bioretention zones, distributed basins, ephemeral areas and rain gardens to manage water on the site. This is considered good practice and demonstrates implementation of water sensitive design which achieves multiple benefits (e.g. water quality, amenity, biodiversity etc.) as well as surface water quantity management.

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