TECHNICAL PAPER 04

Hydrology and flooding impact assessment

Appendix E Record of Independent Peer Review of flood model

NARRABRI TO NORTH STAR—PHASE 2 ENVIRONMENTAL IMPACT STATEMENT

Peer Review of Flood Modelling undertaken for Narrabri to North Star - Phase 2

Customer	ARTC
Project	A11237
Deliverable	00
Version	06
	25 August 2022

Executive Summary

Reports

The following reports were provided to BMT for review; however, ongoing consultation was undertaken throughout the review process that commenced in detail in July 2021.

1. Inland Rail Design Joint Venture (IRDJV 2022a): Environmental Impact Statement Technical Paper 4: Hydrology and Flooding Impact Assessment: Narrabri to North Star (N2NS) Phase 2 – Moree to Camurra North, Ref: 2-0001-262-EAP-00-RP-0033 (2 August 2022).
2. N2NS Phase 2 Consolidated Consistency Review Table-Hydrology and Flooding – Excel Spreadsheet Author: Keith Ng & Modified by Martin Singleton.
3. Inland Rail Design Joint Venture (IRDJV 2022b): Summary details of the March 2021 significant flood event at Moree, Ref 2-0001-262-IHY-00-ME-0001_A (16 July 2021).

General Comments

Provided below are general comments on our review of the numerical catchment flood modelling system and the flooding assessments undertaken for the Inland Rail.

1. IRDJV (2022a) numerical catchment modelling demonstrates the flooding impacts and hazards associated with the proposed operational phase of the IR and the assessment is considered:
   a. consistent with the SEARs requirements; and
   b. 'fit for purpose' for the EIS and planning approval process.

   It should be appreciated, the SEARs requirements (refer to Section 2) provide qualitative 'desired performance outcomes' whilst subsequent approval conditions will include detailed Quantitative Design Limits (QDLs) for IR (refer to Table 2.3 for typical limits). Consequently, the detailed design phase will, where required, resolve identified exceedances and demonstrate compliance to the QDLs and/or, through negotiations with landowners and/or relevant stakeholders, achieve an acceptable outcome to all relevant parties.
2. The latest catchment flood model developed by IRDJV was based on the Moree and Environs WRM (2017) flood model. From our understanding, these models were adopted by Moree Plains Shire Council and used to inform the Moree and Environs Flood Study/Floodplain Risk Management Study and Plan Volume III – Draft Floodplain Risk Management Plan (the Plan) with some additions as identified in their 22 July 2021 Committee meeting.
3. The WRM (2017) modelling largely pre-dates the ARR (2016/2019) update; however, inflows from the greater Gwydir catchment are based on a Flood Frequency Analysis (FFA) undertaken at Gravesend that achieves the requirements of ARR 2019. The Gwydir catchment at Gravesend represents 83% of the catchment area to Moree and is, therefore, a key inflow location for the catchment modelling undertaken.
4. The local hydrologic models and the adopted Gravesend design flow hydrograph based on the 2012 flood event were reviewed and assessed for their establishment and adequacy of their calibration, validation and operation in relation to design events. The establishment of FFA for Gravesend was acceptable, and the calibration and validation of the local hydrological models were also considered acceptable and fit-for-purpose. A relatively high degree of certainty to reproduce accurate design flows has resulted from frequent to rare (i.e. up to 1 in 100yr AEP) flood events when considered together with the hydraulic calibration.

5. A large range of design floods had been simulated in the flood modelling, from relatively frequent events up to extreme events (i.e. 1 in 10yr to 1 in 100yr with climate change and an extreme event of 3 times the 1 in 100yr AEP magnitude). The investigations to date have presented a range of potential flood impacts and levels of flood immunity of the railway line. Given the relatively high degree of certainty regarding the adopted design flows for frequent to rare flood events, the resulting analyses should be considered reliable for use to determine if the final adopted design achieves an acceptable outcome for ARTC, landowners and all relevant stakeholders.
6. The resulting catchment modelling, with further refinement/verification recommended during the detailed design phase (refer to Hydrology and Hydraulic Sections below for recommendations), including the proposed additional sensitivity testing, will provide a high level of confidence that the range of possible flood impacts and flood immunity of the railway line has been captured and the results can be suitably assessed against the QDLs and outcomes agreed with relevant landowners and/stakeholders.
7. It is considered that the design is progressing towards achieving the requirements of the draft Quantitative Design Limits (QDLs), **but is still subject to further refinement to improve this outcome (i.e. reduction of flood impacts) during the detailed design**. Non-compliances are identified, and stakeholder consultation should be initiated/continued to either provide acceptance of the results or provide further mediation (or mitigation) options to the affected stakeholders. Of particular note are the non-complying impacts as follows:
    a. Eighty six (86) residential properties west of Moree Station (Afflux values up to 40 mm) as a result of N2NS Phase 1 and Phase 2 development. However, preliminary assessments indicate that this impact can be mitigated by a combination of measures and will be finalised during the detailed design phase.
    b. Camurra hairpin impacts are observed, and as per IRDJV (2022), this area is still subject to further refinement during detailed design to reduce flood impact and/or acceptance of impact by stakeholders.
    c. Cumulative impacts of IR and highway indicate additional impacts within Moree, between the IR & Highway (i.e. for more frequent events) and north of Moree. As noted by IRDJV (2022), these flood impacts will be reviewed with Transport for NSW to provide an improved solution.
    d. The sensitivity results (i.e. increases to flow and blockage) demonstrate that the higher rail embankment causes diversion of flow through the southern part of the proposal, where the Mehi River and floodplain bridges are located. Flood impacts from these assessments, such as from climate change and blockage cases, cause 50mm to 200mm impacts in the town of Moree, including increased flood hazards. Further optimisation of the cross drainage via reduction of these flood level impacts and flood hazards in Moree via these sensitivity assessments is warranted during detailed design.
8. IRDJV (2022) has undertaken an initial assessment of an extreme flood event (i.e. PMF) and increases in flood impacts and flood hazards occur within Moree. As noted by IRDJV (2022), whilst the PMF water level differences across the railway are likely to be of low risk of sudden failure, floods varying between the 1 in 100yr AEP and PMF may have a greater potential of sudden failure, due to large flood level differences across the railway. Further assessments at locations with sensitive receptors should be undertaken during detailed design, including 'failure impact assessments' to determine the 'potential risk to life' to sensitive downstream receptors/sites. The results of these assessments should be included in the Flood Emergency Response Plan (FERP), including management measures to mitigate the risks to an acceptable level. BMT has not reviewed any aspects associated with the FERP and is not part of our scope of work.
9. Given the WRM (2017) modelling has demonstrated a relatively good correlation and verification to historical flood events, and the IRDJV (2022a) model shows a good correlation with the WRM

models, then the relative level of uncertainty in the flood impact results is reduced and the results provided in the EIS can be relied upon for this stage of the design. However, the flood modelling is subject to further refinement during the detail design stage, and further refinement of the design is required to reduce the flood impacts associated with the design presented to date in some locations.

Where QDLs cannot be reasonably achieved during the detailed design, the acceptability of the flood risks (i.e. uncertainty as detailed in sections below and associated consequences e.g. flood impact, flood immunity, flood hazard) demonstrated through model refinement and sensitivity analyses will need to be accepted by ARTC, landowners and associated stakeholders for the construction phase of the Inland Rail.

Hydrology

FFA at Gravesend

As detailed in WRM (2017) report and from our review, there is adequate data of sufficient quality to enable a FFA to be undertaken. However, the construction of the Copeton Dam provides a significant discontinuity in the gauging record from the commencement of construction in 1968 to 1976. The FFA considered both post-Copeton dam recorded flow and pre-Copeton dam with historical data included. The FFA was undertaken using the FLIKE software using the Bayesian inference methodology as recommended in ARR 2016 and ARR 2019. The pre-Copeton dam flows were adjusted with the use of the Integrated Quantity Quality Model (IQQM).

A summary of the WRM (2017) FFA key points indicates the following:

1. The 1 in 100yr AEP flood discharge at Gravesend is 6,110 m^3/s and the 90% quantile probability limits are 4,370m^3/s to 9,640 m^3/s.
2. The period of record used for the FFA design discharges without using the historical data (i.e. pre gauge data) would appear to overestimate the peak discharges for the larger events. From the FFA assessment without the historical data, it would indicate the 1 in 100yr AEP would increase to 7,570 m^3/s (i.e. 24% larger than the adopted design and equivalent to the 1 in 200yr AEP with the use of historical data)
3. Post Copeton Dam FFA (i.e. 1973 – 2015) indicates the 1 in 100yr AEP is 5,930m^3/s; however reassessment using a further 6 years of data that includes March 2021 (approx. 1 in 20yr AEP), may slightly influence this result.
4. The largest flood on record is the pre-Copeton Dam 1955 flood, with a peak flow of 6,685 m^3/s, with an estimated AEP in the order of 1 in 200yr to 1 in 500yr (refer to WRM, 2017).

From the above points, it is clear that extending the record to 156 years notably lowers the 1 in 100yr AEP design flood event. This extension of record, as reported, appears to be based upon the investigations undertaken by Cameron McNamara Consultants (1983) that found that “the recorded February 1955 flood height has not been exceeded since about 1860”. From a cursory review of flooding in Moree from Trove (https://trove.nla.gov.au/) this assumption appears reasonable and could well support this assertion.

Overall the FFA analysis from this review is supported, and the peak 1 in 100yr AEP of 6,110m^3/s seems a reasonable estimate, noting the 90% quantile probability limits and the peak flow of 7,570m^3/s without the use of historical data. As detailed in the following section, based on BMT URBS hydrological modelling, the peak flow determined by WRM is also supported.

Hydrological Modelling Verification and Design Flows - Gravesend

The FFA undertaken by the WRM (2017) at Gravesend uses the recommended method identified in ARR 2019 and therefore provides confidence in its use for the design of peak flood flows. However, for the Gwydir River at Gravesend, the volume of the flood hydrograph and timing may also have an influence on the IRDJV (2022a) design (mitigation) in meeting the Floodplain Management Objectives (FMO) an QDLs. WRM (2017) adopted the 2012 flood hydrograph shape to represent inflows from the Gwydir River, and this hydrograph appear reasonable based on the historical flood hydrographs.

Independent verification of the WRM (2017) peak flood flow and flood hydrograph (i.e. volume and timing) was undertaken through the construction of an independent URBS hydrological model by BMT. The design discharge was simulated using the ARR (2019) methodology. The initial and continuous losses for the design events have been assessed against the standard ARR (2019) datahub losses and the OEH (2019) report recommendations of using calibrated 'reconciled' (NS2B) losses as per the Phase 1 IRDJV.

The BMT URBS model was verified to the March 2021 flood event (approx. 1 in 20yr AEP), and the results indicate the NS2B 'reconciled' losses provide the closest correlation to the flood hydrograph at Gravesend. Based on the URBS hydrological model (NS2B reconciled losses), the 1 in 100yr AEP flood peak was determined as 6,431m^3/s based on the entire catchment, but excluding any attenuation effects of Copeton Dam. This peak flow compares reasonably well with the FFA peak flow for the 1 in 100yr AEP flood event. It is also noted from WRM (2017), that that the three largest flood peaks in 1910, 1950 and 1955 were not significantly affected by the dam, hence excluding the dam in the URBS model may not be considered as too conservative if the dam was full prior to the event.

A comparison of the 1 in 100yr AEP design flood volume calculated as part of WRM (2017) design flood and the volume from the BMT URBS reconciled flood hydrograph indicates the following:

1. WRM (2017) 30hrs to 96hours (main burst) – 732,379m^3
2. WRM (2017) 0hrs to 96hours (full flood) – 824,283m^3
3. BMT URBS reconciled Full Catchment – 662,603m^3

As noted above, the WRM design flood hydrograph provides a suitable flood volume and in excess of that determined by the BMT URBS model without any attenuation effects from Copeton Dam.

Local Catchment Models between Moree & Gravesend

The remaining portion of the catchment area between Gravesend and Moree was represented by WRM (2017) via local hydrological modelling based on ARR (1987). BMT has undertaken verification of the Tycannah Creek catchment by the development of an URBS hydrological model.

The BMT URBS model was validated, and a peak flow assessment was undertaken based on ARR (2019) using the NS2B 'reconciled' losses and ARR (2019) losses that generally overestimate peak flows when verified to recorded flood events. A comparison to the WRM (2017) XP-RAFTS model and the BMT URBS model is provided below for the 48hr flood event (i.e. as per WRM assessment) and also the critical peak flow:

1. WRM ARR(1987) 1 in 100yr AEP 890m^3/s
2. BMT URBS NS2B 'Reconciled' losses 48hr 1 in 100yr AEP flood event -> 858 m^3/s
3. BMT URBS NS2B 'Reconciled' losses critical 1 in 100yr AEP flood event -> 1,181 m^3/s

As Phase 2 assessment covers Moree to Camurra and the local catchments combined with flood flows from the Gwydir River and Mehi River, the flood flow from the ARR 1987 48hr flood event seems reasonable and consistent with the BMT URBS ARR (2019) assessment.

Overall Acceptability

The IRDJV (2022a) hydrology is based on the WRM (2017) flood assessment that was constructed prior to the ARR (2016 / 2019) guidelines. As previously noted, inflows from the greater Gwydir catchment are based on a FFA at the Gravesend gauge and use the flood event of 2012 for the inflow hydrograph. The FFA assessment meets the requirements of ARR 2019, and the Gwydir catchment at the point of inflow at Gravesend has a catchment area of 11,020 km^2 that represents 83% of the catchment area to Moree.

The remaining portion of the catchment area between Gravesend and Moree was represented by local XP-RAFTS hydrological modelling based on ARR (1987) and the 48hr flood event to coincide with the flows from Gravesend. The peak flows from the local catchment are consistent with the BMT URBS ARR 2019 flood assessment. Furthermore, the peak flood flows from the local catchment are likely to be well before that from the Gwydir catchment and will have limited influence on the overall peak flood levels and flood volume.

Overall the design hydrology adopted by IRDJV (2022a) that is based on the WRM (2017) flood assessment that has been calibrated with hydraulic modelling is considered acceptable for use in the Phase 2 flood assessment and provides an acceptable overall degree of certainty regarding flood risks up to the 1 in 100yr AEP flood event. IRDJV (2022a) have also undertaken climate change sensitivity analyses by increasing peak flows by +20%. This result will provide a range of resulting flood risks (i.e. upper bounds of uncertainty) and associated consequences (e.g. flood impact, immunity & hazard) that ARTC may consider further to determine whether greater factors of safety may be applied and/or further optimisation of the flood mitigations are required.

As documented in ARR (2019), incorporation of a calibrated hydrological model should be considered to appropriately define very rare to extreme flood events (e.g. floods larger than 1 in 200yr AEP) that are used for risk assessments and detailed design. The Copeton dam should be considered as full prior to these extreme events.

Hydraulics

TUFLOW Model

The TUFLOW model is based on the MIKE FLOOD hydraulic model developed for the Moree Plains Shire Council's flood Study for Moree and Environs (WRM, January 2017). The MIKE FLOOD model is a calibrated model and has been previously peer-reviewed. The MIKE FLOOD model was also provided to BMT.

Model inflows were derived from the FFA at Gravesend and a calibrated XP_RAFTS hydrology model as previously discussed. The inflows are directly included in the TUFLOW model from the WRM (2017) MIKE FLOOD model. Key input data from the MIKE FLOOD model was used directly for the TUFLOW model, including:

1. Topographic data
2. Inflow hydrographs
3. Culvert and bridge data
4. Floodplain roughness data.

Additional data was also used to update the topographic data sets, and a finer grid resolution has been used in the TUFLOW model when compared to the MIKE FLOOD model. These additional topographic representations are adequately represented within the TUFLOW model, and the increased grid resolution is also supported. The finer grid size representation used is considered to be adequate for the EIS phase of the investigation. However, as detailed below, further model validation is recommended for the final detailed design.

Model Discretisation

A detailed review of the model discretion was undertaken. This includes structures, roughness, grid size and boundary conditions, including the topography and blockage of culverts.

Cross drainage culverts for both the rail line and highway were represented by one dimensional (1D) structure elements within the two-dimensional (2D) model grid. This is the case for both the existing and design case and is supported. Further review and refinement are, however, recommended where large banks of culverts are proposed, particularly in the design case modelling where the combined bank of culvert width is far greater than the grid cell size. A 2D approach may be preferred in these cases, particularly where velocity may vary across the structure width. A sensitivity test is recommended to inform the best approach for detailed design.

The adopted roughness values are considered appropriate and consistent with the MIKE FLOOD model. If required, these parameters may require further adjustment following the verification of the TUFLOW model to a historical event (e.g. Feb 2012 flood event) and /or consistency with the WRM (2017) design floods as detailed in the following section. It should be appreciated that whilst the TUFLOW model provides greater resolution, particularly within the channels, than that of the MIKE FLOOD model, adjustment of the Manning ‘n’ roughness could be necessary to refine the conveyance and correlate the result closer to known flood levels.

A standard blockage factor of 15% was adopted, based on the ARR (2019) advice of ‘*where the width of that part of the approach flow that is capable of transporting the debris under consideration is significantly less than the total width of the structure, then the culverts/spans within the effective transport width be assessed as blocked to BDES and those outside of that zone be reduced to half BDES*’. As ARR (2019) note a minimum design blockage factor of 25% within the effective transport width, then the universal blockage of 15% is acceptable, given that the following sensitivities have been undertaken:

1. 0% blockage (all culverts);
2. 25% universal blockage
3. 50% universal blockage.

The adopted 15% blockage provides an ‘average’ result and is accepted for the SEARs assessment; however, the detailed design blockage factor for each culvert bank should be used for the detailed design and results documented with reference to the QDLs. The sensitivity assessment of blockage factors (e.g. 0% and x2 the design blockage factor as per ARR 2019 recommendations) will provide an indication of upper and lower design limit impacts. These sensitivity assessments should be used by ARTC as part of their risk assessment of sensitive receptors to determine and suitably address the potential flood damage/liability that could be caused to landowners and/or stakeholders.

Model Validation

The resulting IRDJV (2022a) TUFLOW model for the 1 in 100yr AEP shows a relatively good correlation to the MIKE FLOOD models. Peak flood levels are generally less than 50mm difference across the floodplain and project area. A localised difference of between 100-200mm is noted in the northern area of Moree. For the 1 in 10yr AEP flood event, a significant difference occurs between the models in the Mehi River. Differences in flood levels around structures are also noted.

To support and to further verify the IRDJV (2022a) TUFLOW model, **further model validation will be required in the detailed design** through verification/comparisons against peak flood levels from a recent historical event as per the MIKE FLOOD model to support the TUFLOW model results. The February 2012 flood event provides a recent and significant event for the validation assessment in the detailed design. From the WRM (2017) report, the February 2012 flood event has over 200 surveyed flood levels.

We also note from the Moree Plain Shire Council on-line reports that revised levee modelling north of Moree was recommended and from our understanding, was to be adopted by Council. While the currently adopted TUFLOW modelling potentially provides a conservative analysis, **a sensitivity assessment of the proposed final levee design should be conducted with the current levee height included in the model as part of the detailed design**.

Overall Acceptability

BMT has conducted a technical review of the TUFLOW model and the schematisation that form the basis of the Phase 2 EIS report (IRDJV, 2022a). From this review, we conclude that the TUFLOW model has generally been constructed appropriately and based on this review, we consider the overall approach to hydraulic modelling and methodology is generally appropriate for design modelling at this EIS stage. Recommendations have been provided in relation to some specific topography (i.e levees), culvert schematisation, sensitivity analysis (i.e. climate change, blockage), extreme event assessments and further verification of the flood model results against a historical event and re-validation against the WRM (2017) 1 in 10yr and 1 in100yr flood events for the final detailed design.

As outlined in the body of this review, we recommend the following modelling improvements for the detailed design:

1. Additional TUFLOW model verification, including a historic event assessment for model (e.g 2012);
2. Sensitivity of culverts blockage results (i.e. 0% and 25% blockage) included in the sensitive receivers against the QDLs, while the 50% shall be used as an upper limited risk assessment;
3. A sensitivity test using the revised MIKE FLOOD model incorporating existing levee/storage structures.

This further validation and sensitivity testing will provide a better understanding of the flood immunity of the railway line and provide a range of resulting flood risks (i.e. uncertainty) and associated consequences (e.g. flood impact, flood immunity, flood hazard etc) that ARTC should consider, including as to whether greater factors of safety may be applied in the detailed design.

Given that a large range of flood events, up to severe and extreme events, have been used in the design, flood impacts are unlikely to be significantly affected by this work.

Compliance with Quantitative Design Limits

The flood modelling to date indicates that a full and comprehensive understanding of flooding under a range of flood events has been established, and the assessment of impacts from the proposed rail line against the QDLs and flood immunity is well understood. The resulting modelling and, the sensitivity testing (e.g. climate change and blockage) provide an acceptable level of confidence that the range of possible flood impacts and flood immunity of the railway line has been captured.

It is considered that the design is progressing towards achieving the requirements of the draft Quantitative Design Limits (QDLs), but is **still subject to further refinement** to improve this an acceptable outcome (i.e. reduction of flood impacts as detailed in the 'General Comments') during the detailed design. Non-compliances are identified, and stakeholder consultation should be initiated/continued to either provide acceptance of the impacts or provide further mediation (or mitigation) options to the stakeholders.

Qualifications

This review is based on a desktop assessment and a review of the numerical files. The desktop review is based on the reports previously provided in the section titled 'Reports'. The reports document the methodology of calibration, validation and application of the catchment models and their use for assessment of impacts as a result of the proposed infrastructure.

The final design will need to consider further (as detailed in this report and IRDJV, 2022 report), the flood impacts associated with the proposed railway line for the full range of flood events, including the sensitivity of flows (for example due to climate change, extreme events and flood debris blockage) are appropriately managed with particular regards to (1) impacts to evacuation routes, (2) the potential for an increase of the risk of loss of life at flood sensitive receptors (FSR) and (3) property damage.

Contents

Tables

Figures

1 Introduction

1.1 Background

The Inland Rail Project's proposed Narrabri to North Star (N2NS) provides a connection between Narrabri and North Star in New South Wales (NSW). The section is divided into two Phases (i.e. service packages) being:

1. Phase 1 / Separable Portion (SP1) – Narrabri to Moree and Camurra to North Star
2. Phase 2 / Separable Portion (SP2) – Moree to Camurra.

This 'Independent Peer Review' was undertaken for Inland Rail Design Joint Venture (IRDJV 2022a): Environmental Impact Statement Technical Paper 4: Hydrology and Flooding Impact Assessment: Narrabri to North Star (N2NS) Phase 2 – Moree to Camurra North, Ref: 2-0001-262-EAP-00-RP-0033 (28 March 2022). The scope of work of the Independent Review are identified in Section 1.2 below.

1.2 Scope of Works

BMT was engaged by Australian Rail Track Corporation (ARTC) to undertake the following scope of works as detailed in ARTC Expert Panel and Independent Review of N2NS Separable Portion 2 EIS (SC-2600-0028) Schedule B and provided below for ease of reference.

This review is based upon the IRDJV (2022a) report only and includes the numerical model review based on the quadtree models provided on 10th February 2022.

MILESTONE	DOCUMENTATION PREPARED BY THE EIS SERVICE PROVIDER	INDEPENDENT REVIEWER SCOPE

1
30% Draft EIS
	- Draft Project Description
	- Chapter and technical report outlines including assessment methodology and survey locations
	- Review of assessment extent required, given project description, previous assessment and available information
	- Provide compliance table documenting how the scopes of work addresses the SEARs and ARTC's requirements
	- Confirm the impact assessment method applicable to each environmental value and existing condition assessed
	- Prepare calibrated hydrological model and established hydraulic model
		Milestone 1 memorandum which:
		- Reviews and provides commentary on:
		  - The EIS Service Provider's proposed assessment methodology. This review is to have regard to the NSW Floodplain Development Manual, associated guidance, the methodologies included in ARR2019 and any other documentation identified in the SEARs
		  - The flooding management objectives and design limits (output from Community Consultation activities)
		- Reviews and endorses the calibrated hydrology and hydraulic models, including assumptions, inputs and outputs

2
70% Draft EIS
	- Fieldworks largely complete
	- Baseline impact assessment largely complete
	- Executive Summary outline
	- Draft Figures
	- Final and signed off Project Description
	- Updated compliance table, where appropriate
	- Largely completed environmental risk assessment
		Milestone 2 memorandum which:
		- Reviews and provides technical commentary on:
		  - EIS Service Provider's work to date including findings reports from field works, baseline impact assessments and technical reports
		  - Resolution and close out of previously provided commentary; and
		- Reviews and endorses the hydrology and hydraulic models including assumptions, inputs and outputs.

3
95% Draft EIS
	- Baseline and impact assessment finalised
	- Environmental management and executive summary drafted
	- Figures finalised
	- Technical reports appended
	- Update and issue compliance table
		Milestone 3 memorandum which:
		- Reviews and provides technical commentary on:
		  - EIS Service Provider's work to date including findings reports from field works, baseline impact assessments and technical reports
		  - Resolution and close out of previously provided commentary; and
		- Final technical review conclusions

4 **100% EIS and Submission**	- Completed document, pending review and approval by ARTC - Statement of compliance documenting how the document fully addresses the SEARs	

2 N2NS Phase 2 – Moree to Camurra North EIS (Nov 2020)

As provided in the IRDJV (2022) report, the EIS must demonstrate compliance with the Secretary's Environmental Assessment Requirement (SEARs) relating to surface water. The SEARS requirements are provided in Table 1-1 and Table 1-2 of the IRDJV (2022a) report and are provided below in Table 2.1 and Table 2.2 for ease of reference.

Table 2.1 SEARs for Desired Performance Outcomes

DESIRED PERFORMANCE OUTCOMES	REQUIREMENT
3. Assessment of Key Issues* Key issue impacts are assessed objectively and thoroughly to provide confidence that the project will be constructed and operated within acceptable levels of impact. ** Key issues are nominated by the Proponent in the CSSI project application and by the Department in the SEARs. Key issues need to be reviewed throughout the preparation of the EIS to ensure any new key issues that emerge are captured. The key issues identified in this document are not exhaustive but are key issues common to most CSSI projects.*	**1** The level of assessment of likely impacts must be proportionate to the significance of, or degree of impact on, the issue, within the context of the project location and the surrounding environment. The level of assessment must be commensurate to the degree of impact and sufficient to ensure that the Department and other government agencies are able to understand and assess impacts.
	2 For each key issue the Proponent must: **a** assess the issue (including modelling as relevant), and address and undertake the requirements specified in section 2 **b** describe the biophysical, social and economic environment, as far as it is relevant to that issue, including substantiated baseline data that is reflective of current guidelines where relevant **c** describe the legislative and policy context, as far as it is relevant to the issue **d** identify, describe and quantify (if possible) the impacts associated with the issue, including the likelihood and consequence (including worst case scenario) of the impact (comprehensive risk assessment), the impacts of concurrent activities within the project and cumulative impacts (parallel and sequential) with other projects **e** demonstrate how potential impacts have been avoided (through design, or construction or operation methodologies) **f** identify clear and quantifiable actions, outcomes and, where possible, performance criteria **g** detail how likely impacts that have not been avoided through design will be minimised, and the predicted effectiveness of these measures (against performance criteria where relevant) **h** detail how residual impacts will be managed or offset, and the approach and effectiveness of these measures; and **i** measures to monitor the avoidance, minimisation and offsetting of impacts to ensure quantified outcomes and criteria are met.
	3 Where multiple options to avoid or minimise impacts are available, they must be identified and considered, and the proposed measure justified taking into account the public interest.

Table 2.2 SEARs for Desired Performance Outcomes

REQUIREMENT (SPECIFIC ASSESSMENT REQUIREMENTS)	REPORT REFERENCE
1 Flooding and Hydrology *Key issue and Desired Performance Outcomes:* ▸ The project minimises changes to the existing flood regime's impacts on property, public safety and the environment resulting from alteration of the water flow characteristics of watercourses and overland flowpaths. ▸ The project includes remedial measures to mitigate adverse water flow impacts or flood safety risks caused by the existing rail infrastructure within the project area. Construction and operation of the project avoids or minimises the risk of, and adverse impacts from, infrastructure flooding, flooding hazards, or dam failure.	
1 Description of topographic and hydrological conditions of the site and surrounding area, including:	
a Assessment of the existing hydrology and flooding characteristics of watercourses within and adjacent to the project area. This includes locating and assessing flowpaths emanating from existing culverts, pipes and bridges under the rail formation, or from overtopping of the existing formation in flood events.	Section 4.7, Appendix A
b Description of the existing and proposed topography in areas that could be potentially affected by floodwaters. This includes the spatial location, and the horizontal and vertical dimensions of spoil mounds.	Section 4.7, Appendix A
c Carrying out of investigations to assess the propensity for scour, erosion and geomorphological changes to occur within any watercourses or overland flowpaths affected by the project.	Sections 4.4.2, 6.3.1.2, 6.3.1.9 and 6.3.1.10
2 Design parameters and features, including:	
a Description and justification of quantitative flood management objectives for flooding, hydrological and geomorphological changes resulting from the project. These objectives are to consider land use and include afflux, velocity, extent, duration, hazard and scour potential.	Section 4.6
b Description and justification of the proposed flood planning level (FPL) for the project including the AEP of the flood which will overtop the formation and rail. When establishing the appropriate FPL, consider any impacts on adjacent infrastructure and any alteration works required to improve flood immunity of affected infrastructure.	Sections 4.5, 6.1 and 6.3
c Description of the location and size of existing and proposed pipes, culverts and bridges, and the locations and annual exceedance probabilities (AEPs) of floods that overtop the existing formation and rail.	Sections 5.8, 5.9 and 6.2
d Preliminary engineering designs of the velocity dissipation or other mitigation works that are proposed to avoid adverse offsite scouring on the adjoining land downstream of the project area, adjacent to locations where pipes, culverts or bridges are proposed or where the rail formation may be overtopped.	Sections 4.4.2, 6.2, 6.3.1.2 and 6.3.1.9
e At locations along the rail route, identification of the width of land between the toe of the formation and the downstream boundary of the project area, that is available for the construction of these mitigation works. Where there is insufficient width of project land available for these works, clear identification of the extent of additional land beyond the project boundary that may be required, including the locations where easements over land or acquisition of land may be required.	Sections 4.4.2 and 6.3.1.9
3 Pre-construction and operational phase impacts of the project on flood behaviour for a full range of flood events up to and including the PMF (including consideration of the impacts of climate change and differing storm durations), including:	
a utilisation of 2D hydrologic and hydraulic models that are consistent with ARR and current best practice and utilise topographic and infrastructure data that is of sufficient spatial coverage and accuracy to ensure the resultant models can accurately assess existing and proposed water flow characteristics;	Sections 4.2 and 4.3
b Identification of allowance for blockage of cross-drainage structures to be made in accordance with ARR;	Section 4.3.2.10 and Appendix D

REQUIREMENT (SPECIFIC ASSESSMENT REQUIREMENTS)	REPORT REFERENCE
c having these models independently peer-reviewed with the review findings published in the EIS;	Section 4.8 and Appendix E
d assessing any changes to the potential flood affectation, scouring or geomorphological changes to other properties, assets and infrastructure, over a full range of flood durations and flood frequencies against the proposed flood management objectives;	Section 6.3, Appendix B
e assessing changes in upstream and downstream flowpaths (location, discharges and velocities, including overland flow);	Section 6.3.1.10, Appendix B
f where the existing rail infrastructure has an adverse flood impact on property or people, the flood assessment must consider the extent to which the project alleviates or exacerbates these existing impacts;	Sections 6.3.1.5, 6.3.1.6 and 6.3.5, Appendix B
g assessing impacts of extreme floods up to the probable maximum flood (PMF) including consideration of flood risks to people and property resulting from failure of the formation or washouts of ballast.	Sections 4.2.4 and 6.3.3, Appendix B
h assessing the consistency (or inconsistency) with the applicable Council or DPIE Water floodplain management plans. The requirements of these plans must be discussed with DPIE Water and the relevant Council;	Sections 2, 4.6 and 6.3.5
i assessing whether each component of the project is compatible with the flood hazard of the land and the hydraulic functions of flow conveyance, floodway and flood storage;	Sections 6.3.1.4, 6.3.1.7, 6.3.1.8 and 6.3.1.10, Appendix B
j assessing impacts on farm dams, agricultural infrastructure, crops and activities associated with altered hydrology including volumetric changes in water flows;	Sections 6.3.1.10 and 6.3.1.11, Appendix B
k assessing any impacts that the project may have upon existing community emergency management arrangements for flooding. These matters must be discussed with the State Emergency Service and applicable Council; and	Sections 6.3.1.5, 6.3.1.6, 6.3.1.7, 6.3.1.8 and 6.3.5, Appendix B
l evaluating any social and economic impacts that the project may have on the community as a consequence of changes to flooding and hydrology including dividing or fragmentation of property and changes to property management which could lead to the loss of viability.	Section 6.3.1.12, Appendix B
4 A qualitative assessment identifying land uses and infrastructure in the vicinity of the project susceptible to flood impacts that may arise during the construction phase and measures to mitigate risks of construction impacts occurring.	Section 7.1
5 In the event that operational impacts do not meet the nominated flood management objectives, provide measures to ensure the project's detailed design meets the objectives. Alternatively:	
a demonstrate that design changes to meet objectives at a given project location are not practicable; and	Sections 4.4.1, 4.5, 6.1, 6.2 and 6.3.1, Appendix B
b describe how broad flooding objectives will still be met at a given location; and	Sections 6.3.1 and 8.2, Appendix B
c detail procedures to ensure that the flood performance is acceptable to affected parties.	Sections 6.3.5 and 8.2

Further to the SEARs requirements provided above, Table 2.3 and Table 2.4 provide the anticipated impact and modelling requirements (i.e. Quantitative Design Limits, QDLs) that were set by the Conditions of Approval provided for Phase 1. The criteria (i.e. Table 2.3) are expected to be similar to that of the Phase 2 Flood Design Verification Report and was also provided within IRDJV (2022) report.

Table 2.3 Summary of Phase 2 Impact to QDL and BMT Comments

Parameter	Location or Land Use	Limit	BMT Comments	Has the parameter been addressed
Afflux i.e. increase in flood level resulting from implementation of Critical State Significant Infrastructure (CSSI)	Habitable floors and sensitive infrastructure	10mm increase	Exceedances are noted for the 10% to 1% AEP events.	Ongoing. Further refinement of cross drainage is proposed.
	Non-habitable floors	20mm increase		
	Surrounds of residential buildings, other urban, open space recreational land and infrastructure (excluding sensitive infrastructure)	100mm increase		
	Agricultural land	200mm increase	Exceedances are noted, particularly north of the new greenfield rail loop	Ongoing. Further refinement of cross drainage is proposed.
	Forest and unimproved grazing land	300mm increase		
	Classified roads managed by TfNSW	50mm on areas flooded under existing conditions. Otherwise, no increase.	Exceedances are noted.	Ongoing refinement and consultation proposed.
	Highways and sealed roads >80 km/hr	No increase in depth where aquaplaning risk exists and remains unmitigated. Otherwise 50mm increase	Exceedance of local road in area North of Gydir River and in vicinity of new greenfield rail loop	Ongoing. Further refinement of cross drainage is proposed.
	Unsealed roads and sealed roads<80 km/hr	100mm increase		
Scour/Erosion Potential i.e. increase in flood velocity resulting from implementation of CSSI	Ground surfaces that have been sealed or otherwise protected against erosion. This includes roads and most urban, commercial, industrial, recreational and forested land	20% increase in velocity where existing velocity already exceeds 1 m/s	Localised exceedances in velocity are predicted at several culvert inlets and outlets with some propagating beyond the rail corridor.	Ongoing. Further refinement of cross drainage is proposed.
	Classified roads managed by TfNSW	10% increase in velocity where existing velocity already exceeds 1m/s	Exceedances are noted in the 1% AEP event on the Newell Highway.	Ongoing refinement and consultation proposed.
	Other areas including watercourses, agricultural land, unimproved grazing land and other unsealed or unprotected areas	An erosion threshold velocity (ETV) of 0.5m/s is to be adopted unless otherwise determined through a site specific assessment(s) conducted by an experienced geotechnical or scour/erosion specialist.8 Where existing velocity exceeds ETV, velocity is limited to a 0.025m/s increase. Where existing velocity is less than ETV, velocity is limited to the lesser of: ETV 20% increase9 or 0.5m/s, whichever is greater.	Local increases are observed away from the rail corridor but are limited to localised channels and waterways	Ongoing. Further refinement of cross drainage is proposed in conjunction with further consultation.
Flood Hazard i.e. increase in velocity depth product (vd) and/or flood hazard category resulting from implementation of CSSI. (Does not apply where vd<0.1 m^2/s).	Urban, commercial, industrial, highways and sealed roadways	A 10% increase in vd	>10% Exceedance on 1 buildings	Ongoing refinement and consultation proposed.
	Classified roads managed by TfNSW	10% increase in vd where this does not result in an increase in hazard category. Otherwise, no increase	Exceedances are noted.	Ongoing refinement and consultation proposed.
	Elsewhere	A 20% increase in vd	Exceedances generally limited to culvert inlets and outlets. 5% AEP has exceedances over larger areas downstream (west of rail corridor)	Ongoing refinement and consultation proposed.

Parameter	Location or Land Use	Limit	BMT Comments	Has the parameter been addressed
			Exceedances noted at chainage 680.25m on cropping land and floodway	
Flood Duration i.e. increase in duration of inundation resulting from implementation of CSSI (Does not apply to inundated areas less than 100m2)	Habitable floors	Where existing above floor flooding is: • less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour • greater than 1 hour in duration, up to 5% increased inundation duration. Where existing below floor flooding is: • less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour • greater than 1 hour in duration, up to 10% increased inundation duration.	Exceedances are noted on residential buildings and 1 sensitive receiver	Ongoing refinement and consultation proposed.
	Classified roads managed by TfNSW5	No increase in duration of flood inundation to sections of road not already inundated. Otherwise 10% increase in inundation duration.	Exceedances are noted for all flood events	Ongoing refinement and consultation proposed.
	Highways and sealed roads >80km/	Forthcoming (10% limited adopted in the interim)	Exceedances noted	Ongoing refinement and consultation proposed.
	Elsewhere	Where existing inundation is less than 1 hour in flood duration, the post-development flood duration shall not exceed 1 hour. Where existing inundation is greater than 1 hour in flood duration, up to 10% increase in duration of inundation. No duration limits apply to newly flooded land no greater than 1000m2 in area.		

Table 2.4 Summary of Modelling Requirements and BMT Comments on IRDJV (2022a)

Items	The minimum requirements for the flood modelling	BMT Comments
1	2D flood modelling consistent with current best practice and: (i) the 2019 version (or later version) of Australian Rainfall and Runoff: A guide to flood estimation (ARR); (ii) Floodplain Risk Management Guide – Incorporating 2016 Australian Rainfall and Runoff in studies (OEH 2018) or any subsequent update to this document, or additional guidance provided by EES on the application of ARR within NSW.	Refer Section 3 to Section 5
2	Simulation of the 1%AEP flood event and: (i) at least two other events more frequent than 1%AEP; (ii) at least one other event less frequent than 1%AEP; (iii) additional events required at any specific location in order to allow a full understanding of the variation in flood behaviour between flood events of 1%AEP and 0.5EY; (iv) additional events required at any specific location in order to allow full consideration of flood behaviour in events rarer than 1% AEP and up to the probable maximum flood (PMF) having regard to the potential risks to life and the requirements of the NSW Floodplain Development Manual.	Refer Section 3 to Section 5
3	Inclusion of at least five durations including the critical duration for each flood event. These durations are to be selected to be representative of the range of durations that could occur and include all durations that will be relevant to the design of the CSSI and the assessment of impacts.	Refer Section 3 to Section 5
4	Model coverage to include all parts of the CSSI corridor where inundation could occur and extending a minimum of one kilometre upstream and downstream of the corridor, or further where there is a possibility that the influence of the CSSI may extend beyond one kilometre from the corridor.	Section 5
5	Simulation of not only watercourses but all overland flow paths, including new overland flow paths resulting from the construction of the CSSI	Section 5
6	Model prediction of flood height changes to a resolution no coarser than one (1) centimetre	Section 5
7	Changes in flood behaviour and inundation areas to accurately assess against the QDLs listed in Table 1	Section 5
8	Model boundary locations are to accurately represent Tycannah Creek's flood flow outbreaks and flooding conditions at rail drainage structures.	Section 5
9	Model simulation of cross-drainage structures (including bridges, culverts and pipes) shall take into consideration the potential for blockage to occur in accordance with the procedure in ARR. The peer reviewer must be satisfied that: (i) the design blockage for cross-drainage structures are determined in accordance with the procedure in ARR, using data from the contributing catchment(s); and, if necessary, (ii) appropriate mitigation structures are installed and maintained to block debris from arriving at the entrance to the cross-drainage structure. The blockage calculations and assumptions for each cross-drainage structure are to be provided in the Flood Design Verification Report	Section 5 and Section 6
10	Where bridges are proposed for cross-drainage, the bridge shall be designed so that the modelling has accounted for the approach to freeboard through complementary bridge structural design and consideration of hydraulic flows	Not reviewed by BMT
11.	The flood modelling, the final design of the CSSI and the assessment of flood impacts are to have regard to the following documents and guidelines which are additional to those listed in Section 15.1.2 of the EIS (and Mitigation Measure D6.1 of the SPIR): (a) Moree Floodplain Management Plan; (b) Gwydir Valley Floodplain Management Plan; (c) Narrabri Flood Study – Namoi River, Mulgate Creek and Long Gully, 2016; (d) Narrabri Floodplain Risk Management Study and Plan Volume 1: Supplementary Flood Study – Namoi River, Mulgate Creek and Long Gully, 2019; (e) Australian Rainfall and Runoff: A guide to flood estimation, 2019; (f) Floodplain Risk Management Guide – Incorporating 2016 Australian Rainfall and Runoff in studies (OEH 2018); (g) Australian Disaster Resilience Handbook 7. Managing the Floodplain: A Guide to Best Practice in Flood Risk Management in Australia (AIDR 2017).	Compliance with Moree, Gwydir Valley, Narrabri Flood Study, Narrabri Floodplain Risk Management Study and Plan Volume 1, Floodplain Risk Management Guide and Australian Disaster Resilience Handbook 7 has not been assessed by BMT.

Table 2.5 Summary of FDV Report Requirements and BMT Comments

Items	Indepenent Reviewer Scope (30% & 70%) Requirements	BMT Comments
1	Review and provides commentary on: The EIS Service Provide's proposed assessment methodology. This review is to have regard to the NSW Floodplain Development Manual, associate quidance, the methodologies included in ARR 2019 and any other documentation identified in the SEARS The flooding management objective and design limits (output from the Community Consultation activities)	Completed
2	Review and endorses the calibrated hydrology and hydraulic models, including assumptions, inputs and output.	Completed subject to further validation
3	Review and provide technical commentary on, EIS service provides work to date, including findings report from field works, baseline impact assessment and technical reports.	Completed

3 Review of WRM (2017) Flood Study

3.1 Overview

As documented in IRDJV (2022a), the N2NS Phase 2 assessment has adopted the hydrology provided in the Moree Plains Shire Council's Flood Study for Moree and Enirons. (WRM, 2017). The hydrological modelling comprised the following:

1. Main regional river inflow to the upstream boundary of the hydraulic model was based on Flood Frequency Analysis (FFA) of the gauge record at Gravesend. This represented the primary inflow to the hydraulic model domain; and
2. Local catchment inflows to the modelled area from smaller tributaries and creek systems that enter the Gwydir-Mehi floodplain downstream of Gravesend. These inflows were modelled using the XP-RAFTS hydrological modelling software program and based on the now superseded ARR1987 guideline. These inflows are significant but only constitute approximately 15% of the peak flow that passes through the proposal area.

As noted above, the key hydrological input (i.e. flood hydrographs) into the hydraulic model was based upon the FFA undertaken by WRM (2017) at Gravesend. As documented in ARR 2019, '*where adequate data of sufficient quality are available, it is recommended that an at-site Flood Frequency Analysis (FFA) be used for estimation of the design peak flood discharge quantiles*'. Consequently, IRDJV (2022) has undertaken a detailed review of the WRM (2017) FFA to ensure its acceptable for use and BMT has also provided a high-level review.

3.2 Flood Frequency Analysis (FFA)

3.2.1 Gauging Data

From a review of the WRM (2017) report, there are 12 stream gauges located on the Gwydir River and the Mehi River. The Gwydir River gauge at Gravesend was considered a key reconciliation point with a catchment area of approximately 11,020 km^2 representing approximately 78% of the total catchment to Moree (i.e. approximately 14,106 km^2).

The Gravesend gauge has a long period of record dating back to 1936, and from the WRM (2017) report, located in a relatively confined section of the floodplain. The gauge was, however, impacted by the construction of Copeton Dam, which commenced in 1968 and was completed in 1976. From the WRM (2017) report, the FFA was undertaken for the following:

1. Post Copeton Dam recorded flows (i.e. 1976 onwards); and
2. Full gauge record with adjusted post Copeton Dam flows based on IQQM modelling.

As detailed in WRM (2017) report, there is adequate data of sufficient quality to enable a FFA to be undertaken, however the construction of the Copeton Dam provides a significant discontinuity in the gauging record.

3.2.2 FFA Assessment

The WRM (2017) FFA was undertaken in accordance with ARR (2019) with respect to:

1. Rating curve checks were made;

2. Analysis was undertaken using the recommended FLIKE software package and the Bayesian inference methodology;
3. Adjacent gauges were used to supplement and extend the annual series;
4. Historical data checks were undertaken that indicated that the 1955 flood peak had not been exceeded since 1860; hence it was assumed all rare floods were included in the assessment.
5. Low flows were removed from the series to remove undue influence on the rare flood estimate;
6. Water year was used from October to September.

As previously noted, the IQQM modelling was undertaken to adjust the Pre-Copeton Dam flows to represent the post-Copeton Dam flows. From the assessment provided in the WRM (2017) report, we note that 18 floods prior to 1971 were reduced to account for the dam, while six (6) were excluded from being below the low flow threshold; hence only 12 floods were reduced from the 84 gauge records available.

Since the WRM (2017) assessment, there has been an additional six (6) years of data, with the March 2021 flood having a peak flow in the order of 3,120 m^3/s and approximately the 7th largest flood on the record since 1892. Limited to no flow was discharged from the Copeton Dam in the March 2021 flood event.

3.2.3 Review of Gravesend Stream Gauge Results

A review of the Gravesen Stream Gauge results was undertaken at this key reconciliation point since the catchment to this location represent 78% of the area to Moree and is the key inflow to the hydraulic model.

A summary of the WRM (2017) FFA key points indicates the following:

1. The 1 in 100yr AEP flood discharge at Gravesend is **6,110** m^3/s and the 90% quantile probability limits are 4,370m^3/s to 9,640 m^3/s.
2. The period of record without using the historical data would appear to overestimate the peak discharges for the larger events. From the FFA assessment, it would indicate the 1 in 100yr AEP would increase to **7,570** m^3/s.
3. The period of record without using pre-Copeton Dam flows (i.e. 1973 to 2015) would appear to under estimate the peak discharges slightly with the 1 in 100yr AEP being **5,930** m^3/s.
4. The largest flood on record is the pre-Copeton Dam 1955 flood, with a peak flow of **6,685** m^3/s, with an estimated AEP in the order of 1 in 100yr to 1 in 200yr.

From the above points, it is clear that extending the record to 156 years significantly lowers the 1 in 100yr AEP design flood event. This extension of record, as reported, appears to be based upon the investigations undertaken by Cameron McNamara Consultants (1983) that found that “the recorded February 1955 flood height has not been exceeded since about 1860”. From a cursory review of flooding in Moree from Trove (https://trove.nla.gov.au/) this assumption appears reasonable and Annex A, provides two articles that appear to support this assertion.

3.2.4 Flood Hydrograph

WRM (2017) has not developed a numerical hydrological model of the catchment upstream of Gravesend but rather developed a flow hydrograph from the post-Copeton Dam 2012 flood hydrograph.

The resulting flood hydrograph provided in the IRDJV (2022) TUFLOW flood model is provided in Figure 3.1 below and has a peak flow of 5,974m^3/s (i.e. 97.8% of the FFA peak flow) and the total flood volume is 824,283 ML.

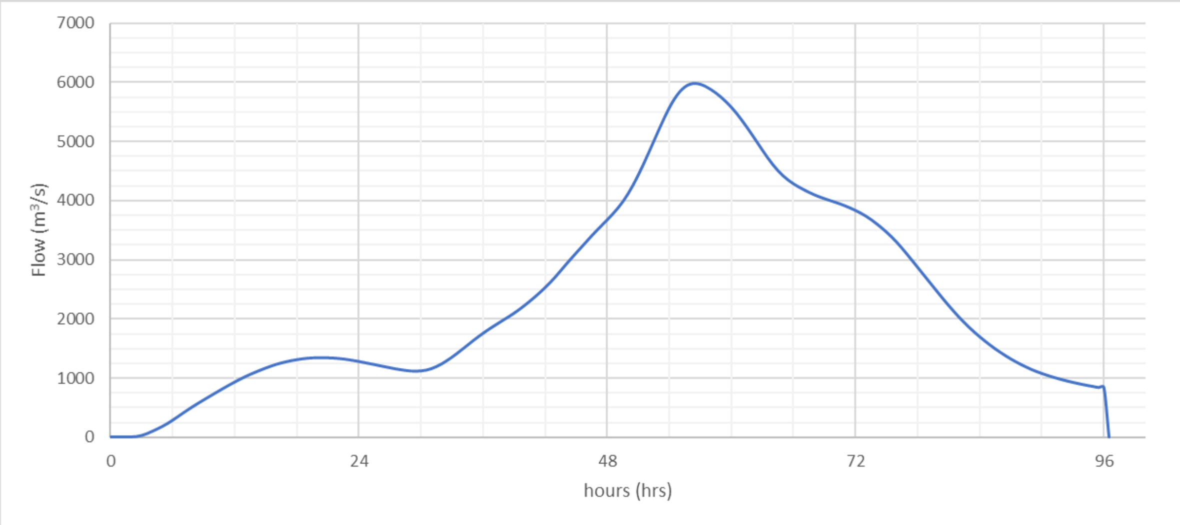


Figure 3.1 Adopted 1 in 100yr AEP Inflow Hydrograph

The above TUFLOW flood hydrograph is identical to the WRM (2017) Mike Flood hydrograph, including all other inflow boundaries.

As the flood hydrograph was developed based on the 2012 flood event at Gravesend and has not been cross-checked with ARR (2019) with regards to peak flows or volume, BMT has developed an URBS hydrological model based on the North Star to Border flood investigation parameters. The hydrological model developed was also calibrated/cross-checked to the most recent March 2021 flood event as discussed in Section 4.

3.2.5 RFFE

ARR (2019) Regional Flood Frequency Estimation (RFFE) tool provides an empirical estimate to verify peak discharges. This tool uses pre-determined flood frequency estimates from nearby gauges and derives estimates on ungauged catchments. ARR (2019) recommends the use of this tool for validation, where appropriate.

As indicated by the OEH (2019) assessment, RFFE can significantly over or underestimate peak flows when compared to at-site FFA and 'reconciled losses' generally provide a better fit to at-site FFA. Notwithstanding this, the results of the RFFE are provided below for the 1 in 100yr AEP, noting the RFFE is unlikely to appropriately reflect Copeton Dam's influence:

1. Entire Catchment (excluding influence of Copeton Dam) – **7,840** m^3/s;
2. Catchment Downstream of Copeton Dam – **5,770** m^3/s

The RFFE estimate provided above for the 'Entire Catchment' is considered unreliable as the shape is very irregular. However the peak flow at Gravesend stream gauge is in the order of 5,700 m^3/s to 7,800m^3/s and compares reasonably well with those from the FFA.

The irregular catchment shape is also noted from the BMT URBS catchment modelling assessment (refer to Section 4) as peak flows determined at the Gravesend stream gauge location were similar, regardless of the contribution of the Copeton Dam upstream catchment. Volume of runoff was, however, notably different and may influence the peak flow at Moree.

3.3 Local Catchment Assessments

A number of XP-RAFTS models were developed for the catchment areas downstream of Gravesend, which included the following:

1. Halls Creek
2. White Swamp
3. Gwydir River
4. Marshalls Pond Creek
5. Mehi River
6. Mia Mia Creek
7. Eatons Pond Creek
8. Slaughterhouse Creek
9. Mosquito Creek.

The local catchments represent a total area of 3,086 km^2 and, as previously mentioned, are approximately 22% of the total catchment to Moree and as noted by WSP (2021), contribute only 15% of the peak flow at Moree.

WRM (2017) design events used ARR (1987) methodology as the assessment pre-dated ARR (2016). WSP (2021) have reviewed the numerical models with respect to the ARR (2019). The results from the assessment indicate that ARR (2019) increases critical peak flows by +7%, +37% and +42% for the three events assessed, while for the 48hour storm, peak flows varied with two catchments reducing to -35%, -22% and one catchment increasing by +10%.

BMT also updated this model to provide design flow events using the ARR (2019) methodology to enable an additional verification method. Similar to the URBS assessment, the model was simulated for two sets of losses which are:

1. WRM Adopted Losses – these are the initial and continuous losses adopted in the WRM study and are 30 mm and 4.5 mm/hr
2. ARR (2019) Datahub Losses – 34mm and 1 mm/hr

The results from the assessment are presented in Table 3.1.

Table 3.1 Hydrologic Flow Comparison

Comparison Location	(1 in X) AEP	WRM ARR 1987	WRM XP-RAFTS ARR2019 Ensamble		BMT URBS ARR 2019 Ensamble	
			WRM Losses (m^3/s)	ARR2019 Losses (m^3/s)	Verification Losses (m^3/s)	ARR2019 Losses (m^3/s)
Horeshoe at Tycannah Creek – 48 hour duration (i.e. not critical flow)	5	228			140	361
	20	509			397	662
	100	890			858	1097
Horeshoe at Tycannah Creek (critical peak flow 12hrs for ARR 2019)	5	-	123	364	427	390
	20	-	340	695	729	688
	100	-	742	1157	1181	1195

The results from WRM's XP-RAFTS model for the ARR (2019) datahub losses produced similar peak discharge to the values found in the URBS BMT hydrological model. A review of the XP-RAFTS model for the other 7 internal catchments was undertaken, the discretisation and results of the ungauged catchments are consistent with the Tycannah Creek assessment.

Overall the WRM XP-RAFTS models are considered acceptable, and their use for inflows into the greater regional catchment is considered appropriate when considering that the peak flows are likely to pass much earlier than the regional flows, and the contribution is limited to 22% of the total catchment and 15% of the total peak flow.

4 Gravesend Hydrological Modelling Verification

4.1 Overview

The FFA (refer to Section 3.2) undertaken by the WRM (2017) uses the recommended method identified in ARR 2019 and therefore provides confidence in its use for the design of peak flood flows. However, for the Gwydir River at Gravesend, the volume of the flood hydrograph and timing will also have a dominant influence on the IRDJV (2022) design (mitigation) in meeting the Floodplain Management Objectives (FMO) as detailed in Section 2.

WRM (2017) adopted the 2012 flood hydrograph to represent inflows from the Gwydir River. The inflow represents the post Copeton Dam and the adopted flow hydrograph is similar to the 1955 flood event (refer to Figure 4.3). Independent verification of the WRM (2017) peak flood flow and flood hydrograph (i.e. volume and timing) and ultimately IRDJV (2022a) design was undertaken through the construction of an independent URBS hydrological model by BMT. The independent hydrologic model was developed using the Unified River Basin Simulator (URBS), an industry-standard hydrologic software package. The URBS hydrologic model developed is shown in Figure 4.1, and one parameter set was assessed for the URBS hydrological model, this was based on the ARTC Inland Rail North Star to Border (NS2B) flood assessment.

The design discharge was simulated using the ARR (2019) methodology. The initial and continuous losses for the design events have been assessed against the standard ARR (2019) datahub losses and the OEH (2019) report recommendations of using calibrated reconciled (NS2B) losses.

4.2 North Star to Border (NS2B) Parameter Set Review

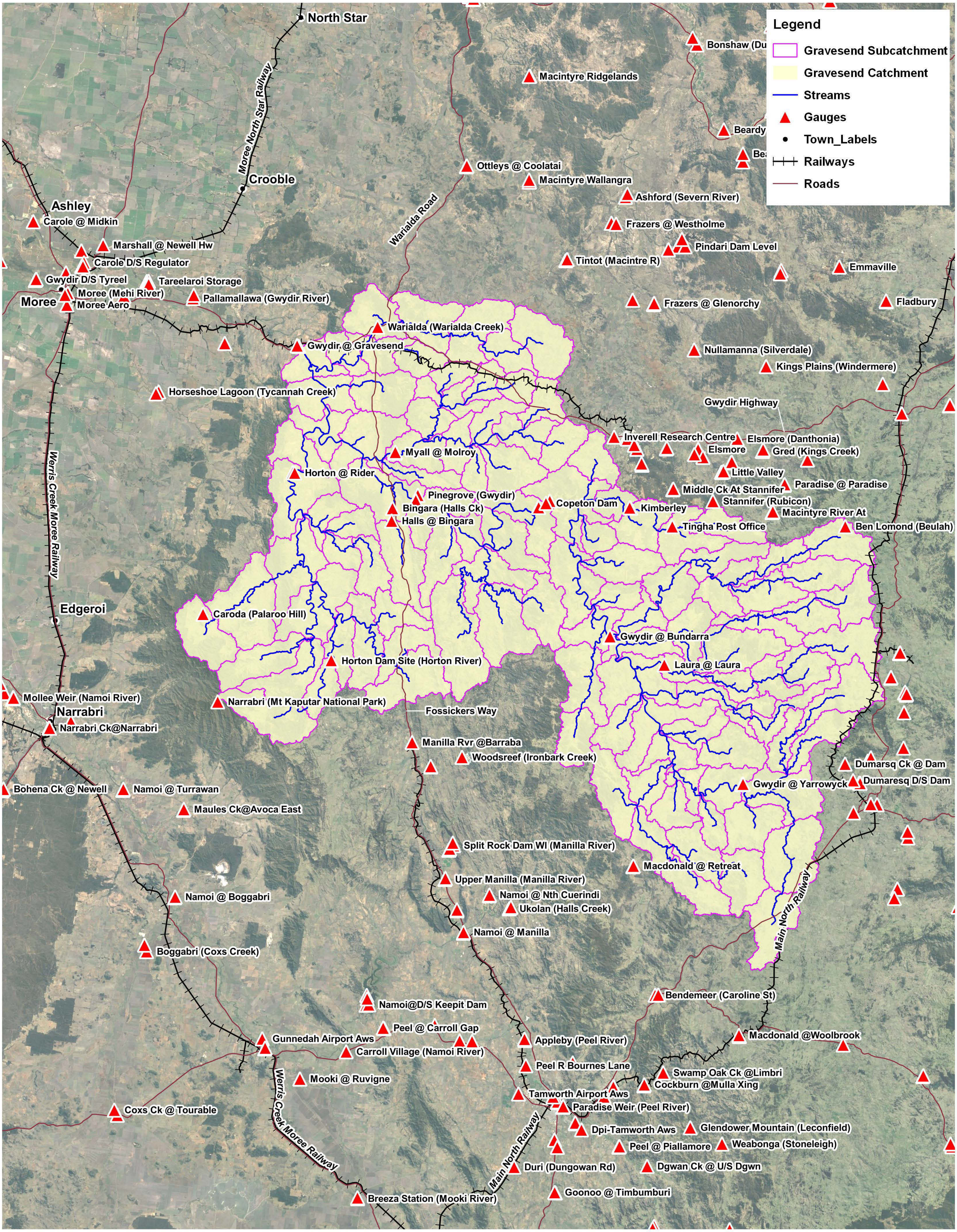
4.2.1 Background

BMT undertook a review of the Future Freight Joint Venture (FFJV, 2021) Hydrology and Flooding assessment for the adjacent Macintyre River catchment. The Macintyre River system is located adjacent to and north of WSP (2021) Phase 2 catchments, as presented in Figure 4.2. As identified by ARR (2019), the transfer of model parameters from Neighbouring Catchments is a best practice approach and is a special case of the ‘regional relationship’ type approach discussed in ARR (2019).

The (FFJV, 2021) updated the Department of Primary Industry Environment (DPIE) hydrological and hydraulic modelling for ARTC. A detailed re-calibration of the hydrological models (i.e. URBS models) was undertaken for the purpose of creating a set of consistent models capable of reproducing all three calibration events using a fixed set of parameters, thereby greatly improving confidence in the model calibration as well as the models’ ability to produce flows for non-calibration events (i.e. Design Events). The re-calibration included:

1. Review and update of previous model data, including rainfall and gauge ratings;
2. Inclusion of additional rainfall and stream gauge data, where available; and
3. Increased emphasis on calibration to the January 2011 flood, which provides a significant amount of more recent and reliable data, not available in the previous DPIE model calibration.

An overview of the re-calibration and model parameters are presented below.



LEGEND

BMT's SubCatchments

Streams

Roads

Railways

Title:

URBS Hydrological Model

Drawing: **4.1**

Rev: **A**

BMT endeavours to ensure that the information provided in this map is correct at the time of publication. BMT does not warrant, guarantee or make representations regarding the currency and accuracy of information contained in this map.

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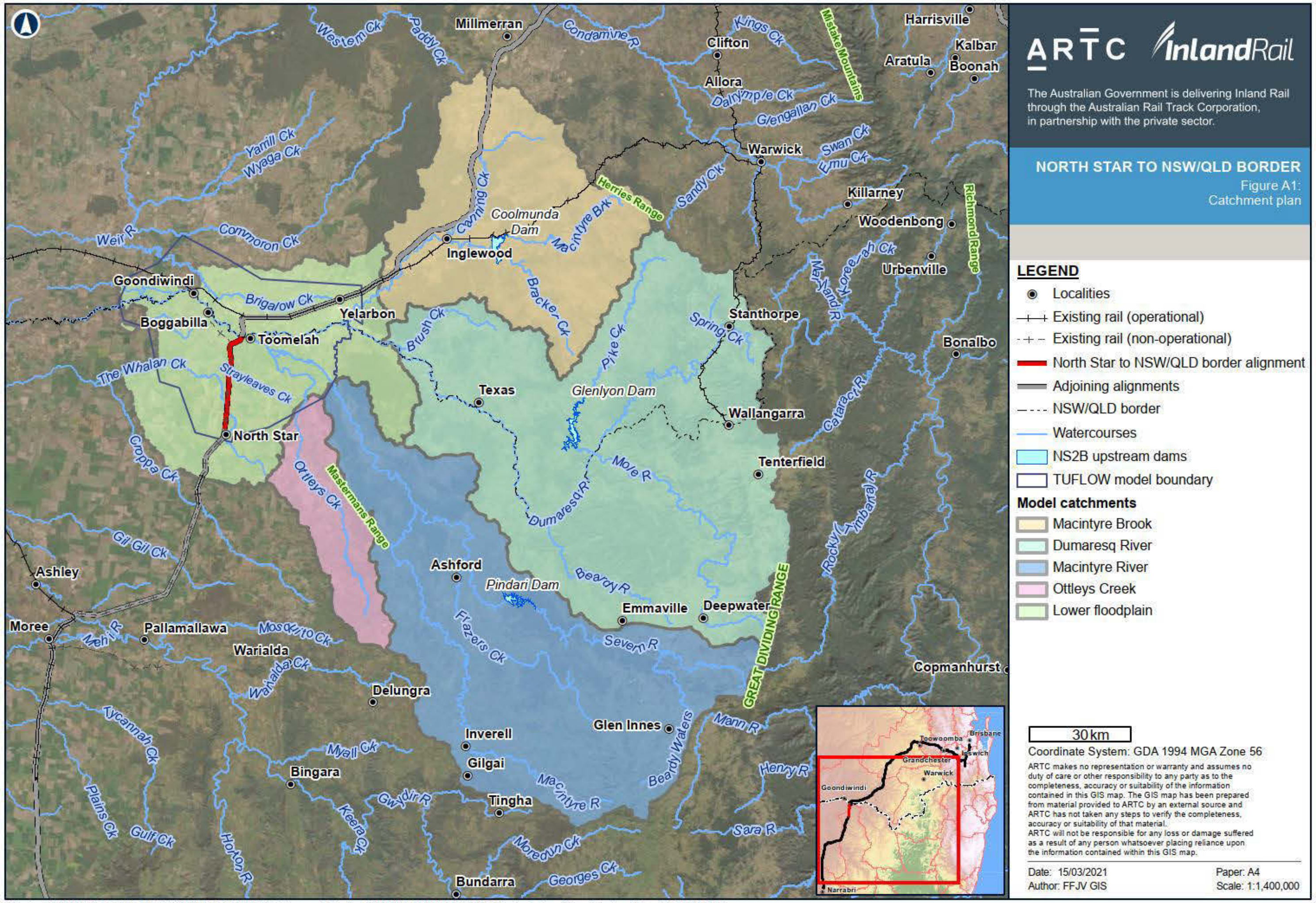

Figure 4.2 North Star to Border and RDJV Catchments

4.2.2 Calibration Parameters

Within the Macintyre River system, there was a significant amount of gauging data available and this data was used by FFJV (2021) for FFA. As detailed in FFJV (2021), there was adequate data of sufficient quality to enable a FFA to be undertaken at each gauge and also to allow a detailed calibration of the hydrological model for design purposes. The re-calibration achieved several significant outcomes:

1. successfully calibrated at multiple stream gauges within the catchment, demonstrating that they are internally consistent and that they successfully represent the runoff contributions from all parts of the catchment in terms of both magnitude and timing;
2. multiple events of different magnitude and duration using a single set of parameters demonstrating that the routing characteristics are representative of the real catchment and are consistent over a wide range of flows; and
3. FFA reconciled initial and continuing losses were developed.

Overall, the re-calibration and improvements achieved by FFJV (2021) indicate that the models were reliably representing the physical stream routing characteristics present in the catchment and provided improved confidence that the models can be used to reliably represent other flood events other than the specific calibration floods.

The adopted parameters used for the re-calibration are presented in FFJV (2021) report and presented below for ease of reference in Table 4.1.

Table 4.1 ARTC (2021) URBS Calibration Parameters

Parameters	Macintyre River	Dumaresq River	Macintyre Brook	Ottleys Creek	Macintyre Floodplain
Alpha	0.45	0.45	0.45	0.45	0.45
n	0.85 [a]	0.85	0.85 [b]	0.85	1.0
Beta	1.2	1.2	1.2	1.2	1.2
m	0.8	0.8	0.8	0.8	0.8
x	0.3	0.3	0.3	0.3	0.1
Reach Length Factors	0.6 to 1.6	1.0 to 3.0	0.8 to 2.0	1.0	0.3 to 3.0
Initial Loss (mm)					
1976	20 to 60	30 to 70	60 to 80	30	60
1996	50 to 100	40 to 80	45 to 60	30	30
2011	25 to 50	20 to 40	30	50	30
Continuing Loss (mm/h)					
1976	2.4 to 3.3	2.5 to 4.5	2.8 to 4.0	3.5	2.0
1996	1.2	0.5 to 3.0	0.5 to 3.0	3.5	3.0
2011	1.6 to 3.5	0.8 to 2.7	1.0 to 1.4	2.1	2.1

Table notes:
a n=1.0 for lower reach between Ridgeland and Holdfast
b n=1.0 for lower reach between Inglewood and Booba Sands

The FFJV (2021) calibrated URBS model was also used to determine design peak flows and hydrographs based on the Ensemble Event methodology described in ARR (2019). The FFJV (2021) review of the design peak flows, based on both the ARR Data Hub Losses and 'Reconciled Losses' through comparison with the FFA, are presented in Table 4.2.

Table 4.2 ARTC (2021) URBS Initial and Continuing Loss Parameters

Catchment	ARR Data Hub Losses		Reconciled Losses	
	Initial	Continuing	Initial	Continuing
Macintyre River to Holdfast	35 mm	2.4 mm/h	25 mm	2.4 mm/h
Dumaresq River to Glenarbon	29 mm	4.6 mm/h	29 mm	3.0 mm/h
Macintyre Brook to Booba Sands	27 mm	1.2 mm/h	30 mm	2.5 mm/h
Ottleys Creek	57 mm	0.1 mm/h	30 mm	3.5 mm/h
Lower Macintyre Floodplain	47 mm	0.3 mm/h	30 mm	3.0 mm/h

The reconciled loss approach is recommended as per the OEH (2019) report for NSW. The average losses are 2.88mm/hr.

4.3 March 2021 Verification

Based on the NS2B parameters set for the URBS model, the recent March 2021 flood event was used to determine the adequacy of the URBS catchment model developed and the subsequent ARR (2019) design flows.

For the March 2021 flood event, no flow was discharged from the Compton Dam, hence the hydrological model excluded the upper Compton Dam catchment, hence the effective catchment area to Gravesend was reduced from 11,020 km^2 to 5,740 km^2. The resulting calibration/ verification is shown in Figure 4.3 with an initial loss of 25mm and a continuing loss of 2.0mm/hr.

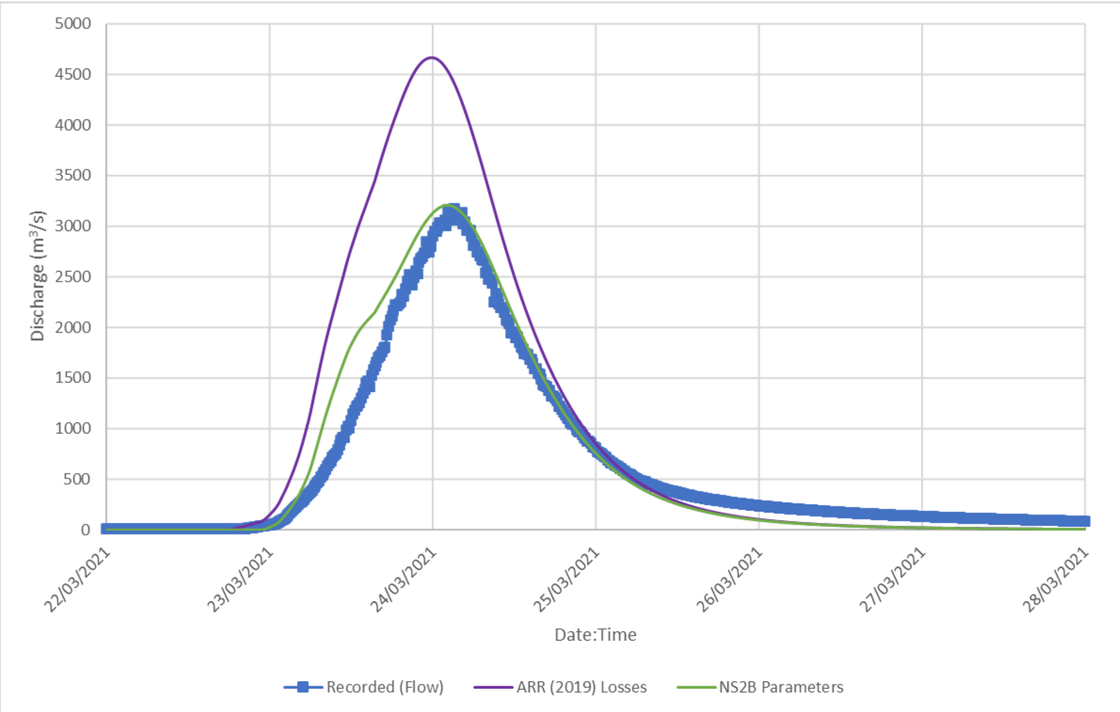

Figure 4.3 March 2021 Calibration | NS2B & ARR (2019) Losses

As presented in the above hydrograph above, the adopted NS2B parameters (i.e. Alpha, Beta, n, m, x and Reach length =1) provide a good calibration without any change to the standard parameters and losses that are consistent with the 'reconciled' losses. The ARR (2019) losses appear to substantially over estimate the peak flow flow by 50%.

4.4 Standard ARR Design Events

The URBS hydrologic model was used to determine design flows for the runoff to Gravesend stream gauge using the Design Event Approach (DEA) based on the Ensemble Event methodology described in ARR (2019). As detailed in ARR (2019), the parameter set used for this assessment was consistent with the derived parameters determined from NS2B.

Whilst the hydrological parameters sets remain unchanged ARR (2019) and OEH (2019) recommend the use of average catchment losses or FFA-Reconciled losses. The reconciled initial and continuous losses used for the assessment were based on consideration of NS2B assessment (refer to Table 4.2) and the March 2021 flood calibration event, while the assessment also considered the ARR (2019) standard data hub losses, the resulting losses used for the assessment were as follows:

1. NS2B (i.e. reconciled losses / avg. catchment losses) –> IL = 30 mm and CL 2.5 mm/hr.
2. ARR 2019 Datahub Losses –> IL = 34mm and CL= 1mm/hr

A comparison of the flood hydrographs determined by BMT based on reconciled losses and ARR (2019) data hub losses and the adopted WRM (2017) flow hydrograph is presented Figure 4.4.

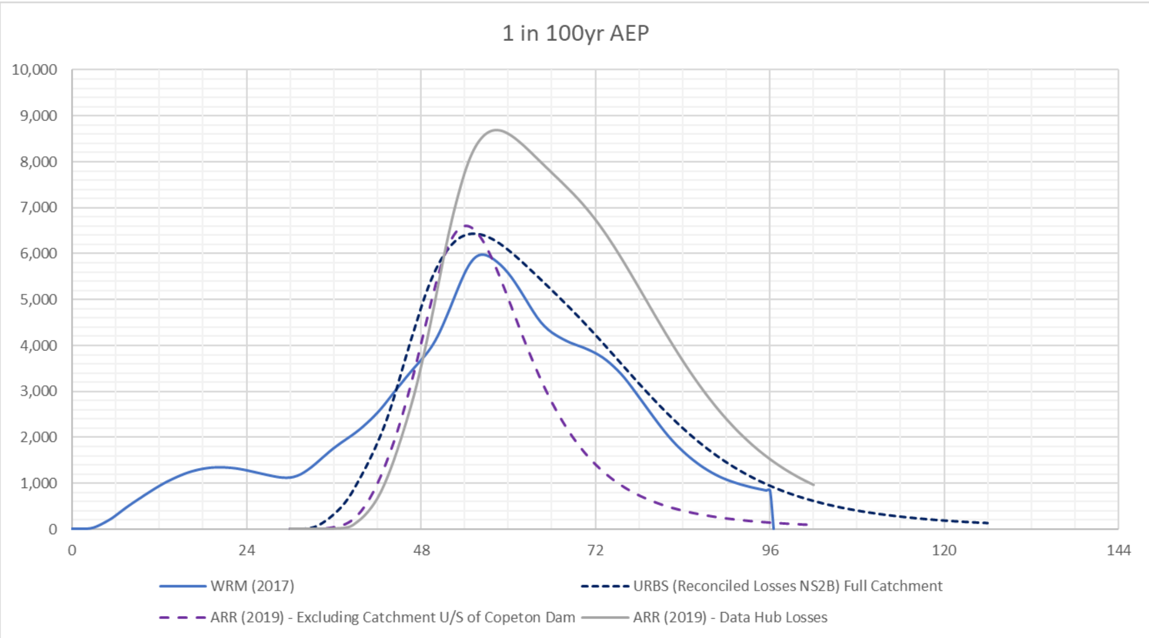

Figure 4.4 1 in 100yr AEP Design Flows at Gravesend

As noted in the above graph, the 'reconciled' design flows determined from the URBS catchment model compares well with the WRM (2017) adopted flow hydrograph, noting the URBS catchment model does not contain any attenuation effects from the Copeton Dam (i.e. URBS model is considered conservative since there is no attenuation from the dam), but includes the full catchment area. The ARR (2019) full catchment assessment with a peak flow in the order of 8,700m^3/s appears to again over-estimate the peak flows determined by the FFA, but it does show the catchments sensitivity to continuing loss rates.

A comparison of the flood volumes calculated as part of WRM (2017) design flood and the volume from the BMT URBS reconciled flood hydrograph from the 30hrs to 96hours are as follows:

1. WRM (2017) 30hrs to 96hours – 732,379m^3
2. WRM (2017) 0hrs to 96hours – 824,283m^3
3. BMT URBS reconciled Full Catchment – 662,603m^3
4. BMT URBS reconciled Excluding Catchment upstream of Copeton Dam – 459,045m^3

The above volumes indicate the WRM (2017) is likely to be conservative on volumes when compared with ARR (2019) standard ensemble flood events and hence the adopted flood hydrograph based on the use of the 2012 flood event is considered reasonable.

This is also demonstrated by the WRM (2017) historical flood water level hydrographs which are provided below for ease of reference.

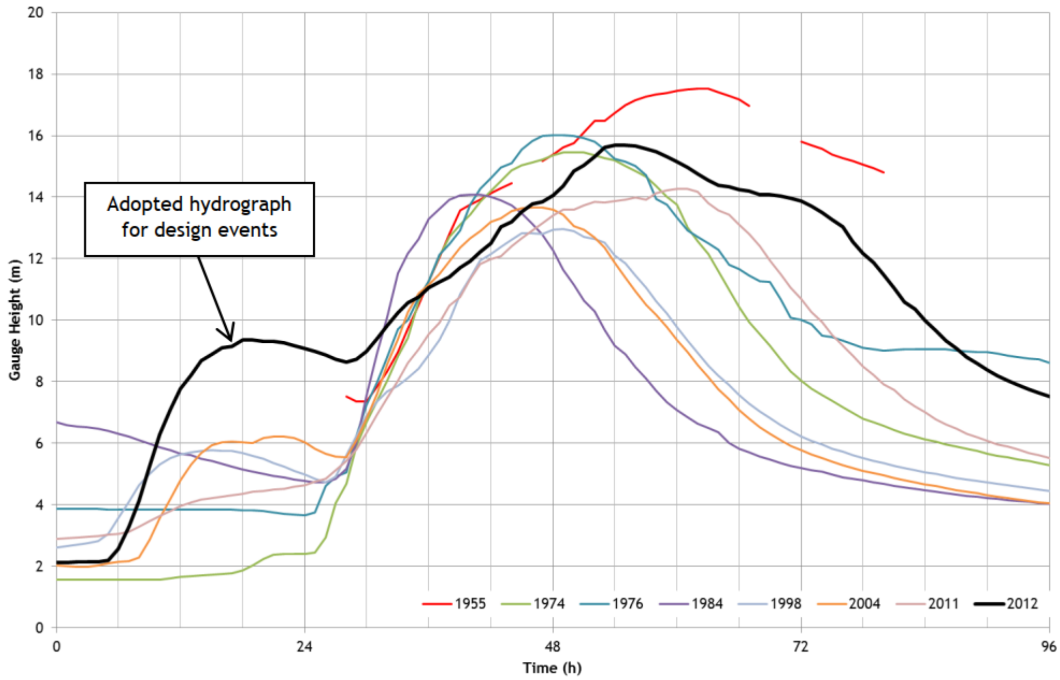

Figure 4.5 1 in 100yr AEP Adopted Design Hydrograph at Gravesend

4.5 Climate Change

WSP (2021) have adopted a 20% increase in flow to represent climate change. Given the inflow at Gravesend is based on the 2012 flow hydrograph and scaled, the method of increasing the flow by 20% rather than rainfall intensity is appropriate.

The increased peak flow is therefore 7,332 m^3/s which is similar to the WRM (2017) assessment of :

1. 1 in 200yr peak flow of 7,520m^3/s, based on the historical data set; and
2. FFA based on not using any historical data (i.e. 1937 to 2015) of 7,570 m^3/s for the 1 in 100yr AEP.

The +20% therefore provide a suitable sensitivity assessment with regards to the residual uncertainty associated with the FFA.

4.6 Extreme Events

The PMF flood, as reported in the WSP (2021) report, is based on the WRM (2017) extreme event, which was the 1 in 100yr AEP flood event factored by 3. Whilst the assessment is an extreme event, further assessments will be required in the detailed design to determine the 1 in 2,000yr AEP used for bridge design and the PMF for risk assessments.

As documented in ARR (2019) and illustrated in Figure 4.6, FFA may be used to estimate peak flood flows up to approximately 1 in 200yr to potentially 1 in 1,000yr AEP with suitable data, but high uncertainty. However, for more extreme flood events and for detailed design, consideration of a calibrated hydrological model should be considered to appropriately define very rare to extreme flood events.

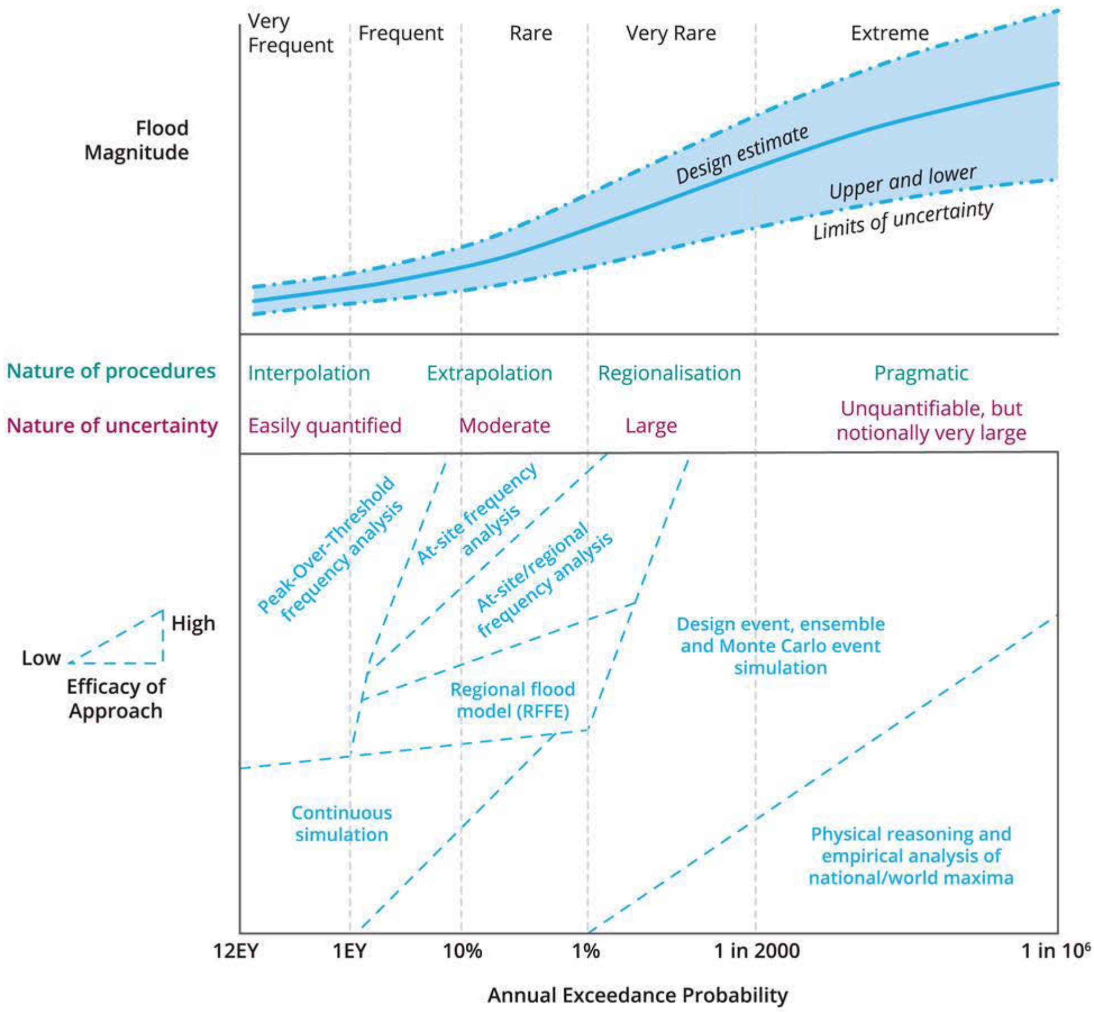

Figure 4.6 Illustration of Relative Efficacy of Different Approaches for the Estimation of Design Floods

5 Hydraulic Assessment

5.1 Overview

A review of the Inland Rail Design Joint Venture: Environmental Impact Statement Technical Paper 4: Hydrology and Flooding Impact Assessment: Narrabri to North Star (N2NS) Phase 2 – Moree to Camurra North, Ref: 2-0001-262-EAP-00-RP-0033 (28 March 2022) and associated numerical hydraulic model files was undertaken.

To enable the review, the hydraulic model files for both pre and post development scenarios were provided to BMT electronically. This section of the review covers the technical aspects of the TUFLOW model development including the TUFLOW model coverage, setup and performance.

The hydraulic model files provided covers the Gwydir-Mehi river system which encompasses the proposal site. The TUFLOW model is based on the MIKE FLOOD hydraulic model developed for the Moree Plains Shire Council's flood study for Moree and Environs (WRM, January 2017). The MIKE FLOOD model is a calibrated model and has been previously peer reviewed. The MIKE FLOOD model was also provided to BMT.

Model inflows are derived from a FFA at Gravesend and a calibrated XP_RAFTS hydrology model developed for the Moree and Environs flood study. The hydrology has been reviewed separately in section 3 of this report and the inflow are directly included in the TUFLOW model from the WRM (2017) MIKE FLOOD model.

5.2 Overall Methodology Review

The EIS Report for the Phase 2 portion of the investigation, prepared by ARTC, involves the upgrade of approximately 13.7 km of existing rail corridor between Moree and Camurra North within New South Wales. The additional construction of 1.6km of realigned rail corridor is also proposed. A TUFLOW hydraulic model was constructed to represent this length of upgrade based on the calibrated WRM (2017) MIKE FLOOD model.

The hydraulic modelling system used is the TUFLOW hydraulic modelling system and specifically the 2020 version (2020-10-AA) utilising the Heavily Parallelised Computations (HPC) solver functionality in conjunction with the 'Quadtree' functionality for finer grid resolution in specific areas of interest. To construct the model, key input data from the MIKEFLOOD model was used including:

1. Topographic data
2. Inflow hydrographs
3. Culvert and bridge data
4. Floodplain roughness data.

Figure 5.1 is an extract from the WSP 2021 report showing the model extent.

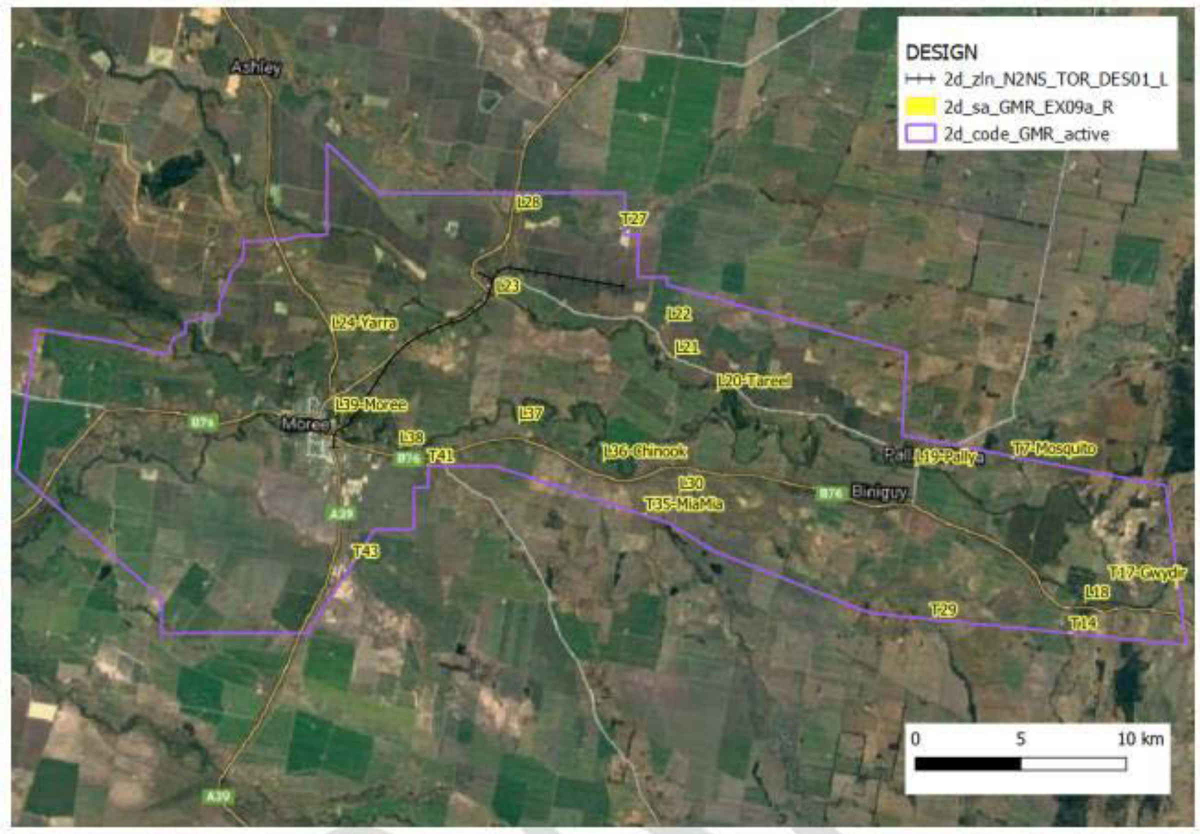

Figure 5.1 TUFLOW Model Extent

The TUFLOW model was developed in two stages with Stage1 being based soley on the MIKE FLOOD model data with a 10m grid resolution.

Once constructed the TUFLOW model was simulated for the 1% and 10% AEP events and compared against the same MIKEFLOOD events for validation.

Following validation, the Stage 2 development of the of the TULOW model included an update with more recent or accurate topography data and the incorporation of the quadtree functionality. The areas represented by quadtree includes 100m upstream and downstream of the rail corridor at a grid resolution of 2.5m

A review and discussion on the modelling methodology is presented below.

5.2.2 TUFLOW Model Validation

Figures 4-5 and 4-6 of the WSP 2021 report present the comparison of peak water levels from each model for the 1% and 10% AEP flood events.

As discussed in the report, the 1% AEP shows good correlation between the two models with generally less than 50mm difference across the floodplain and project area. A localised difference of between 100-200mm is noted at the northern area of Moree.

The 10% AEP shows a significant difference between models in the Mehi River. The report provides the explanation of this being a result of flow distribution in the upper portion of the catchment with more flow being directed towards the Mehi River system in the TUFLOW model for this event. The difference in grid resolution is provided as the most likely cause of the redistribution with the TUFLOW model having a finer resolution in this area compared to the MIKEFLOOD model which uses a coarse flexible mesh. As a result, the report indicates that the TUFLOW is likely to be more accurate due to the finer grid resolution, which we generally support.

Differences in the way structures are represented between the two models is also provided with regard to the differences around structures. It is noted that the increased Mehi River levels in the 10% AEP have little impact on the rail corridor and that the remainder of the project area within the floodplain shows a reasonable comparison.

To further support and verify the WSP (2021) TUFLOW model development, BMT recommend that additional supporting documentation and explanation be provided to justify the higher predicted water levels in the Mehi River system for the 10% AEP be included. In addition, model validation should also be check again a recent historical event as per the MIKE FLOOD model to support the TUFLOW model results against recorded levels. It is understood that the IRDJV will conduct further model calibration at the detailed design phase of the project which will include refinement and calibration to significant flood event including the November 2011, February 2012 and March 2021 events.

5.2.3 Topography

The existing case model topography used the MIKEFLOOD DEM for the initial setup and validation and then included additional datasets to develop the existing case base model used for assessments. It is noted that the data sets used to develop the MIKEFLOOD model were not available and the study has relied upon the extracted DEM for the MIKEFLOOD model.

Topographic data sets used to create the MIKEFLOOD DEM were:

1. Gwydir 2013 AAM project LIDAR tiles (approximately 33,600 hectares surrounding Moree including 27 kilometres upstream and 7.5 kilometres downstream)
2. Gwydir Extension Project LIDAR tiles (537 hectares north of Moree)
3. L0086 Moree – LPI 2012 Project LIDAR tiles (944 hectares to the south-east of Moree)
4. 1 metre resolution upstream DEM provided by the NSW Government (22,620 hectares) originating approximately 14 kilometres east of Moree and extending a further 26 kilometres upstream
5. 1 metre resolution downstream DEM provided by the NSW Government (54,690 hectares) including Moree township and extending approximately 20 kilometres downstream of Moree; and
6. The following ground point survey datasets:
    a. Moree Biniguy cross-sections (2000)
    b. Moree and surrounds (2006)
    c. Moree and surrounds (2013)
    d. Gwydirfield (2015).

Topographic data sets used to update the TUFLOW model for assessment include:

1. ARTC LiDAR survey (2017) – 0.2 metre resolution covering approximately a 1 kilometre wide strip along the project corridor (note that this LiDAR dataset was validated against ground survey and used to define the top of rail level in the flood model)
2. ARTC site survey of local features and infrastructure within the rail corridor
3. Gwydir 2013 AAM LiDAR (as described above); and

4. Mosaic DEM from the MIKE FLOOD model.

Zshape attributes have been used to provide definition of creek/river inverts and to pick up top of levee and embankment features.

As previously noted, this updated topographic model should be validated to a historical flood event (i.e Feb 2012, for which topographic data is still valid) and a comparison made to the WRM (2017) 1 in 100yr AEP flood event where topographic data updates are valid. BMT considers the updated topographic representation to be reasonable within the TUFLOW model based on the available data, and subject to the above verification.

5.2.4 Railway and Highway Representation

Within the TUFLOW hydraulic model, the highway ridge line was identified within the LIDAR survey and schematised using a TUFLOW 2d_zline. This is outlined in Section 4.3.2.3 of the WSP 2021 report. The assessment of the future highway upgrade has used the same method using design details provided by TfNSW. This is considered appropriate in representing the highway.

The existing rail level was represented in a similar manner and was based on ARTC LIDAR survey (0.2m resolution) to define the top of rail level as well as site survey. The design model reflects the rail line upgrades as detailed in the WSP (2021) report which consists of track raising and culvert and bridge upgrades. The methodology is considered appropriate in representing both the railway and highway within the study area for the EIS report phase.

5.3 Hydraulic Structures

5.3.1 Culverts

Cross drainage culverts for both the rail line and highway were represented by one dimensional (1D) structure elements within the two-dimensional (2D) model grid. This is the case for both the existing and design case. As described above, the embankments for the rail and road are represented by specific ridge lines within the 2D model grid.

A review of the culvert structures indicates a reasonable representation of culverts for both the existing and design case models. It is noted that the present-day highway condition culverts are based on the MIKE FLOOD model data and that estimations using on-site and aerial photos have been made where additional data is required.

The design model reflects the rail line upgrades as detailed in the FDVR, which consists of track raising and culvert and bridge upgrades. A review of the culvert representation indicates a reasonable schematisation of these structures. We note some minor instabilities in a limited number of structures that will require further refinement as part of the detailed design.

As a sensitivity test, further review and refinement is recommended where large banks of culverts are proposed, particularly in the design case modelling where the combined bank of culvert width is far greater than the grid cell size. A 2D approach may be preferred in these cases, particularly where velocity may vary across the structure width. Such a sensitivity test at the detailed design phase will help inform the best approach.

5.3.2 Bridges

Bridges within the TUFLOW models have been represented by using the ‘Layered Flow Constriction’ elements within the 2D grid. Form loss coefficients (representing piers) and blockage factors have been applied. Bridge abutments were represented within the 2D model grid.

The layered flow constriction representation has generally been divided into four layers with each layer representing:

Layer 1 – FLC value representing the bridge piers with blockage factor where required to represent reduced waterway opening. FLC value varies depending on bridge design and for this project the range was from 0.16 to 0.55 depending on the length of the bridge.

Layer 2 – FLC value (1.56) representing the bridge deck and parapet with 100% blockage factor;

Layer 3 – FLC value (0.50) representing bridge safety barriers/railings with 50% blockage factor; and

Layer 4 – Flow over the top of railings – assumed to be unimpeded.

The design model reflects the rail line upgrades as detailed in the FDVR which consists of track raising and culvert and bridge upgrades. The representation of bridge structures within the TUFLOW models is considered acceptable and appropriate.

5.4 Grid Size

A grid resolution of 10m has been adopted for all models. Discussion in the WSP 2021 report, Section 4.3.2.9 indicates that three different grid resolutions of 5m, 10m and 20m were tested and that the 10m resolution was adopted as a balance between grid resolution fine enough to represent catchment features and model run times.

Given the broadscale nature of the flood plain, 10m resolution, combined with channels and levees represented by 2d_Zshape elements, would generally provide adequate resolution of the floodplain for initial design modelling. To represent the road and rail corridor in finer detail, the quadtree functionality within TUFLOW has been applied for a width of 100m upstream and downstream of the rail corridor giving a gris resolution of 2.5m within this area.

Overall, the grid size representation is considered to be adequate for the EIS phase of the investigation.

5.5 Boundary Conditions

Boundary conditions used within the TUFLOW models have been sourced directly from the calibrated MIKE FLOOD hydraulic model. Where catchments extend upstream beyond the TUFLOW model boundaries, 2d_bc boundaries, flow versus time (QT) hydrographs have been applied.

Sub-catchments that lie within the TUFLOW model extent have been input as 2d_sa boundaries (QT) as a point source. The locations replicate those of the MIKE FLOOD model. Downstream boundaries in the TUFLOW models are applied as water levels versus flow (HQ) 2d_bc boundaries. Slopes have been derived from the corresponding channel beds.

Overall the application of the boundary conditions is appropriate and acceptable.

5.6 Floodplain Roughness

Floodplain roughness was represented by Mannings 'n' values, adopted from the calibrated MIKE FLOOD model. The adopted values are shown in the following table as described in the WSP 2021 report.

Table 5.1 Adopted Roughness Values

Land Use	Mannings 'n' value
Floodplain	0.085
Riparian vegetation – general	0.075
Riparian vegetation – Lower Mehi River	0.080
Parklands and grassed areas	0.070
Open water – general	0.030
Open Water – Mehi River	0.045
Buildings	0.300
Roads	0.025
Existing Rail/Airport	0.040
New Rail corridor	0.020

Whilst the adopted roughness values are considered appropriate and consistent with the MIKE FLOOD model, if required, these parameters may require further adjustment following the verification of the TUFLOW model to a historical event (i.e. Feb 2012 flood event) and /or consistency with the WRM (2017) design floods. It should be appreciated that whilst the TUFLOW model provides greater resolution, particularly within the channels that the MIKE FLOOD, adjustment of the Manning n roughness could be necessary to refine the conveyance and correlate the result closer to known flood levels. It is noted; however, that previous benchmark testing of a number of hydrodynamic modelling systems (Collins, FACE publication, 1996), that MIKE FLOOD and TUFLOW produced very similar results using the same roughness parameters.

5.7 Agriculture Infrastructure

The WSP (2021) report indicates that the numerous flood storages located within the floodplain have been nulled from the 2D domain (i.e. not represented in the model) based on the approach adopted in the WRM (2017) MIKEFLOOD model. This approach is based on the conservative assumption that the storage will be full or partially full during flood events and will not contribute to lowering flood levels. It has also been assumed that the storage has undergone regular maintenance and/or modifications which are likely to have occurred post LIDAR survey. As such, by being nulled from the 2D domain, these modifications will impact on the predicted flood behaviour.

BMT note the assumptions as described above and consider the adoption as acceptable being based on the adopted and calibrated MIKEFLOOD model. However, we note that a subsequent investigation (Moree FMP Recommendations Investigation, July 30, 2021) was conducted for Moree Plains Shire Council, which investigates the recommendations of a peer review conducted by GCA Engineering Solutions (March 2019) of the Moree and Environs Draft Floodplain Risk Management Study and Plan.

As part of these additional investigations by Moree, the nulled out levees were surveyed and included in the MIKE FLOOD model. The results indicate that the levees commence overtopping in the 5% AEP event and greater and for 1% AEP widespread overtopping of levees occurs. Afflux mapping indicates that up to 600mm reduction in flood levels across the floodplain and between 100-200mm in the northern section of Moree. Provided below in Figure 5.2, is an extract from the report showing the 1% AEP water level differences.

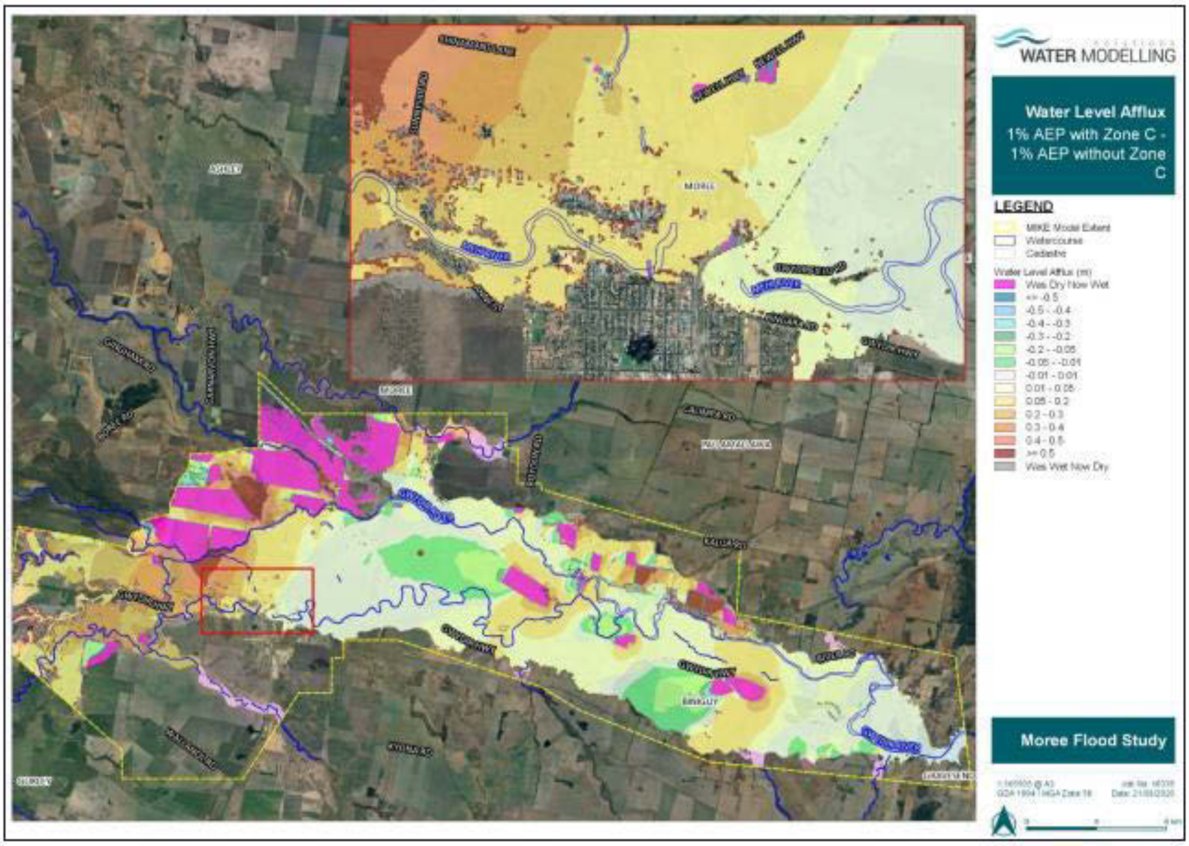

Figure 5.2 Water Level Afflux

From our understanding, the revised levee modelling was recommended to be adopted by Council, and while the currently adopted TUFLOW modelling potentially provides a conservative analysis, a sensitivity assessment of the proposed design should be conducted at the detailed design phase with the current levee height included in the model.

5.8 Summary and Recommendations

BMT has conducted a technical review of the TUFLOW model and the schematisation that forms the basis of the the Inland Rail Design Joint Venture: Environmental Impact Statement Technical Paper 4: Hydrology and Flooding Impact Assessment: Narrabri to North Star (N2NS) Phase 2 – Moree to Camurra North, Ref: 2-0001-262-EAP-00-RP-0033 (28 March 2022).

Based on this review, we consider the overall approach to the hydraulic modelling and methodology is generally appropriate for the EIS phase modelling. Further recommendations to be considered at the detailed design phase from this review include:

1. Additional documentation and reporting in relation to the model verification;
2. Consideration of a historic event (e.g. Feb 2012) assessment for model validation.
3. A sensitivity test based on the revised MIKE FLOOD model incorporating existing levee/storage structures.

6 Blockage Assessment

6.1 Overview

As required by the SEARs, 'identification of allowance for blockage of cross-drainage structures to be made in accordance with ARR'. This review was undertaken to determine if:

1. the design blockage for cross-drainage structures are determined in accordance with the procedure in ARR, using data from the contributing catchment(s); and, if necessary,
2. appropriate mitigation structures are installed and maintained to block debris from arriving at the entrance to the cross-drainage structure.

As detailed by IRDJV (2022a), 'specific blockage factors at each structure were estimated using the latest guidance in Chapter 6, Book 6 of ARR2016, and found to vary between 12.5% and 25%. IRDJV (2022) used an average factor of 15% in the design to provide a consistent factor across all drainage structures.

A desktop review of the design blockage for cross-drainage structures was undertaken cognisant with the procedures provided in ARR (2019). It should be appreciated that our review is limited to a desktop assessment, and field visits have not been undertaken. As detailed by ARR (2019), a desktop assessment cannot provide the level of confidence that would be obtained from a field visit, and consequently, reliance was placed on IRDJV (2022a) assessments that have inspected the site. Where possible, future designs should consider maintenance records that could be available.

6.2 ARR 2019 – Blockage Methodology

6.2.1 Debris Length (L10)

As noted by ARR (2019), the L_{10} value *'is preferably estimated from a sampling of typical debris loads. However, if such data is not available, it should be determined from an inspection of debris on the floor of the source area, with due allowance for snagging and reduction in size during transportation to the structure'.*

IRDJV (2022) has adopted a uniform L_{10} value of 5m; however, no specific details are provided on how this was derived; however the debris potential was also considered 'low'.

6.2.2 Blockage Factors

ARR (2019) details the proposed blockage methodology, and from a review of this, the most likely inlet blockage levels (BDes%) are detailed in ARR (2019),Table 6.6.6 and provided below for reference.

Table 6.6.6. Most Likely Inlet Blockage Levels - B_{DES}%

Control Dimension Inlet Clear Width (W) (m)	AEP Adjusted Debris Potential At Structure		
	High	Medium	Low
$W < L_{10}$	100%	50%	25%
$L_{10} \leq W \leq 3{*}L_{10}$	20%	10%	0%
$W > 3{*}L_{10}$	10%	0%	0%

Consequently, if the culvert width is below the L_{10} value, then a minimum 25% blockage is considered appropriate when a low risk of blockage is identified. It is also noted that the minimum opening height should be designed with at least 1/3 of the width. For existing structures, the opening height should be taken at not less than 50% of the assessed debris L_{10} (Length).

Before the finalisation of ARR (2019), we note that the Engineers Australia Stage 2 report on Blockage of Hydraulic Structures (EA, 2013) provided generic blockage factors (refer to EA, 2013 - Table 7.1). An extract is provided below.

Table 7.1: Suggested 'Design' and 'Severe' Blockage Conditions for Various Structures

Type of structure		Blockage conditions	
		Design blockage	Severe blockage
Pipe inlets and waterway culverts	*Inlet height < 3 m, or width < 5 m:* Inlet Chamber (culverts)	0/20% [3]	100% [4]
	Inlet height > 3 m and width > 5 m: Inlet Chamber (culverts)	0/10% [3]	25% [3]
	Culverts and pipe inlets with effective debris control features	As above	As above
	Screened pipe and culvert inlets	0/50%	100%
Bridges	Clear opening height < 3 m Clear opening height > 3 m Central piers	[5] 0% [7]	100% [6] [7]

The above extract indicates that where a culvert inlet height is below 3m or has a width less than 5m then a blockage between 0 to 20% would apply and 100% for severe blockage assessments.

BMT has reviewed other portions of the Inland Rail EIS. Based on this experience, a blockage factor of 25% was typically applied to all culverts with a sensitivity of 0% and 50% to determine the impact on sensitive receptors along the alignment. However, for the detailed design, we note that catchment specific investigations of vegetation cover and potential for debris blockage can better inform the likely range of blockage factors to be considered, and therefore each bank of culverts should be individualised for blockage factors rather than the adopted 'average' of 15%, including individualised potential mitigation measures.

6.3 Review of IRDJV (2022a) – Blockage

Culvert waterway crossings proposed in Table 6-2 of WSP (2021) indicates the dimensions range typically range from 1800 x 600 to 3600 x 2100 for RCBC. Based on a L10 value of 5m and that the debris potential was classed as 'low', this would indicate that for a culvert with a width (W) < 5m, a minimum blockage factor of 25% should theoretically apply, noting that if the catchments have largely been cleared and cropping is underway, that too needs to be considered in setting blockage factors.

IRDJV have also adopted guidance from ARR (2019) that indicates '*where the width of that part of the approach flow that is capable of transporting the debris under consideration is significantly less than the total width of the structure, then the culverts/spans within the effective transport width be assessed as blocked to BDES and those outside of that zone be reduced to half BDES*'. As IRDJV (2022a) have adopted a universal blockage of 15%, this is considered acceptable, given that the following sensitivity have been undertaken:

1. 0% blockage (all culverts);
2. 25% universal blockage
3. 50% universal blockage.

6.4 Assessment of Blockage Factors

The adopted 15% blockage provides an 'average' result and is accepted for compliance to the QDL; however, the resultant blockage of 25% blockage should also be considered with reference to the QDL to ensure exceedances are not significant in the detailed design. The 0% blockage provides an indication of upper limit downstream impacts, and this shall also be considered with reference to compliance to the QDLs in the detailed design to ensure exceedances are not significant. The universal 50% blockage assessment should be considered to ensure flood impacts do not cause excessive flood hazards.

Results from the blockage assessment has demonstrated that the higher rail embankment causes diversion of more flow through the southern part of the proposal, where the Mehi River and floodplain bridges are located. Flood impacts from these assessments cause 50mm to 200mm impacts in the town of Moree, including increased flood hazards. Further optimisation of the cross drainage via reduction of these flood level impacts and flood hazards in Moree is considered to be warranted during detailed design.

Ultimately, these sensitivity analyses shall assist in detailed design in defining the upper and lower envelope of flood impact on both upstream and downstream properties and would allow an assessment of the effect on sensitive receptors. Individual landowner consultation and/or formal agreement requirements may need to be considered following further refinement of these sensitivity assessments based upon the upper and lower bounds of the blockage assessment. This will ensure impacts are acceptable to landowners and/or that potential liability is suitably addressed.

7 Sensitivity Assessment / Extreme Event Assessment

7.1 Overview

As detailed in ARR (2019), *'sensitivity analysis is a standard engineering technique that provides information on how model outputs are affected by changes in model inputs. Such analyses do not provide estimates of uncertainty, but they do provide a useful means of identifying which factors have greatest influence on the outcome.*

As detailed in ARR (2019) - Two Dimensional Modelling in Urban and Rural floodplains, a discussion is also provided on sensitivity testing, and an example of sensitivity testing to help quantify a model's uncertainty was given as follows:

1. *Adjust hydraulic roughness parameters values up and down by 20%.*
2. *Increase inflows by 20%.*
3. *For downstream boundaries, not at a receiving water body such as the ocean, vary the stage discharge or water level upwards to check that the water levels in the area of interest are not greatly affected.*
4. *Apply blockages and greater losses to hydraulic structures and inlets.*
5. *Apply lower discharge coefficients across embankments such as roads.*

Other useful sensitivity tests include:

6. *Making the model's resolution finer to check that results do not demonstrably change.*
7. *Varying the timestep and other computational parameters.*

From a review of the IRDJV (2022) report and the BMT independent assessments, the following sensitivity assessments were considered a requirement to assist in depicting and demonstrating the potential design impacts of the construction of N2NS IR as follows:

1. +20% increase in flow - WRM (2017) and consequently IRDJV (2022a) hydrology has a relatively high degree of residual certainty due to the FFA undertaken; however, some residual uncertainty remains with the analysis, therefore an increase in flow the design flow (i.e. 1 in 100yr AEP flood event) could result;

2. Blockage of culverts (refer to Section 6) – ARR (2019) highlights the range of possible blockage factors and recommends '*that the sensitivity to such a variation in design blockage levels be incorporated into analysis by considering both an 'all clear' and blocked at twice the calculated 'guideline blocked' level scenarios*'.

The Hydraulic roughness values (increase and decrease by ±20%); sensitivity may be undertaken during detail design, following further verification of the TUFLOW flood model:

As provided in ARR (2019), *the sensitivities provide insight and*, when combined with *'some judgement regarding the relative accuracy of the different factors, can highlight which areas of analysis warrant further investigative effort'.* With regards to the sensitivities undertaken by IRDJV, the results provided by IRDJV should be used by ARTC to demonstrate the uncertainty of design impacts of the railway (i.e against QDLs), so that landholders and stakeholders appreciate the range of potential flood impacts and also for ARTC to appreciate flood immunity and damage risk of the railway.

7.2 Increases Flows (+20% / Climate Change)

7.2.1 Overview

As documented in IRDJV (2022), the project was designed to deliver a minimum of 1 in 20 year AEP flood immunity to the Top of Formation (TOF), with the overarching requirement that the track is not to be overtopped at the 1 in 100yr AEP flood event. Consequently, the sensitivity of +20% design flows provides a sensitivity assessment that highlights areas of the N2NS IR that are susceptible to changes of flow that may occur from either the FFA or from model parameterisation uncertainty.

A summary of the FFA flow at Gavesend is as follows:

1. 1 in 100yr AEP (incl. historical data) 6,110 m^3/s
2. 1 in 100yr AEP (incl. historical data) 90% quantile probability limits are 4,370 m^3/s to 9,640 m^3/s (using the expected AEP quantiles).
3. **1 in 100yr AEP + Climate Change 7,332 m^3/s**
4. 1 in 100yr AEP (no historical data) 7,570 m^3/s
5. 1 in 200yr AEP 7,520 m^3/s

Whilst the +20% was considered by IRDJV as an assessment of climate change, as demonstrated above, there is an element of residual uncertainty associated with the FFA, and therefore this sensitivity assessment is appropriate for considering the impact of the N2NS IR upon sensitive receptors.

7.2.2 Impacts on Sensitive Receptors

From the IRDJV (2022) report, the increase in flow and the result of the higher rail embankment diverts more flow through the southern part of the proposal where the Mehi River and floodplain bridges are located. Diversion of flood water south is of concern as it increases the flood level within the township of Moree. **Impacts within Moree are in the order of 100mm and include increases in the flood hazard**. It is considered that during detail design further optimisation and/or mitigation measures are required to reduce the flood level increases and flood hazard is required and this assessment should be considered with more extreme events as discussed in Section 7.3.

Afflux was also described in the IRDJV (2022) report for the railway line and were in the order of 250mm up to 360mm and the combined length of overtopping was 1700m of the 13.7km upgraded section and 1.6km of new rail.

7.3 Very Rare / Extreme Flood Assessment (1 in 2,000yr AEP)

IRDJV (2022) has undertaken an initial assessment of an extreme flood event (i.e. PMF as defined by WRM 2017 at 18,330 m^3/s at Gravesend). As per the SEARs requirements, extreme flood events are required for consideration of flood risks to people and property resulting from the failure of the formation or washouts of ballast.

From the results presented in IRDJV (2022), increases in flood impacts and flood hazards occur within Moree in a similar manner to those with +20% increase of flow (i.e. climate change). Whilst it is accepted that the PMF results in relatively small water level difference across the railway as it is submerged, hence a low risk of sudden failure, floods between the 1 in 100yr AEP and PMF may present much larger flood differences across the railway and may have a greater potential of sudden failure. As a consequence, further assessment (i.e. very large to extreme events) at locations with sensitive receptors should be undertaken during detailed design.

The results from the additional assessments of very rare/ extreme flood events should be used and then progressed further with a ‘failure impact assessment’ to determine the ‘potential risk to life’ to sensitive downstream receptors/sites (i.e. areas used as a habitable place of occupation or could have a notable impact on itinerants on the highway). The results of these assessments should be included in the FERP, including management measures to mitigate the risks to acceptable levels.

8 Compliance to Quantitative Design Limit

8.1 Overview

The design for the rail infrastructure on the external environment at this EIS stage is required to meet the SEER's qualitative performance criteria. However, as per Phase 1 of the assessment of N2NS, the impact assessment was governed by flood impact criteria known as Quantitative Design Limit (QDLs). Table 2.3 summarises the QDLs by which performance is to be assessed as well as an indication of compliance.

Section 6 of the IRDJV (2022) provides an impact assessment of the rail infrastructure design against the required QDLs for the project. Typical industry practice is to apply the QDLs up to the 1 in 100-yr AEP flood event. However, we consider there are exceptions to the prescribed standards that should be recognised during landholder negotiations whereby unacceptable flood impacts may arise in rarer flood events, such as:

1. Flood events greater than the 1% AEP may cause an unacceptable flood risk to third parties/ landholders. For example, achieving a design that causes no flood impact on floor levels in the 1% AEP may cause an unacceptable flood hazard (e.g. risk to life and/or evacuation routes) to occupants in rarer flood events.
2. Flood impacts with regards to level and duration on existing infrastructure and/or agricultural land in more frequent events may be of particular importance to stakeholders and/or landholders. As an example, a prescribed impact of 150mm on a flat and wide floodplain may cause notably more economic loss than a 500mm flood level increase in a rare flood event. These potential impacts will need to be considered further during third party/ landholder negotiations.

As previously highlighted in this report, some level of uncertainty will remain with the adopted design flood event flows. The use of sensitivity analyses/ checks (i.e. blockage factors, climate change or 1 in 200yr AEP, roughness) should be used in the detailed design to assist third party/ landholder negotiations in ensuring the upper and lower bounds of flood impacts and hazards are appropriately addressed. The use of sensitivity analyses/ checks (i.e. design events up to the PMF) will ensure impacts and flood risk (ie. risk to life and/ or evacuation) are acceptable to landowners and that potential flood damage liability is suitably addressed to an acceptable level at the detailed design stage.

The following sections provide a review of QDLs assessment for each component.

8.2 Flood Impacts

The IRDJV (2022) report provides commentary on the impact assessment conducted for the rail upgrade. The impact assessment compares the results of the proposed rail upgrade against the flood impact criteria outlined in Table 4-8 of the IRDJV (2022) report and reproduced in Table 2.3, Section 2 of this report. The results used for the assessments from the model output are:

1. Flood level
2. Flood velocity
3. Flood duration
4. Flood hazard.

The report compares the results against key impact criteria which are:

1. Afflux

2. Velocity
3. Duration
4. Hazard.

A summary of the key outcomes in the impact assessment is provided below.

8.2.1 Afflux

Afflux at buildings generally shows a reduction in the total number impacted. Four (4) buildings exceed the afflux criteria by >10mm.

Agricultural land generally meets the criteria. Agricultural land located at chainage 680.25, north of the greenfield section, shows exceedances.

Afflux at sensitive receiving areas shows exceedances at two locations (TAFE Agricultural Skills Centre and Moree Gun Club).

The Newall Highway shows exceedances at localised sections. Exceedances are predominately in the 5% AEP.

8.2.2 Scour/Erosion Potential

The report indicates the velocity increases are generally limited to inlets and outlets of proposed culverts. Scour protection is proposed at these locations to the limit of potential scour velocity.

Local increases are observed away from the rail corridor but are limited to localised channels and waterways and are considered low risk.

8.2.3 Flood Hazard

The Newall Highway overall assessment of hazard is noted to have a net reduction. Impacts are predominantly observed in the 5% AEP. A localised section on the Highway show exceedances of the hazard criteria. The Carnavon Highway shows a similar pattern of impact to the Newall Highway, with exceedances greatest in the 5% and 2% AEP events.

The Gwydirfield Road shows a net reduction in flood hazard. Back Pally Road also shows a net reduction in hazard; however, impacts are noted east of the greenfield section of rail.

One (1) residential building exceeds the hazard criteria on the 2% AEP and one (1) building in the 1% AEP.

Exceedances are also noted across a large area west of the rail corridor across primarily agricultural land and most notably in the 5% AEP. Similarly, the floodway at chainage 680.25km shows hazard exceedances across a range of events.

8.2.4 Flood Duration

Exceedances of duration are experienced by residential buildings across the 5% to 1% AEP events. Sensitive receivers (Agricultural Skills Centre) show exceedances in the 2% AEP event.

The Newall Highway and other roads (Carnavon Highway, Gwydirfield Road, Back Pally Road) all show localised exceedances of flood duration along their length.

8.2.5 Climate Change

Extensive overtopping and hence, reduced immunity of the rail is predicted for the 1% AEP with climate change.

As a result, larger impacts are experienced, primarily on the upstream (eastern) side of the rail, but also west within Moree, resulting in greater and more impacts on sensitive receivers.

8.2.6 Extreme Event Impacts

The report notes that for extreme flood events, the impacts occur over areas that would experience significant damage in this event and therefore, the impacts are likely to be minimal. However, further analysis is proposed in the detailed design on embankment failure to ensure flood hazards are not exacerbated.

8.2.7 Cumulative Impacts

The cumulative impacts assessment has been analysed in two components within the report. These consist of:

1. The combined effect of N2NS Phase 1 and Phase 2
2. The combined effect of the proposal and the Newall highway upgrade.

For the combined phases 1 and 2 cumulative assessment, up to 86 properties are predicted to experience increased flood levels in the 1% AEP event. The increases are experienced around Moree Station and towards the town centre. No impacts are predicted in the 2% AEP.

Section 7.2.1 of the IRDJV 2022a report provides an assessment of mitigation measures that predicts a reduction in flood impacts for the impacted area within Moree. Measures include an increase in rail level up to 50mm north of Moree Station and the inclusion of a bund south of Alice Street crossing within the rail corridor.

The combined effect of the proposal and upgraded Newall Highway results in an increase in flood levels on properties located in the area between the rail and highway. The report indicates that the impacts are primarily a result of the Highway upgrade but also the rail upgrade to a lesser degree.

8.2.8 Summary

A summary and recommendations of the hydraulic impacts assessment of the IRDJV 2022a report is provided below.

In relation to the presentation of the hydraulics impacts, key areas of impact exceedance should be presented at a finer scale at the detailed design stage with key features identified. Features should include:

1. Location of residential properties/buildings exceeding impact criteria;
2. Location of other landuse areas where impacts are exceeded,
3. The location on roads where impacts/hazard are exceeded or reduced.

A review of the flood impact maps and discussions indicates that further refinement of cross drainage structures is required to achieve a better balance of flow distribution across the proposed rail upgrade and to reduce current impacts on properties where possible.

As noted in the 5% AEP flood event, a significant amount of impact exceedance generally occurs as well as the northern area around the proposed greenfield upgrade for a range of flood events. It is acknowledged that these areas have been identified in the recommendations in the IRDJV 2022a report, with further refinement to be conducted in the detailed design phase of the project.

We also recommend that while, in general, net reductions in hazard are observed on the assessed roads, a review should be conducted on the areas where hazard impacts exceed the impact criteria. This will help establish if the increase causes a higher or lower risk to that section of the road.

9 Summary

9.1 General Comments

Provided below are general comments on our review of the numerical catchment flood modelling system and the flooding assessments undertaken for the Inland Rail.

1. The WRM (2017) modelling largely pre-dates the ARR (2016/2019) update; however, inflows from the greater Gwydir catchment are based on a Flood Frequency Analysis (FFA) undertaken at Gravesend that achieves the requirements of ARR 2019. The Gwydir catchment at Gravesend represents 83% of the catchment area to Moree and is, therefore, a key inflow location for the catchment modelling undertaken.
2. The local hydrologic models and the adopted Gravesend design flow hydrograph based on the 2012 flood event were reviewed and assessed for their establishment and adequacy of their calibration, validation and operation in relation to design events. The establishment of FFA for Gravesend was acceptable, and the calibration and validation of the local hydrological models were also considered acceptable and fit-for-purpose. A relatively high degree of certainty to reproduce accurate design flows has resulted from frequent to rare (i.e. up to 1 in 100yr AEP) flood events when considered together with the hydraulic calibration.
3. A large range of design floods had been simulated in the flood modelling, from relatively frequent events up to extreme events (i.e. 1 in 10yr to 1 in 100yr with climate change and an extreme event of 3 times the 1 in 100yr AEP magnitude). The investigations to date have presented a range of potential flood impacts and levels of flood immunity of the railway line. Given the relatively high degree of certainty regarding the adopted design flows for frequent to rare flood events, the resulting analyses should be considered reliable for use to determine if the final adopted design achieves an acceptable outcome for ARTC, landowners and all relevant stakeholders.
4. The resulting catchment modelling with further refinement/verification recommended as detailed in the Hydrology and Hydraulic Sections below for detailed design, including the proposed additional sensitivity testing, will provide an acceptable level of confidence that the range of possible flood impacts and flood immunity of the railway line has been captured.
5. It is considered that the design is progressing towards achieving the requirements of the draft Quantitative Design Limits (QDLs), **but is still subject to further refinement to improve this outcome (i.e. reduction of flood impacts) during the detailed design**. Non-compliances are identified, and stakeholder consultation should be initiated/continued to either provide acceptance of the results or provide further mediation (or mitigation) options to the affected stakeholders. Of particular note are the non-complying impacts as follows:
    a. Eighty six (86) residential properties west of Moree Station (Afflux values up to 40 mm) as a result of N2NS Phase 1 and Phase 2 development. However, preliminary assessments indicate that this impact can be mitigated by a combination of measures and will be finalised during the detailed design phase.
    b. Camurra hairpin impacts are observed, and as per IRDJV (2022), this area is still subject to further refinement during detailed design to reduce flood impact and/or acceptance of impact by stakeholders.
    c. Cumulative impacts of IR and highway indicate additional impacts within Moree, between the IR & Highway (i.e. for more frequent events) and north of Moree. As noted by IRDJV (2022), these flood impacts will be reviewed with Transport for NSW to provide an improved solution.

d. The sensitivity results (i.e. increases to flow and blockage) demonstrate that the higher rail embankment causes diversion of flow through the southern part of the proposal, where the Mehi River and floodplain bridges are located. Flood impacts from these assessments, such as from climate change and blockage cases, cause 50mm to 200mm impacts in the town of Moree, including increased flood hazards. Further optimisation of the cross drainage via reduction of these flood level impacts and flood hazards in Moree via these sensitivity assessments is warranted during detailed design.

6. IRDJV (2022) has undertaken an initial assessment of an extreme flood event (i.e. PMF) and increases in flood impacts and flood hazards occur within Moree. As noted by IRDJV (2022), whilst the PMF water level differences across the railway are likely to be of low risk of sudden failure, floods varying between the 1 in 100yr AEP and PMF may have a greater potential of sudden failure, due to larger flood level differences across the railway. Further assessments at locations with sensitive receptors should be undertaken during detailed design, including 'failure impact assessments' to determine the 'potential risk to life' to sensitive downstream receptors/sites. The results of these assessments should be included in the Flood Emergency Response Plan (FERP), including management measures to mitigate the risks to an acceptable level. BMT has not reviewed any aspects associated with the FERP and is not part of our scope of work.

7. Given the WRM (2017) modelling has demonstrated a relatively good correlation and verification to historical flood events, and the IRDJV (2022a) model shows a good correlation with the WRM models, then the relative level of uncertainty in the flood impact results is reduced and the results provided in the EIS can be relied upon for this stage of the design. However, the flood modelling is subject to further refinement during the detail design stage, and further refinement of the design is required to reduce the flood impacts associated with the design presented to date in some locations.

   Where QDLs cannot be reasonably achieved during the detailed design, the acceptability of the flood risks (i.e. uncertainty as detailed in sections below and associated consequences e.g. flood impact, flood immunity, flood hazard) demonstrated through model refinement and sensitivity analyses will need to be accepted by ARTC, landowners and associated stakeholders for the construction phase of the Inland Rail.

9.2 Hydrology

The IRDJV (2022a) hydrology is based on the WRM (2017) flood assessment that was constructed prior to the ARR (2016 / 2019) guidelines. As previously noted, inflows from the greater Gwydir catchment are based on a FFA at the Gravesend gauge and use the flood event of 2012 for the inflow hydrograph. The FFA assessment meets the requirements of ARR 2019, and the Gwydir catchment at the point of inflow at Gravesend has a catchment area of 11,020 km^2 that represents 83% of the catchment area to Moree.

The remaining portion of the catchment area between Gravesend and Moree was represented by local XP-RAFTS hydrological modelling based on ARR (1987) and the 48hr flood event to coincide with the flows from Gravesend. The peak flows from the local catchment are consistent with the BMT URBS ARR 2019 flood assessment. Furthermore, the peak flood flows from the local catchment are likely to be well before that from the Gwydir catchment and will have limited influence on the overall peak flood levels and flood volume.

Overall the design hydrology adopted by IRDJV (2022a) that is based on the WRM (2017) flood assessment that has been calibrated with hydraulic modelling is considered acceptable for use in the Phase 2 flood assessment and provides an acceptable overall degree of certainty regarding flood risks up to the 1 in 100yr AEP flood event. IRDJV (2022a) have also undertaken climate change sensitivity analyses by increasing peak flows by +20%. This result will provide a range of resulting flood risks (i.e.

upper bounds of uncertainty) and associated consequences (e.g. flood impact, immunity & hazard) that ARTC may consider further to determine whether greater factors of safety may be applied and/or further optimisation of the flood mitigations are required.

As documented in ARR (2019), incorporation of a calibrated hydrological model should be considered to appropriately define very rare to extreme flood events (e.g. floods larger than 1 in 200yr AEP) that are used for risk assessments and detailed design. The Copeton dam should be considered as full prior to these extreme events.

9.3 Hydraulics

9.3.1 General Comments

The TUFLOW model is based on the MIKE FLOOD hydraulic model developed for the Moree Plains Shire Council's flood Study for Moree and Environs (WRM, January 2017). The MIKE FLOOD model is a calibrated model and has been previously peer-reviewed. The MIKE FLOOD model was also provided to BMT.

A detailed review of the model discretion was undertaken. This includes structures, roughness, grid size and boundary conditions, including the topography and blockage of culverts. Cross drainage culverts for both the rail line and highway were represented by one dimensional (1D) structure elements within the two-dimensional (2D) model grid. This is the case for both the existing and design case and is supported. Further review and refinement are, however, recommended where large banks of culverts are proposed, particularly in the design case modelling where the combined bank of culvert width is far greater than the grid cell size. A 2D approach may be preferred in these cases, particularly where velocity may vary across the structure width. A sensitivity test is recommended to inform the best approach for detailed design.

The adopted roughness values are considered appropriate and consistent with the MIKE FLOOD model. If required, these parameters may require further adjustment following the verification of the TUFLOW model to a historical event (e.g. Feb 2012 flood event) and /or consistency with the WRM (2017) design floods as detailed in the following section. It should be appreciated that whilst the TUFLOW model provides greater resolution, particularly within the channels, than that of the MIKE FLOOD model, adjustment of the Manning 'n' roughness could be necessary to refine the conveyance and correlate the result closer to known flood levels.

A standard blockage factor of 15% was adopted, based on the ARR (2019) advice of '*where the width of that part of the approach flow that is capable of transporting the debris under consideration is significantly less than the total width of the structure, then the culverts/spans within the effective transport width be assessed as blocked to BDES and those outside of that zone be reduced to half BDES*'. As ARR (2019) note a minimum design blockage factor of 25% within the effective transport width, then the universal blockage of 15% is acceptable, given that the following sensitivities have been undertaken:

1. 0% blockage (all culverts);
2. 25% universal blockage
3. 50% universal blockage.

The adopted 15% blockage provides an 'average' result and is accepted for the SEARs assessment; however, the detailed design blockage factor for each culvert bank should be used for the detailed design and results documented with reference to the QDLs. The sensitivity assessment of blockage factors (e.g. 0% and x2 the design blockage factor as per ARR 2019 recommendations) will provide an indication of upper and lower design limit impacts. These sensitivity assessments should be used by ARTC as part of their risk assessment of sensitive receptors to determine and suitably address the potential flood damage/liability that could be caused to landowners and/or stakeholders.

9.3.2 Model Validation

The resulting IRDJV (2022a) TUFLOW model for the 1 in 100yr AEP shows a relatively good correlation to the MIKE FLOOD models. Peak flood levels are generally less than 50mm difference across the floodplain and project area. A localised difference of between 100-200mm is noted in the northern area of Moree. For the 1 in 10yr AEP flood event, a significant difference occurs between the models in the Mehi River. Differences in flood levels around structures are also noted.

To support and to further verify the IRDJV (2022a) TUFLOW model, **further model validation will be required in the detailed design** through verification/comparisons against peak flood levels from a recent historical event as per the MIKE FLOOD model to support the TUFLOW model results. The February 2012 flood event provides a recent and significant event for the validation assessment in the detailed design. From the WRM (2017) report, the February 2012 flood event has over 200 surveyed flood levels.

We also note from the Moree Plain Shire Council on-line reports that revised levee modelling north of Moree was recommended and from our understanding, was to be adopted by Council. While the currently adopted TUFLOW modelling potentially provides a conservative analysis, **a sensitivity assessment of the proposed final levee design should be conducted with the current levee height included in the model as part of the detailed design**.

9.3.3 Overall Acceptability

BMT has conducted a technical review of the TUFLOW model and the schematisation that form the basis of the Phase 2 EIS report (IRDJV, 2022a). From this review, we conclude that the TUFLOW model has generally been constructed appropriately and based on this review, we consider the overall approach to hydraulic modelling and methodology is generally appropriate for design modelling at this EIS stage. Recommendations have been provided in relation to some specific topography (i.e levees), culvert schematisation, sensitivity analysis (i.e. climate change, blockage), extreme event assessments and further verification of the flood model results against a historical event and re-validation against the WRM (2017) 1 in 10yr and 1 in100yr flood events for the final detailed design.

As outlined in the body of this review, we recommend the following modelling improvements for the detailed design:

1. Additional TUFLOW model verification, including a historic event assessment for model (e.g 2012);
2. Sensitivity of culverts blockage results (i.e. 0% and 25% blockage) included in the sensitive receivers against the QDLs, while the 50% shall be used as an upper limited risk assessment;
3. A sensitivity test using the revised MIKE FLOOD model incorporating existing levee/storage structures.

This further validation and sensitivity testing will provide a better understanding of the flood immunity of the railway line and provide a range of resulting flood risks (i.e. uncertainty) and associated consequences (e.g. flood impact, flood immunity, flood hazard etc) that ARTC should consider, including as to whether greater factors of safety may be applied in the detailed design.

Given that a large range of flood events, up to severe and extreme events, have been used in the design, flood impacts are unlikely to be significantly affected by this work.

9.4 Compliance with Quantitative Design Limits

The flood modelling to date indicates that a full and comprehensive understanding of flooding under a range of flood events has been established, and the assessment of impacts from the proposed rail line against the QDLs and flood immunity is well understood. The resulting modelling and, the sensitivity testing (e.g. climate change and blockage) provide an acceptable level of confidence that the range of possible flood impacts and flood immunity of the railway line has been captured.

It is considered that the design is progressing towards achieving the requirements of the draft Quantitative Design Limits (QDLs), but is **still subject to further refinement** to improve this an acceptable outcome (i.e. reduction of flood impacts as detailed in the 'General Comments') during the detailed design. Non-compliances are identified, and stakeholder consultation should be initiated/continued to either provide acceptance of the impacts or provide further mediation (or mitigation) options to the stakeholders.

9.5 Qualifications

This review is based on a desktop assessment and a review of the numerical files. The desktop review is based on the reports previously provided in the section titled 'Reports'. The reports document the methodology of calibration, validation and application of the catchment models and their use for assessment of impacts as a result of the proposed infrastructure.

The final design will need to consider further (as detailed in this report and IRDJV, 2022 report), the flood impacts associated with the proposed railway line for the full range of flood events, including the sensitivity of flows (for example due to climate change, extreme events and flood debris blockage) are appropriately managed with particular regards to (1) impacts to evacuation routes, (2) the potential for an increase of the risk of loss of life at flood sensitive receptors (FSR) and (3) property damage.

10 References

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Annex A Historical Review of Floods

Flood, Storm Warnings Issued As 1860 Rain Record Is Broken

The Weather Bureau last night issued flood warnings for towns on the Bellinger, Macleay and Hastings Rivers and their tributaries. Earlier it had issued a warning to towns in western N.S.W. between the MacIntyre and Lachlan Rivers.

The Bureau yesterday afternoon issued a storm warning to shipping between Coff's Harbour and Newcastle.

The 90-year-old rainfall record for Sydney was broken about 12.30 p.m. yesterday.

The previous record was 82.76 inches for the whole of 1860.

By 12.30 p.m. yesterday the Weather Bureau on Observatory Hill had recorded falls totalling 82.77 inches this year.

At 9 p.m. the total registration had reached 83.07 inches, with more showers forecast for to-day.

Kempsey Rain

More than four inches of rain fell in 12 hours at Kempsey yesterday.

Kempsey police fear floods because heavy rain has fallen at Armidale, Georges Creek, Hickeys Creek, Comara and Walcha.

If the rain continues for 12 or 24 hours police expect Kempsey to be flooded during the week-end.

Four houses were flooded at Armidale where 120 points fell in seven hours yesterday.

Armidale police warned people to put their furniture on blocks when the Dumaresq Creek flooded at 1.30 p.m. and covered the main street.

Fresh floods are expected at Moree. Heavy rain fell on the upper reaches of the Gwydir yesterday and on Wednesday.

Moree police last night said the outlook was "grim," but did not expect the river to reach the record July level.

At Gravesend the Gwydir has risen to 25 feet and to 15 feet at Pallamallawa.

Mr. J. Williams, who records rainfall at Turramurra for the Weather Bureau, said that up to 8 p.m. last night 94.7 inches had fallen in his suburb since the beginning of the year.

The chief of the Bureau, Mr. J. Hogan, said yesterday: "An unusual feature of the rain in Sydney this year was the consistently high monthly averages.

"These reached a peak in June when 25.3 inches were recorded, the highest rainfall for any month since records have been kept," he said. "In July it was 13.23 inches."

He said that frequent cyclones bringing moist tropical air through Queensland into N.S.W. in a south-easterly direction were largely responsible for the high rainfall.

"But while N.S.W. and Queensland have been getting a soaking Western Australia, Tasmania and the areas east of Australia have had below normal rains," he said.

"And because of the rain there has seldom been any time since the beginning of the year that some part of Queensland or N.S.W. was not subject to flooding."

Rainfall records for the Illawarra district have been shattered this year.

Corrimal has already registered more than 100 inches and the Wollongong registration exceeds 98 inches. Previous record was 83.36 inches in 1890.

Millions Lost

According to officials of the Department of Agriculture, the record rainfall has cost producers and consumers an almost incalculable sum of money—certainly millions of pounds.

Here are some points made by the officials and industry spokesmen:

- Vegetable and fruit crops were devastated, cutting supplies to Sydney, forcing wholesale and retail prices to record levels.
- The rain delayed shearing, and in some districts, thousands of head of livestock were either drowned or died from starvation.
- The rain produced a plague of blowflies that has killed thousands of sheep.
- Floods washed out railway lines and disorganised railway traffic.
- They disrupted coal production and caused a loss of about 300,000 tons and caused gas rationing.
- Rain interfered with building and caused a production loss of hundreds of thousands of bricks.

● **Pictures, page 5; rainfall graph, page 13.**

Service March To-day Wet Or Fine

Squally showers forecast for to-day are not likely to stop the all-Services march of 1,000 men with 75 fighting and service vehicles through city streets.

Recruiting officials said last night they expected the march

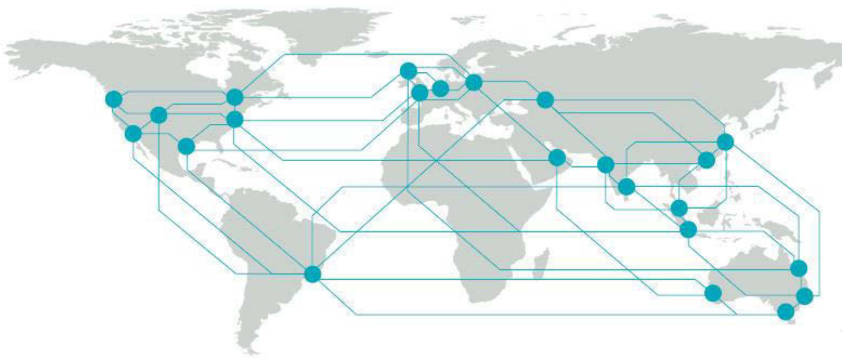
The Moree Flood.

Few people, even in Moree, realise how near the town was last week to a repetition of the great flood of January 15, 1910, that ever memorable day in the memory of the inhabitants, who got the surprise of their lives when they saw the waters slowly creeping up in the main streets, entering the hotels, filling the cellars, and taking complete possession of the town. All but 12½ inches of rain fell in six weeks. By that time the rivers were full to the brim, and had just commenced to flow over their banks. Another downpour, and nothing could have stopped a flood, but fortunately none came. By Wednesday afternoon things were at their worst, the water from Bundarra and the upper reaches of the Gwydir having come down and swelled the streams at Moree. On the day named, a number of townspeople left Moree, some by motor, some by taxi, others by sulky, to see with their own eyes the state of the plain. At the western end of the town is the Broadwater, a deep and rugged ravine, generally dry, but which in the rainy season receives the surplus waters of the Gwydir and takes them in a swirling stream to the Mehi, which flows at the back of the town, passes under the splendid bridge connecting Moree with the railway station, at least a mile away, and finally discharges its contents into the Barwon above Collarenebri.

At one time the Gwydir used to join the Mehi at Moree, in the Watercourse country half way between Moree and the Barwon, but of late years it has left its original course, as marked on the map, and about twelve miles west of Moree at a place called the Raft from the obstructions caused by floating timber, it has spread out over the Watercourse between Moree and the Barwon, where

At one time the Gwydir used to join the Mehi at Moree, in the Watercourse country half way between Moree and the Barwon, but of late years it has left its original course, as marked on the map, and about twelve miles west of Moree at a place called the Raft from the obstructions caused by floating timber, it has spread out over the Watercourse between Moree and the Barwon, where it inundates and is absorbed by the surrounding plain. A glance at the map will show better than words can describe how the rivers flow, that is, in the rainy season, for in the dry season the Broadwater and the Mehi are only intermittent pools.

Last year the Gwydir submerged the whole of the intervening country between it and Moree, and at Yarraman House, near the saleyards, where Mr. Glennie resides, the waters were over 6ft. high, half in and half under the house. Fortunately for him, the water did not get into the house this year, but it was not far off, and spread over the surrounding plain, and even covered parts of the main road leading to the Yarraman bridge, where a motor car with half a dozen occupants got temporarily stuck, and had to be pulled out by a passing horse. The bridge itself, which is just three miles from Moree, was dry, but four miles beyond on the Ashley road the Carore Creek was in full flood, and covered not only the Carore bridge, but the very tops of the rails, so that not a vestige of the bridge could be seen. The postmaster (Mr. Collett) and a mailman went out that same afternoon in a taxi to see if the mails could be carried over the bridge, but had to return. At Pallamallawa the river was 30ft. high, or within a foot or two of its level during the January flood, but fortunately that was the highest point reached, and from that moment matters quietened down, the waters found their way down the Barwon or some other channel, till they were eventually lost in the sea, there to renew the eternal round, be sucked up by the sun and dissipated in showers and storms in some other part of this curious world. And with the dispersal of the waters peace again reigned in Moree.



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