

RESPONSE TO REQUEST FOR INFORMATION

GEMCO | EXCESS WATER DISPOSAL (OCEAN OUTFALL) PROJECT

No. Request	Response
1. Provide an overview of the current and proposed mining operation relevant to the proposed action including pit location, footprint and depth.	GEMCO's mining operation occurs under, and is described in, its approved Mining Management Plan FY25 to Closure (MMP). GEMCO employs an open cut strip mining method to mine manganese ore, whereby the deposit is divided up into several different quarries. Within each quarry the orebody is exposed and mined in sequential strips that are typically between 40-60 metres (m) wide. Mining is undertaken cyclically at several (typically 10) quarries, with each quarry area in various stages of mining, backfilling and rehabilitation. To support the various mining stages and mine operations at GEMCO, a total of 22 quarries has active water management and pumping infrastructure currently in operation across the Western Leases. Quarry dimensions are determined by the nature and extent of the orebody, but are typically in the following ranges: • 200 to 1000 m long; • 60 to 80 m wide; and • 10 to 50 m deep. Figure 1 displays the general quarry areas and proposed mine quarry areas earmarked in the mine plan. Figure 2 to Figure 4 display the proposed approximate depths for each quarry development until the end of mine life.
2. Provide the current and predicted site water balance including the existing and increased dewatering volumes.	Water balance and dewatering volumes GEMCO has a significant water surplus year-round. Anywhere between 8,000-13,000 megalitres (ML) of water is moved through the mine's water management infrastructure monthly. Future forecasts indicate that a significant water surplus will exist at GEMCO during the remainder of the operational phase with a lower-level surplus into closure. Typically, groundwater is responsible for the bulk of water generated at quarries, especially during the dry season when rainfall is negligible. Current average groundwater inflows are about 8,000 ML per month across the site. It is predicted that this will remain relatively consistent until mid-2028 and increase throughout late 2028 to 2029 (to 10,000 ML per month with peaks up to 12,000 ML per month) with the commissioning of new quarries. Groundwater inflow rates will reduce post 2029 as deeper quarries are exhausted. Notable quantities of surface water can also be generated during the wet season by intense or prolonged rainfall or tropical cyclone activity. For example, Tropical Cyclone Megan impacts in March 2024 resulted in around an additional 26 GL of excess water being generated and stored at the mine site, with similar additional significant volumes reporting from recharged aquifers to quarries in the months following. Runoff is currently estimated at 15-20% of total volumes reporting to quarries and water storages in a 'typical' wet season. Currently, on average per month, approximately 500-1,000 ML of water is consumed via concentrator operations, 200-400 ML is consumed via dust suppression and 3,500-6,000 ML is discharged to bush.

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	The actual dewatering volumes during FY24 and FY25 and a base case forecast of water are provided in Figure 5³. This figure illustrates that the internal demand for excess water (makeup water and dust suppression), even at maximum demand, is relatively minimal, and is not sufficient to manage predicted water volumes. Relevantly, the Proposed Action will not of itself increase the volume of excess water released from GEMCO's quarries, but rather provide another point and method for the release of excess water. Water balance modelling GEMCO uses two main tools to quantify, predict and manage water volumes and movement across the Western Leases. These are the: • Operational water balance model (for short and medium term decision making); and • numerical groundwater model (to inform GEMCO's longer term approach to water management and dewatering). Operational water balance model GEMCO's operational water balance model is used to track and monitor quarry inflows, quarry water levels and water storage levels and to make management decisions over the short (day to day) and medium term (up to 2 years in advance). The model is used to: • maintain desired water levels in the quarries being mined to ensure dry and trafficable working conditions; • prevent quarries and water storages from overtopping; • maintain water storages within the operational ranges; • coordinate scheduling of the mine path; • quantify pumped volumes from quarries and water storages to coordinate the deployment of dewatering assets (pumps) and pipelines; • coordinate the disposal of mine water by discharge to bush; and • ensure bush discharge sites have sufficient rest periods (i.e. no discharge) during the dry season, thereby reducing risks to vegetation e.g. potential excessive inundation / water logging. The model has been developed with key input / output values including: • quarry inflow estimates measured from flowmeters; • water storage capacity curves for quarry and water storages (calculated by depth-volume relationship); • inflows and outflows to water storages, groundwater and bushland; • surface water runoff from overland flow, quarry and water storage catchments; and • evaporation. Each parameter input / output to the model is either measured (in the case of volumes) or estimated based on catchment scale relationships.

³ The predicted excess water volumes incorporate considerable variability due to tropical rainfall conditions (+/-20%).

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	GEMCO updates the operational site water balance model monthly. Numerical groundwater model GEMCO has developed a numerical groundwater model for the Western Leases to inform and support GEMCO's long-term water management strategy. The numerical model includes all planned quarries on the Western Leases, as informed by GEMCO's current mine plan. The key objectives of the model are to: • provide an updated estimate of groundwater inflow rates across the Western Leases for the remainder of mine life; • quantify the effects that dewatering may have on groundwater drawdown and saline intrusion over the remainder of the mine life and post closure; and • evaluate the range of effects, including drawdown, that may result from site water management decisions including discharge to bush, or the Proposed Action. The model is underpinned by multiple data sets including: • GEMCO's geological database that details geological layers across the Western Leases, obtained from over 25,000 drillholes; • groundwater data captured from the site bore network, comprising of over 120 bores; • mine inflow data captured before and after the implementation of the site's flowmeter telemetry system; • recharge estimates captured from previous hydrogeological reports and numerical models; • estimates of excess water generated; • stream flow data from the two main rivers at the site, the Angurugu and Emerald Rivers; • Light Detection and Ranging (LiDAR) capturing high resolution topography; and • various other data sets including: ○ quarry and river water quality information, mapped vegetation (including groundwater dependent ecosystems (GDEs) and culturally significant sites); and ○ climatic and mean sea level data from the Bureau of Meteorology. The model is being used to predict drawdown over the remainder of the mine life and post mining. It takes into consideration both existing and increased dewatering volumes as indicated under the Proposed Action in the Referral. GEMCO will progressively update the model to inform water management strategy, options and mine plans.
3. Provide further information on the onsite water management system upstream of the proposed pump and pipeline infrastructure, including, but not limited to:	
a. description of the pit dewatering methodology	Sump dewatering is the primary dewatering method used across quarries. Sump pumps are placed at the base of quarries and box cuts and piped through spur lines to connecting trunk lines before being sent to water storages. The general quarry dewatering methodology includes:

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	• installation of drainage channels along the edge of the mining cut; • draining the water to a sump (located in the lowest elevation area of the strip); • pumping water out of the quarry using diesel driven mechanical and electrically driven pontoon pump(s) along large diameter, high capacity high density polyethylene (HDPE) pipelines; • rehandling or storage of water in non-active quarry voids for future use as process water or in dust suppression; and • discharging of excess volumes to bush in accordance with the MMP. GEMCO has also implemented advanced boxcuts ahead of quarry strips to depressurise aquifers. Advanced boxcuts are an effective method of dewatering in advance of mining and play an important role for mining below the water table. They are used across the site and are particularly effective where high inflows are encountered, or long-term dewatering infrastructure is required. In several cases quarries have multiple sumps and pumps due to high inflows and the size of the quarries.
b. identifying where pits are used as staged water storage prior to discharge (where relevant).	Current key water storages across the Western Leases include those at F3, BSC and DSS Water Storages (refer to Figure 1). Mining is planned to occur adjacent to F3 and BSC water storages from 2027 onwards, and for this reason the water storages must be moved to NH2 and ES quarry voids to allow for mining to continue. Whilst currently some excess water is discharged directly from individual quarries to bushland (in the order of <5% of quarry inflows) without storage, moving forward, the intention is to capture 90-100% of quarry inflows in water storages before using that water in the operation or discharging it. This will ensure maximum operational flexibility with respect to reticulating and managing excess water volumes and water quality requirements.
c. excess water management measures and whether these are meeting relevant environmental criteria, e.g. discharge of excess water to native vegetation.	Water produced during dewatering activities is, in the first instance, reticulated to the ore processing plant to an area referred to as Dam 1 and used for dust suppression at the mine. Any surplus (excess) water, that cannot be used at the mine, is discharged into native vegetation (bushland) adjacent to the quarries under controlled conditions. This activity is approved under GEMCO's existing Mining Authorisation and MMP. GEMCO has obtained a Waste Discharge Licence (WDL) from the Northern Territory government to discharge water from the northern quarries into the Angurugu River. However, this proposed riverine discharge has not yet commenced as GEMCO is consulting with the Anindilyakwa Land Council (ALC) and has commenced the process to seek an Authority Certificate under the <i>Aboriginal Sacred Sites Act 1989</i> (NT) for the riverine discharge in accordance with the terms of the WDL. Riverine discharge is not considered part of the long-term solution for excess water management at the site given the limitations on discharge volumes and expiry of the WDL in 2028. Discharges to bushland occur typically on the western side (downgradient position) of active quarries. Bush discharge locations have been selected based on: • catchment topography; • soil characteristics; • vegetation communities; and • constraints such as mine path requirements, and community access and the location of culturally significant sites. A network of pipelines and pumps has been installed between quarries, water storage and bush discharge locations to ensure controlled distribution of excess water. The flowmeters, quarries and water storages are integrated into GEMCO's process control management system

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	(Citect SCADA) to support effective water management operations. To minimise potential local impacts by saturation, bush discharge is spread across multiple points per catchment, using a diffuser and manifold set-up at the end of each pipeline (where possible), as opposed to single point discharge. Sediment retention traps and diffusers are installed at the discharge end to avoid erosion and generation of turbidity. GEMCO schedules the discharges monthly and reviews weekly any potential impacts involving a multi-disciplinary team. The scheduling of discharges to bushland is influenced by receiving environment conditions, discharge water quality and any scheduled rest periods for each discharge location. Discharge points are periodically shut off to allow for water infiltration and limit the risk of inundation and waterlogging. A comprehensive monitoring program for bush discharge is aimed at supporting sustainable water management and mining requirements. GEMCO's current monitoring program for bush discharges includes, but is not limited to: • visual inspections of source and discharge points; • water quality monitoring (surface water and groundwater); • visual inspections of catchment vegetation health; • drone surveys to assess vegetation change at all active and inactive discharge locations; • physical ground-truthing; • short-wave infrared (SWIR) remote monitoring to identify and monitor areas of surface ponding and discharge migration; • Normalised Difference Vegetation Index (NDVI) assessments of vegetation; • monitoring of groundwater levels; and • review of discharge volumes and discharge quality. The current bush discharge monitoring program has been designed to provide a comprehensive view of the management of bush discharges and potential effects on the receiving environment. The consolidated data collected on bush discharge activities are reviewed by a GEMCO multi-disciplinary working group on a weekly basis and reported to the ALC. Water quality trigger values for the discharge monitoring program are agreed with the ALC and approved by the NT Government. The outcomes of the monitoring program and an assessment of conformance of the bush discharge activities with the relevant environmental criteria are provided annually in the Environmental Mining Report (EMR). The EMR is an ongoing annual performance reporting requirement (specified under the now repealed <i>Mining Management Act 2001</i> (NT)) for holders of MMPs. Please refer to the EMR for FY24 for a detailed discussion of the outcomes of the bush discharge monitoring program. The report also includes information on the monthly discharge sources and results from monthly water quality monitoring. The EMR for FY25 is currently being prepared.
4. Provide further information on the extent of current and predicted groundwater drawdown and the environmental values potentially at risk within the extent of current and predicted drawdown over the life of the proposed action.	Extent of current and predicted groundwater drawdown GEMCO operate several quarries below the water table to access manganese ore, which results in groundwater inflows and local groundwater lowering adjacent to quarries. GEMCO has assessed drawdown under current and future quarrying scenarios. Currently drawdown ranges between 2 and 4 m for most quarries. Current predictions in relation to drawdown include: • As mining proceeds, groundwater drawdown cones are predicted to develop to around 6-8 m. • Post mining, groundwater levels re-bound rapidly with the majority of quarries predicted to have recovered significantly 2-3 years after

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	quarrying ceases across the whole of the Western Leases. Reference should also be made to the information provided at Request #2 above, regarding GEMCO's groundwater modelling, including the water balance model and numerical groundwater model. Environmental values The environmental values identified within the extent of current and predicted drawdown over the life of the Proposed Action include GDEs and sensitive vegetation types other than GDEs (e.g. mangroves, monsoon vine thicket, riparian vegetation). Importantly, environmental values at risk are considered unlikely to be affected by the Proposed Action, as discussed further below at Request #5.				
5. Describe the potential direct, indirect and cumulative impacts, including to hydrology, groundwater dependent ecosystems and cultural heritage, of the proposal taking into consideration: a) existing and increased dewatering volumes	Note: By email dated 15 April 2025, a representative of the NT EPA clarified that, in response to this question, the NT EPA was seeking "information about the potential impact of removing groundwater and surface water from the upstream operations to maintain productivity under existing and proposed conditions, including existing dewatering volumes (whether discharged to the marine, riverine, estuarine or terrestrial environment) and any proposed ongoing increase to dewatering volumes". Potential impacts Dewatering at GEMCO has been ongoing for over 40+ years and has historically occurred at inland areas where ore bodies are shallower and groundwater levels are deeper, thereby resulting in lower inflows and drawdown. Additionally, quarrying has predominantly occurred in dry woodland areas where dominant tree species comprise of <i>Eucalyptus tetrodonta</i>. No significant impacts on hydrology, GDE and cultural heritage from drawdown have been observed to date. For the remainder of the mine life, quarrying will continue to progress west into areas deemed more sensitive with respect to vegetation types. At the same time, potential drawdown and saline intrusion is expected to increase as: • average submergence depth of the ore body will increase, resulting in high inflows; • quarrying will occur in areas with shallower groundwater levels; and • deposits will be mined closer to the coastline or estuarine areas with the potential to induce saline water. The potential direct and indirect impacts from drawdown are listed in the following table. <table> <tr> <th>Potential impact / Value</th><th>Description</th></tr> <tr> <td>Hydrology</td><td> Increased dewatering volumes could have the potential to alter the local water table, leading to changes in surface water flow patterns and potential reduction in the water availability for terrestrial ecosystems. However, local permanent river systems, including the Angurugu River and Emerald River, are considered low risk, given that: • predicted dry season baseflow remains within the same order of magnitude of current baseflow; and • reductions in dry season baseflow are not considered material to river health, especially given the large flow volumes experienced during wet season. Other waterways are ephemeral and not considered strongly influenced by drawdown. Potential impacts to hydrology from GEMCO's operations will continue to be monitored using GEMCO's existing water monitoring programs (as described in the EMRs, MMP and this RFI response). </td></tr> </table>	Potential impact / Value	Description	Hydrology	Increased dewatering volumes could have the potential to alter the local water table, leading to changes in surface water flow patterns and potential reduction in the water availability for terrestrial ecosystems. However, local permanent river systems, including the Angurugu River and Emerald River, are considered low risk, given that: • predicted dry season baseflow remains within the same order of magnitude of current baseflow; and • reductions in dry season baseflow are not considered material to river health, especially given the large flow volumes experienced during wet season. Other waterways are ephemeral and not considered strongly influenced by drawdown. Potential impacts to hydrology from GEMCO's operations will continue to be monitored using GEMCO's existing water monitoring programs (as described in the EMRs, MMP and this RFI response).
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	GDE and other sensitive vegetation types Groundwater drawdown in the upper aquifer may result in reduced water availability at confirmed or potential GDEs. This could potentially result in stressed vegetation and impaired ecological function. The inclusion of marine discharge may result in a reduction in seepage (from reduced bush discharge) to the aquifers. However, the presence of large water storage quarries and continuing selective discharges of freshwater to bushland are expected to act as 'recharge mechanisms' and buffers for drawdown. Quarrying already occurs adjacent to sensitive vegetation types and close to the coast. No groundwater impacts from saline intrusion or groundwater lowering have been observed to date suggesting adjacent vegetation is not sensitive to nearby pumping stresses. Potential impacts to GDEs and other sensitive vegetation types from GEMCO operations will continue to be monitored using GEMCO's existing water monitoring programs (as described in the MMP, EMRs and this RFI response).
	Cultural heritage and sacred sites Impacts on cultural heritage and sacred sites are site specific as they are dependent on how sensitive (if at all) the value of the sites is to an impact to water or groundwater. In general, locations that are spatially overlaid with water and vegetation features may be impacted on by drawdown through direct impacts on the feature. Potential impacts to sensitive vegetation types from GEMCO's operations will continue to be monitored using GEMCO's existing water monitoring programs (as described in the MMP, EMRs and this RFI response). Any evaluation of potential impacts to cultural heritage and sacred sites will involve engagement with the ALC and relevant Traditional Owners.
	Indirect impacts Indirect impacts from dewatering activities may include potential saline intrusion within the upper aquifer (refer to further discussion below) to quarries near the coast or adjacent to the tidal reaches of the rivers. Saline intrusion in the upper aquifer is considered a worst-case risk. This is on the basis that that saline intrusion would preferentially occur via the ore body and lower aquifer rather than the upper aquifer. This has been observed at an existing quarry where freshwater is seen to perch above brackish groundwater in the ore body/lower aquifer. Thus, salinity may not propagate into plant root zones with a freshwater lens maintained above a brackish or saline or body/lower aquifer. Potential saline intrusion will be monitored through the existing groundwater monitoring bore network and quarry water quality monitoring programs as described in the MMP, EMRs, and this RFI response.

The likelihood and extent of any potential described impacts related to drawdown and potential saltwater intrusion will be influenced by several factors including:

- Position of the saltwater interface in coastal and estuarine areas - which is not well constrained off lease. Groundwater modelling has taken (and will continue to take) a conservative approach to this saltwater position with the saline interface being assumed onshore (inland from the coast) and upstream in the major rivers (resulting from tidal effects).
- Stratification in aquifers – site monitoring indicates that saline intrusion occurs preferentially via the lower aquifer, with the upper aquifer remaining fresh to brackish. Though persistence of this stratification, risk of saline intrusion impacts to GDEs/sensitive receptors remains significantly reduced.
- Rainfall intensity and recharge - current and historical studies have indicated rainfall recharge is substantial - in the order of 30-35% of annual wet season totals (2001-2024 average – 1308 mm). This highlights that surface water buffering and rainfall play a key role in shallow and deep groundwater quality and saline wedge behaviour. Significant fluxes, dilution and groundwater discharge will also

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	occur annually. Potential impact management and mitigation The management of potential impacts relies on an effective monitoring program and adaptive management based on site specific risks. Early detection of potentially adverse impacts will continue to inform the water management strategy. Potential impacts to environmental values and receptors from GEMCO operations will continue to be monitored using GEMCO's existing water monitoring programs (as described in the EMRs, MMP and this RFI response).
b) existing and increased discharges to the marine environment	Note: By email dated 15 April 2025, a representative of the NT EPA clarified that, in response to this question, the NT EPA was seeking "to understand whether there are any other existing or proposed marine discharges in the vicinity of the proposal that would lead to cumulative impacts on the environment (e.g. outfalls, sewage, stormwater, ballast water)." Sewage outfall is the only existing discharge from GEMCO operations at the Milner Bay port facility and has been considered for potential cumulative impacts. As reported in the MMP and EMRs, GEMCO conducts sewage effluent and mixing zone monitoring in accordance with the conditions of the former Waste Discharge Licence 163-01 and the more expansive Marine Environmental Monitoring Program (MEMP). The sewage monitoring program spans five (5) sites in the vicinity of the Port area, while the MEMP spans eight (8) ocean water sampling sites at control areas to the north and south of the port operations and 16 sites within the port area itself. As indicated in the Referral documentation, for the proposed discharge of excess water from the mine, the key water quality analytes requiring the highest levels of dilution to achieve marine water quality objectives are nitrate, salinity and pH. All other analytes assessed are predicted to return to levels approximating ambient conditions (i.e. below the adopted trigger values) within ~100 m from the outfall diffuser and will therefore not coincide spatially with any other discharges. Additionally, the modelled edge of the mixing zone for pH from the mine dewater discharge is predicted to terminate ~120 m southeast of the nearest known discharge point at the sewage outfall. Assessment of the potential for cumulative impacts therefore focuses on nitrate and salinity. Nitrate is monitored as part of the sewage monitoring program, while salinity is monitored indirectly through measurements of EC and temperature. The following outcomes are reported in the most recent annual monitoring report (EMR) covering monthly samples from July 2023 to June 2024: - Nitrate was below detection (<0.01 mg/L) for all seawater samples and ranged between 0.01-4.24 mg/L in the sewage samples. - Salinity in seawater measurements (converted from conductivity and temperature measurements) ranged between 27.1 Practical Salinity Unit (PSU) and 39.5 PSU and was below 0.5 PSU in all sewage samples. At the nearest seawater site to the sewage outfall (WDL67B1, located 100 m from the outfall), seawater measurements ranged between 28.1 PSU to 36.9 PSU. Comparison of the seawater samples to the sewage samples indicates significant dilution of the sewage plume, with seawater samples well aligned with typical seawater values and demonstrating minimal influence of the sewage at the nearest seawater site to the sewage outfall. Nevertheless, some highly localised (e.g. within 100 m distance) cumulative impacts may be realised in the immediate vicinity of the sewage outfall where, on rare occasions (based on the modelled 1st percentile dilution contours), the nitrate and low salinity plume of the mine discharge water may intersect with the sewage outfall plume. Regarding ballast water discharges, as per Australian biosecurity requirements, ballast water is comprised of clean oceanic water. Further, GEMCO Port procedures require all ballast to be clean prior to discharge. These two factors negate the potential for cumulative impacts associated with ballast water discharges coinciding with the proposed mine dewater plume. Stormwater runoff from the Milner Bay area is managed through clean/dirty water separation and sump and pump arrangements to retain any runoff from product areas, with potential impacts evaluated in the MEMP and reported in the annual EMRs. Therefore, potential cumulative impacts regarding stormwater are not relevant to the Proposed Action.

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	In summary, any potential cumulative impacts to marine water quality are expected to be localised around the sewage outfall and are not anticipated to impact more broadly on the environmental values of Milner Bay. The MMP and EMRs describes existing monitoring programs for Milner Bay, and the Referral describes proposed additional measures to be implemented for the Proposed Action.
6. Provide supporting documents that are not publicly available, including:	
a. IPE (2023). Development of Water Quality Trigger Values for Discharge to Marine Environment. Prepared by Indo-Pacific Environmental for GEMCO, DRAFT revision B, July 2023.	The referenced document was finalised in October 2023. The finalised version of this document has been provided in Appendix A .
b. Red Earth Engineering (2024). GEMCO Excess Water Disposal Project Hydrology and Hydraulic Modelling Report. Prepared for South 32 – Groote Eylandt Mining Company (GEMCO). Dated 20 September 2024.	The document is provided in Appendix B .

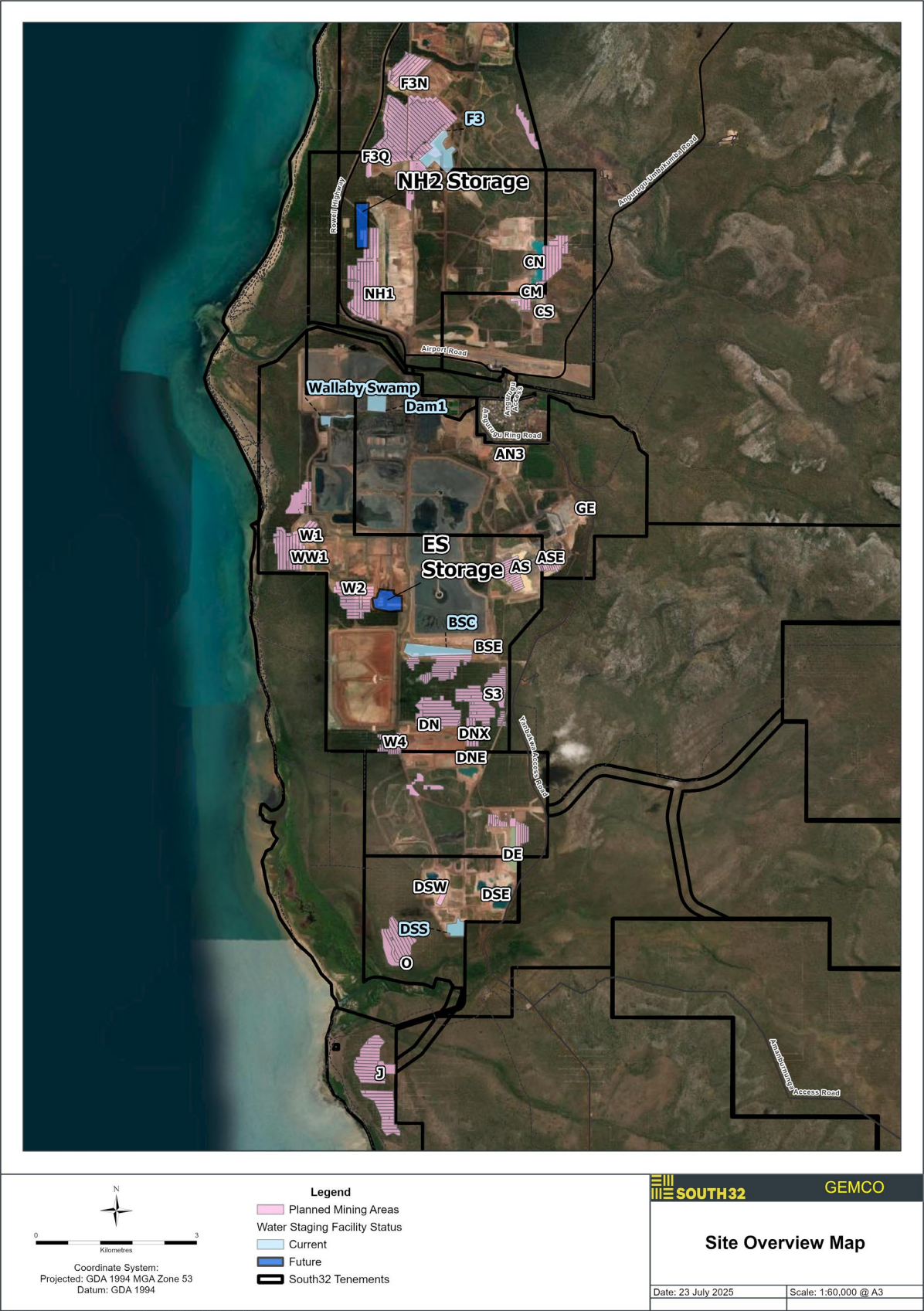


Figure 1: GEMCO Western Leases quarries, existing and proposed water storages and mining areas

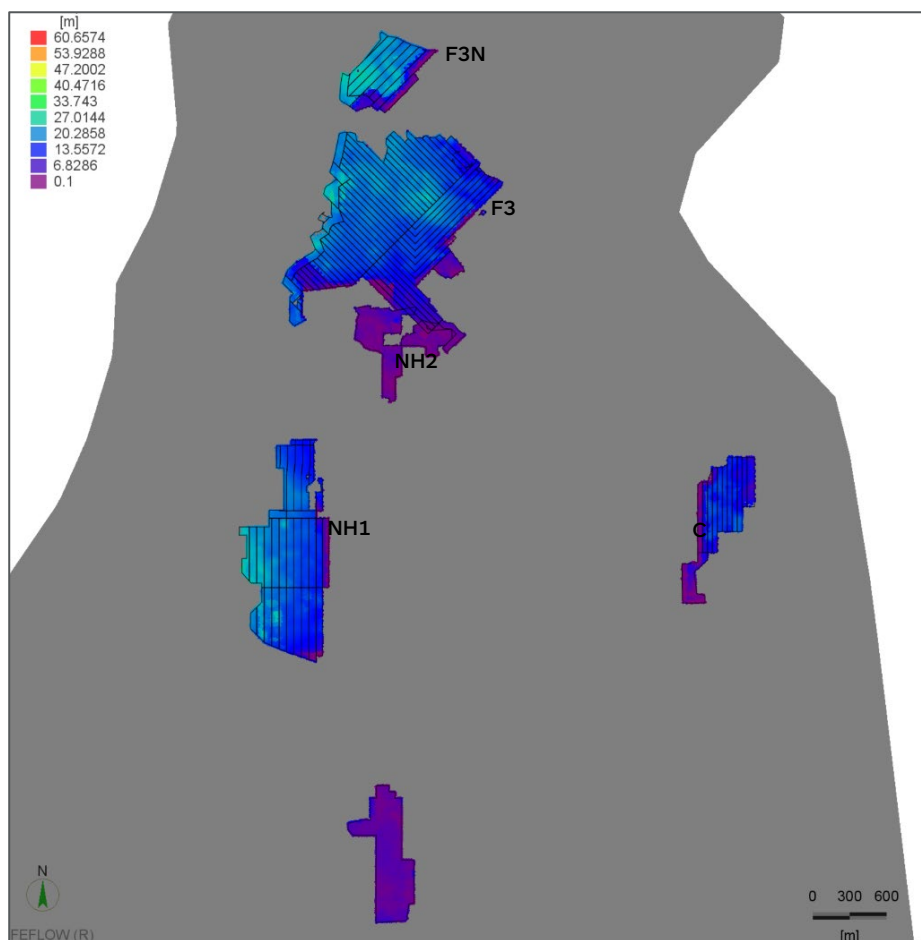


Figure 2: Proposed quarry depths (m below ground level) for the Northern Quarries

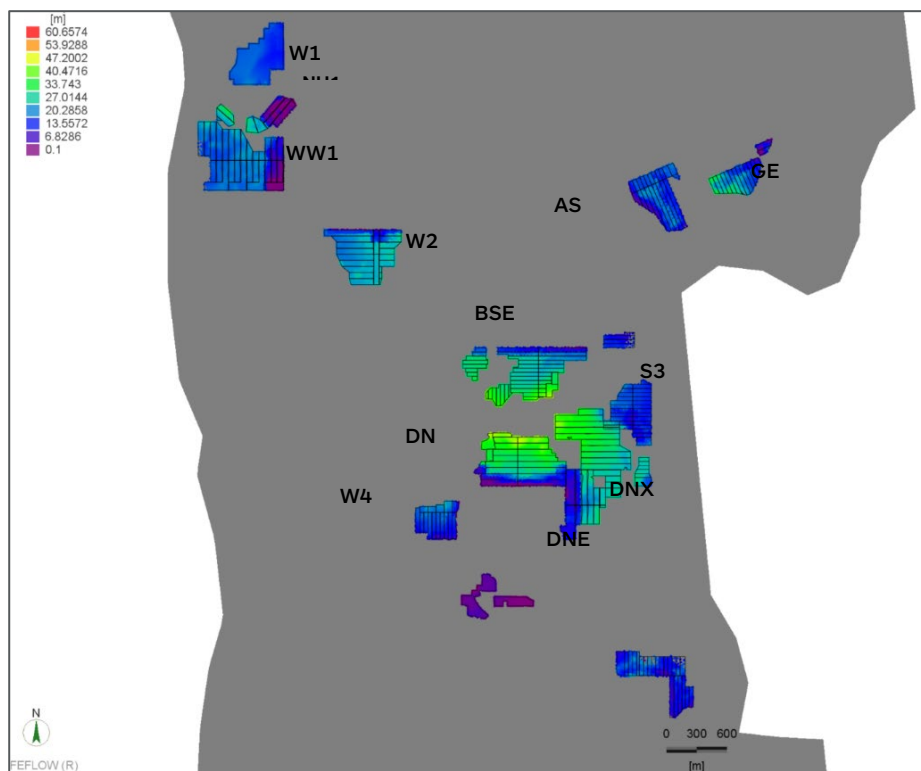


Figure 3: Proposed quarry depths (m below ground level) for the Central Quarries

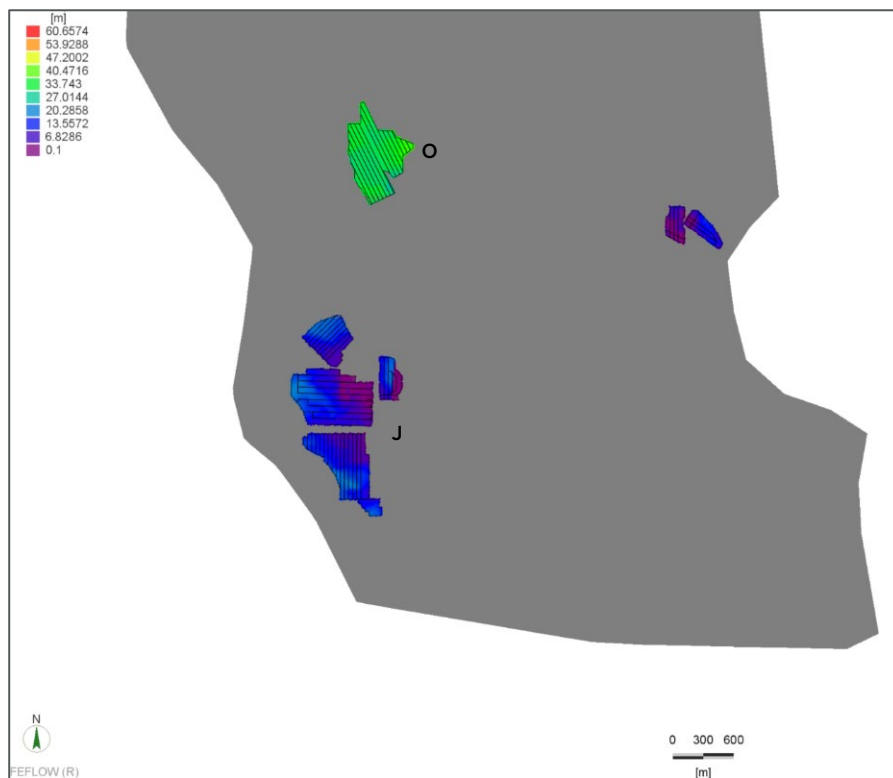


Figure 4: Proposed quarry depths (m below ground level) for the Southern Quarries

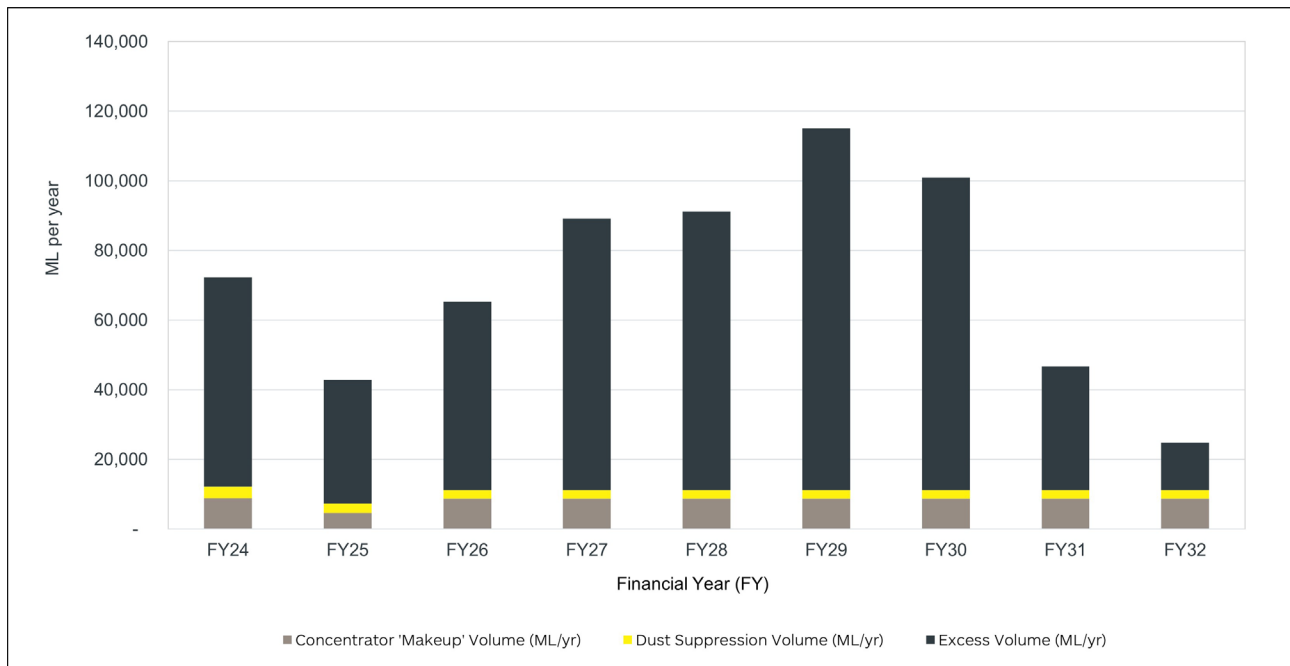


Figure 5: Actual and predicted excess water volumes (FY24 to FY32)

Appendix A: IPE 2023 Report





INDOPACIFIC

Environmental

DEVELOPMENT OF WATER QUALITY TRIGGER VALUES FOR DISCHARGE TO MARINE ENVIRONMENT

Prepared for:

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Project ID: 23027

Document Control

Project: Development of water quality trigger values for discharge to marine environment						IPE Project ID: 23027	
Client: Groote Eylandt Mining Company Pty Ltd				Client Contact:	Will Longworth / Jeremy Barnett		
Rev	Intent	Author	Organisation	Date	Reviewer	Organisation	Date
A	Internal draft	J. Wansbrough	IPE	25-07-2023	S. Longbottom	IPE	26-07-2023
B	Client Draft	J. Wansbrough	IPE	26-07-2023	E. Lazzarotto	WSP	05-09-2023
0	Final	J. Wansbrough	IPE	03-10-2023			

Disclaimer

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EXECUTIVE SUMMARY

The Groote Eylandt Mining Company / South 32 (GEMCO) operates a manganese mine on Groote Eylandt, located approximately 650km southeast of Darwin and 50km from the Northern Territory mainland and eastern coast of Arnhem Land. The quarry mining process utilised by GEMCO requires clearing of vegetation, prior to the removal of topsoil and overburden, to access the manganese ore. To facilitate the safe and practical extraction of the ore, dewatering is often required. Dewatering is also undertaken from the various tailings storage facilities (TSF) to maintain safe operations. Currently surplus water is discharged to surrounding bushland, however dewatering volumes are projected to increase up to potentially 100 GL per year.

Alternative surplus water disposal options are being investigated to deal with the increased volume and potential deterioration in water quality, particularly increases in salinity. One option being considered is an ocean outfall at the GEMCO Port facility in Milner Bay. If an ocean outfall is selected as the preferred option, an appropriate monitoring program will need to be in place to monitor and guide water management to ensure environmental impacts are minimised. As such, GEMCO approached Indo-Pacific Environmental to review the historical monitoring data sets and develop appropriate marine trigger values for assessment of the impact of ocean disposal of surplus water. This work is required to support the GEMCO Excess Water Disposal Prefeasibility Study. The trigger values proposed in this report are provided to support the hydrodynamic modelling assessment of the potential impact zone which will take into account GEMCO's dewatering quality, predicted dewatering volumes, and the receiving environment conditions. The proposed trigger values provided within this report may also be used to support any discharge license application or amendment to GEMCO's Mine Management Plan should the ocean outfall option be deemed viable.

A comprehensive review of the quarry discharge water quality monitoring data set revealed a suite of analytes which were consistently detectable in the quarry discharge water. These analytes, termed analytes of interest, were then assessed for potential risk to receiving environment. An initial suite of 45 analytes of interest were identified following examination of the quarry discharge water quality data set. Following comparison with analyte concentrations in the marine receiving environment and assessment of ANZG (2018), ANZECC & ARMCANZ (2000) guidelines and a comprehensive literature review, this was refined to a suite of 27 proposed trigger values for analytes present in the quarry discharge water which may present a risk to the receiving environment. The proposed trigger values, number of exceedances in the quarry discharge water data set, and the worst case scenarios for hydrological modelling purposes are summarised in Table 8 of this document.

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1 INTRODUCTION

1.1 *Background and Historical Sampling*

The Groote Eylandt Mining Company (GEMCO) operates a manganese mine on Groote Eylandt, which is located approximately 650km southeast of Darwin and 50km from the Northern Territory mainland and eastern coast of Arnhem Land. The mining process utilised by GEMCO requires clearing of vegetation, prior to the removal of topsoil and overburden, to access the manganese ore. To facilitate safe and practical extraction of the ore dewatering is often required. Dewatering is also undertaken from the various tailings storage facilities (TSF) to maintain safe operations. A portion of the resultant water is used for operational requirements, while surplus water is discharged to surrounding bushland. Discharge may occur within or outside of GEMCO's lease boundaries subject to regulatory approval. Due to increases in production, the number of quarries, and an increase in ore depth, the volume of water discharged has increased in recent years and is expected to continue increasing.

To maintain compliance with GEMCO's Mining Management Plan (MMP) and ensure dewatering activities do not cause significant environmental impacts, GEMCO undertakes monitoring of water quality before discharge for comparison to a range of trigger values. These trigger values were developed by GEMCO in 2019 and provide guideline values for key contaminants likely to be present in the quarry and TSF discharge water. To establish the trigger values an ICP-MS analysis of 49 metals was performed on all samples collected from all active quarries and TSFs. Trigger values were then developed for analytes which were consistently detectable within samples and likely to have adverse environmental impact. Water quality is assessed against these trigger values prior to the commencement of discharge and monthly thereafter. If exceedances are identified, water is contained until it is demonstrated that water quality meets the trigger values.

GEMCO recently commissioned a review of the discharge water quality monitoring data set and trigger values for discharge to bushland (Indo-Pacific Environmental 2023a). This review was commissioned to assess the appropriateness of the trigger values in light of the expanded monitoring data set, and to propose a trigger value for electrical conductivity. This was due to concerns over rising salinities in some quarries reducing the suitability of discharge to bushland. The review proposed an interim electrical conductivity trigger value of 250 $\mu\text{S}/\text{cm}$. This conservative interim trigger value was proposed due to uncertainty in the salinity tolerance of receptor plant species. Due to the relatively low EC trigger value proposed there were a substantial number of exceedances ($n = 76$) in the discharge monitoring data set. This indicated there may be future operational constraints to discharge of excess water to bushland.

As such, due to the projected increases in the volume of water required to be discharged and the suitability for bushland disposal of a portion of the discharge, GEMCO is investigating the feasibility of ocean discharge for excess water at a location adjacent to GEMCO's port facility (Figure 1). To support this investigation, GEMCO requested that Indo-Pacific Environmental undertake a review of GEMCO's historical water quality data sets and develop a suite of appropriate trigger values for discharge of excess water to the marine environment. This work is anticipated to support hydrodynamic modelling of the outfall location to determine the effect of mixing on contaminant concentrations and define a potential impact zone from the outfall.

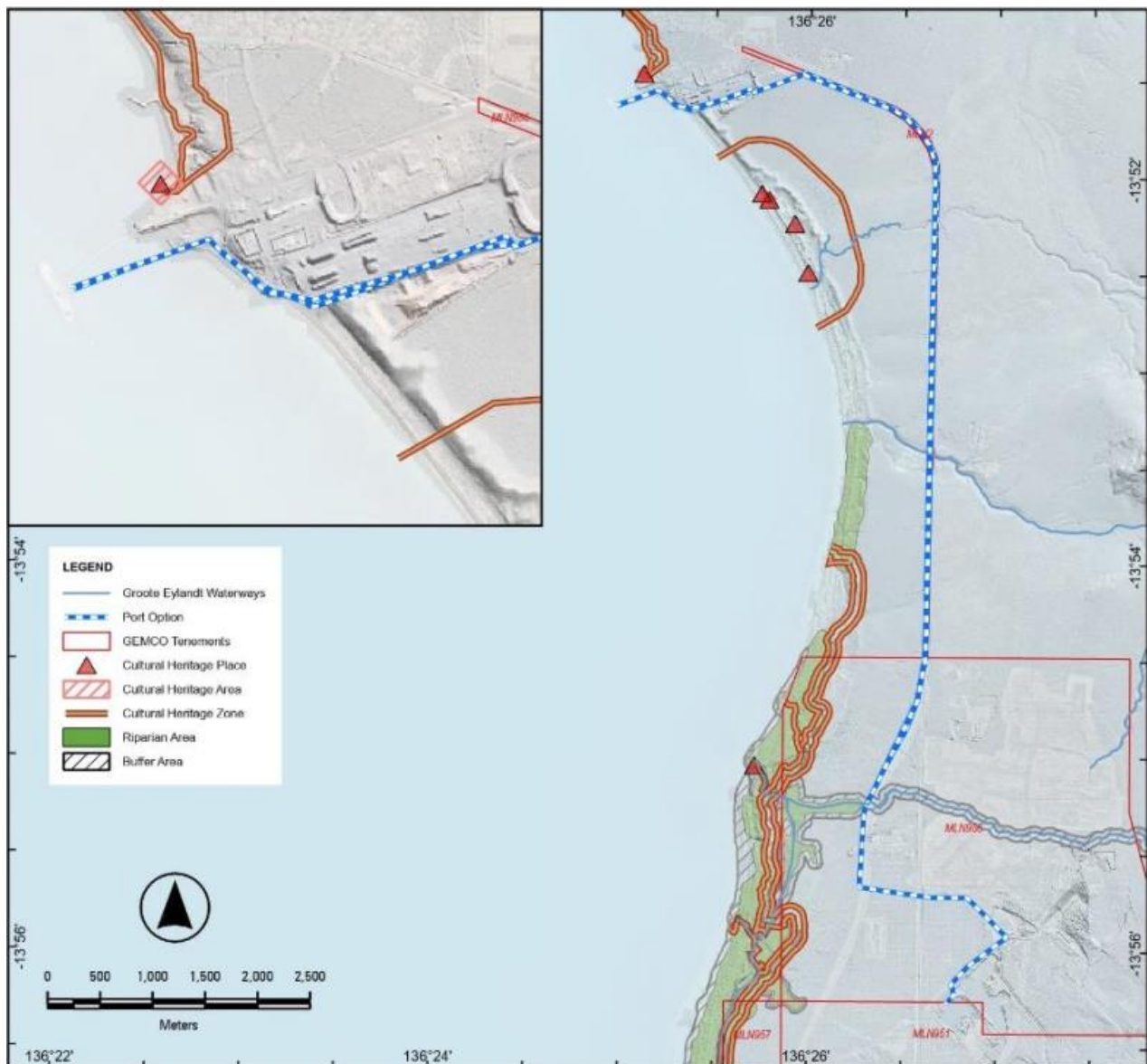


Figure 1. Potential ocean outfall location for excess water disposal at Milner Bay, Groote Eylandt. Map provided by GEMCO.

1.2 Aim and Objectives of the Current Study

This report aims to define appropriate marine trigger values for the proposed ocean disposal of water derived from GEMCO's mine dewatering.

Specifically, the objectives to address this aim were to:

- review the historical data set from the monitoring of quarry dewatering discharge water quality;
- review the historical data set from the GEMCO Marine Environmental Monitoring Program (MEMP) to characterise the receiving environment;
- identify the key contaminants of concern for the marine environment, and develop appropriate trigger values for these analytes;
- assess the existing water quality data of all quarry sites in light of suggested marine trigger values; and
- provide appropriate 'worst-case' contaminant concentrations for use in hydrodynamic modelling.

2 METHOD

2.1 *Review of Historical Data Sets*

The data sets used in this report comprised GEMCO's historical water quality monitoring data sets from the Marine Environmental Monitoring Program and the Quarry Water Quality Monitoring Program. On commencement of the project, the most up-to-date versions of the data sets were provided by GEMCO on the 06/07/2023, this report only includes the data set provided by GEMCO up to that date.

The provided data sets were analysed in the R Environment for Statistical Computing. Each data set was investigated for erroneous values which were excluded from further analysis. Erroneous values were rare and included duplicate data, electrical conductivity data with impossible values, NAs in the data, and a measurement of lead concentration with an unusually high LOA. Data was filtered and standardised to the same units where necessary. Where recorded concentrations were below the limit of analysis (LOA) a value of 50% of the LOA was used. All concentrations of metals and metalloids are assessed as the dissolved fraction which is generally considered to be the bioavailable concentration.

2.1.1 Identification of analytes of interest in discharge water

The identification of analytes of interest in the quarry discharge water data set followed the same protocol used by GEMCO in the initial 2019 development of trigger values for discharge of excess quarry water to bushland and used in the 2023 review of these trigger values (Indo-Pacific Environmental 2023a). The full quarry discharge water data set was examined, with each analyte assessed on the basis of the number of measurements in the data set compared to the number of measurements where the analyte was detected above the limit of analysis (LOA). This approach assumes that the analysis of the discharge data set is sufficiently comprehensive to have identified all potential contaminants which are likely to have a negative impact on the receiving environment.

2.1.2 Characterisation of the receiving environment

The annual marine monitoring data set was used to characterise the analyte concentrations currently present in the receiving environment. In some areas, naturally occurring analyte concentrations may be above those presented as national default guideline values (DGV), with local marine organisms adapted to higher analyte concentrations than those used to develop the DGV's. To determine the background analyte concentrations, it is generally necessary to assess unimpacted reference sites.

The GEMCO marine monitoring data set was filtered to include only ocean water samples and included multiple sites ($n = 12$) surrounding its shipping port which are considered potential impact sites, in addition to 8 control sites, comprising 5 north of the port, and 3 sites south of the port facility (Appendix 1). The marine monitoring data was first assessed to determine if major analyte concentrations varied between control sites and potential impact sites. The distributions of analyte concentrations of control sites and potential impact sites were

visualised using box plots to assess any difference between control and impact site analyte concentrations (Appendix 2). There was no evidence that using the port sites as part of the marine data set would lead to overestimation of background analyte concentrations. The visual assessment of analyte concentrations indicated that control sites had equal or greater analyte concentrations than potential impact sites for the majority of analytes examined, with the exceptions of molybdenum, strontium, and selenium, where port sites had higher analyte concentrations than control sites (Appendix 2). The similarity between potential impact and control sites is likely driven by extensive mixing in the marine environment. We consider the inclusion of the potential impact site data unlikely to skew assessment of background marine analyte concentrations.

When considering characterisation of the receiving environment we consider it appropriate to include only analytes which may be naturally present in the receiving environment. As such, we did not consider the concentrations of anthropogenic pollutants such as hydrocarbons as part of this assessment of the receiving environment.

2.2 Development of Marine Trigger Values

The development of the proposed trigger values for dewatering discharge to the marine environment considered the following factors when determining the appropriate analytes and concentrations to set trigger values for.

The Declared Beneficial Use Area for Groote Eylandt Area Marine Waters encompasses the area surrounding the proposed dewatering discharge point. The area is considered to be a slightly to moderately disturbed ecosystem. For ecosystems with this rating, aquatic biodiversity may have been adversely impacted to a measurable degree, however ecosystem integrity is mostly retained. The maintenance of biodiversity should be considered a key management goal and any trigger values suggested should reflect this. When discharging, wastewater trigger values may be applied to the discharge point, or a mixing zone may be implemented. A mixing zone is a defined area or volume of water surrounding the waste discharge point where water quality may exceed the trigger values or what is required to protect environmental values. Performance against the trigger values is then assessed at compliance points at the boundary of the mixing zone, rather than at the specific discharge point. The trigger values proposed in this document are intended to be applied to a mixing zone for the discharge of excess quarry dewatering wastewater.

The Australian & New Zealand Guidelines for Fresh & Marine Water Quality (ANZG 2018) outline current best practice for the management of water quality values in Australia. In general, it is considered important to consider multiple lines of evidence when assessing water quality. These may include direct assessment of the stressor (i.e. presence of toxicants) or the ecosystem receptor (change in biodiversity, bioaccumulation, toxicity testing). The guidelines indicate that assessments of a waste discharge generally relate to the chemical and physical stressor line of evidence and assess the concentrations of discharged toxicants or other physico-chemical stressors. ANZG (2018) provides a suite of water quality default guideline values (DGV) to use as a general tool to ensure toxicant concentrations do not exceed harmful levels. In addition to the toxicant and

physico-chemical stressor DVGs provided by ANZG (2018) there are a different suite of physico-chemical stressors provided historically by ANZECC & ARMCANZ (2000). These provide additional guidelines for physico-chemical stressors not updated by ANZG (2018) and are considered for inclusion where appropriate.

In addition to the suggested default water quality guideline values prescribed by ANZG (2018) or ANZECC & ARMCANZ (2000) we undertook a supplementary literature review to identify any analytes for which additional data was available.

Where analytes already had either an ANZG DVG or a low reliability trigger value prescribed by ANZG (2018) we considered only literature which followed the outlined methodology for the development of new DVGs in Australia. There are currently a number of high quality publications proposing default guideline values for analytes which currently do not have high reliability DVGs available. These publications follow the process set out in the Australian guidelines for the derivation of species sensitivity distributions which form the basis of the DVG. They provide additional information for contaminants with low reliability ANZG DVGs, however it is important to note that prior to public consultation and review, they are not ANZG DVGs. Where analytes had no ANZG DVG or low reliability trigger value and little ecotoxicological research available we assessed general ecotoxicological publications for any guiding information available for trigger value justification.

Finally, following the ANZG (2018) guidance we assessed the historical marine water quality monitoring data set provided by GEMCO to characterise the receiving environment. Where ecotoxicological data is unavailable or when local conditions result in higher analyte concentrations than provided by the ANZG (2018) DVGs, the use of reference data to derive site specific trigger values is recommended. For slightly to moderately disturbed ecosystems the 80th percentile of the reference data set may be used as a site specific trigger value (ANZG 2018).

3 RESULTS AND DISCUSSION

3.1 *Review of Historical Quarry and TSF Data sets and Identification of Contaminants of Interest*

3.1.1 Summary of data set

The historical quarry discharge water quality data set contained a total of 15 533 observations from 22 quarries over a 15 year period from 2008 – 2023, although the majority of the data for most analytes was collected in the 2020 – 2023 period. In total 148 analytes were measured within this data set, however many of these were only assessed on a small number of occasions, often at the beginning of the monitoring period. In general, analytes which were only measured on a small number of occasions were those for which there was no detections above the LOA and were considered unlikely to be present in the discharge water.

3.1.2 Identification of contaminants of interest

As outlined in Section 2.1.1 the discharge water data set was initially examined for analytes that were consistently detectable in the discharge water. Table 1 below outlines metals and metalloids which were detectable above the LOA within the discharge water quality data set. In addition to the commonly assessed metals and metalloids listed in Table 1, the discharge water quality data set also contained a substantial number of measurements of the concentration of 'rare-earth' and associated elements. There is some evidence that this group of elements may have similar ecotoxicological profiles and are listed separately in Table 2. Non-metal toxicants and potential physico-chemical environmental stressors are detailed in Table 3.

Table 1. Metals and metalloids which were detectable in concentrations above the limit of analysis (LOA) for the quarry dewatering water quality monitoring data set. Concentrations are in µg/L. Ratio represents the number of detections compared to the number of samples for each analyte. Graphs outlining the distribution of each analyte concentration are presented in Appendix 3.

Analyte	Number of Samples	Detections above LOA	Ratio	Min	Quantile				Max
					20 th	50 th	80 th	95 th	
Aluminium	389	122	0.31	5	5	5	20	464	2920
Antimony	188	2	0.01	0.5	0.5	0.5	0.5	0.5	2
Arsenic	195	1	0.01	0.5	0.5	0.5	0.5	0.5	5
Barium	389	295	0.76	0.5	0.5	2	9	39.6	121
Boron	192	13	0.07	25	25	25	25	54.5	170
Cadmium	195	3	0.02	0.05	0.05	0.05	0.05	0.05	0.2
Caesium	374	14	0.04	0.5	0.5	0.5	0.5	0.5	8
Chromium	195	5	0.03	0.5	0.5	0.5	0.5	0.5	2
Cobalt	194	5	0.03	0.5	0.5	0.5	0.5	0.5	5
Copper	195	13	0.07	0.5	0.5	0.5	0.5	1	10
Iron	387	15	0.04	25	25	25	25	25	1040
Lithium	186	33	0.18	0.5	0.5	0.5	0.5	1	17
Manganese	389	389	1.00	2	18	51	128.4	314	8020
Molybdenum	188	8	0.04	0.5	0.5	0.5	0.5	0.5	3
Nickel	195	29	0.15	0.5	0.5	0.5	0.5	4	13
Rubidium	186	52	0.28	0.5	0.5	0.5	1	3	8
Silver	188	1	0.01	0.5	0.5	0.5	0.5	0.5	2
Strontium	188	184	0.98	0.5	6	10	36.6	113.7	285
Tin	186	4	0.02	0.5	0.5	0.5	0.5	0.5	3
Titanium	186	6	0.03	5	5	5	5	5	70
Zinc	390	62	0.16	2.5	2.5	2.5	2.5	24	196

Table 2. Rare-earth and associated elements present in the GEMCO quarry discharge water data set. Concentrations are in µg/L. Graphs outlining the distribution of each analyte concentration are presented in Appendix 4.

Analyte	Number of Samples	Detections above LOA	Ratio	Min	Quantile				Max
					20 th	50 th	80 th	95 th	
Dysprosium	186	14	0.08	0.5	0.5	0.5	0.5	3.75	23
Erbium	186	14	0.08	0.5	0.5	0.5	0.5	3	22
Europium	186	1	0.01	0.5	0.5	0.5	0.5	0.5	1
Gadolinium	186	13	0.07	0.5	0.5	0.5	0.5	2	8
Holmium	186	7	0.04	0.5	0.5	0.5	0.5	0.5	7
Lanthanum	186	21	0.11	0.5	0.5	0.5	0.5	6	19
Lutetium	186	3	0.02	0.5	0.5	0.5	0.5	0.5	2
Neodymium	186	22	0.12	0.5	0.5	0.5	0.5	8	26
Praseodymium	186	13	0.07	0.5	0.5	0.5	0.5	2	5
Samarium	186	13	0.07	0.5	0.5	0.5	0.5	1.75	5
Terbium	186	3	0.02	0.5	0.5	0.5	0.5	0.5	2
Thulium	186	3	0.02	0.5	0.5	0.5	0.5	0.5	3
Ytterbium	186	12	0.06	0.5	0.5	0.5	0.5	2	17
Yttrium	186	27	0.15	0.5	0.5	0.5	0.5	35	261

Table 3. Non-metal toxicants and physico-chemical stressors present in the quarry discharge water data set. Concentrations are in µg/L unless otherwise specified. Graphs outlining the distribution of each analyte concentration are presented in Appendix 5.

Analyte (Unit)	Number of Samples	Detections above LOA	Ratio	Min	Quantile				Max
					20 th	50 th	80 th	95 th	
>C10 - C40 Fraction (sum)	376	5	0.01	50	50	50	50	50	1670
Electrical Conductivity at 25°C (µS/cm)	248	248	1	23	54	85	380.2	1120	3780
Nitrogen as Ammonia	43	13	0.30	2.5	2.5	2.5	37	111.8	1040
Nitrate Nitrogen	47	46	1	1	71.4	211	466	684	951
Total Nitrogen	42	42	1	20	92	215	558	881	1030
pH – Field (pH units)	48	48	1	4.6	5.3	5.7	6.4	6.8	6.9
Phosphate	42	14	0.33	0.5	0.5	0.5	2	6.9	9
Total Phosphorus as P	42	16	0.38	2.5	2.5	2.5	9	14	23
Suspended Solids (mg/L)	182	95	0.52	2.5	2.5	5.5	23.6	89.6	844
Turbidity (NTU)	345	345	1	0.2	1.9	5.2	23	222.8	3230

3.1.3 Summaries of identified contaminants of interest

3.1.3.1 Metals and metalloids

In total, 21 metal and metalloid potential analytes of interest were identified from preliminary assessment of the historical quarry discharge water quality data set. Given the nature of the ore body, manganese was unsurprisingly the most commonly detected element, with 389 measurements, all of which were above the LOA. As with all of the analytes of interest that were identified, the distribution of manganese concentrations in the data set was highly left skewed. The median manganese concentration observed was 51 µg/L, with the 80th and 95th percentiles recorded at 128 and 314 µg/L respectively. The maximum manganese concentration observed in the discharge water quality data set was very high, being 8020 µg/L (Table 1).

Two other elements were observed to have very high detection ratios. Strontium had a detection to measurement ratio of 0.98 out of 186 measurements, while barium had a detection ratio of 0.76 out of 389 measurements indicating that these elements are commonly present in measurable quantities in the quarry discharge water. Median strontium concentrations were 10 µg/L, while the maximum recorded concentration was 285 µg/L. Barium concentrations were relatively low with a median of 2 µg/L and a maximum of 121 µg/L.

Other elements which had moderately high detection ratios (>0.15) included aluminium, rubidium, lithium, zinc, and nickel. Aluminium was detected in 31% of samples (n = 389) and the median concentration was 5 µg/L, while the maximum recorded concentration was 2920 µg/L. Rubidium was detected in 28% of samples (n = 186), however concentrations were generally low, the median was 0.5 µg/L (<LOA), while the maximum concentration was 8 µg/L. Lithium was detected in 18% of samples (n = 186), and concentrations were similar to rubidium, with a median of 0.5 µg/L (<LOA), and a maximum concentration of 17 µg/L. Both zinc and nickel had median and 80th percentile concentrations <LOA with maximum concentrations of 196 µg/L and 13 µg/L recorded respectively (Table 1).

3.1.3.2 Rare-earth and associated elements

Overall, 13 rare-earth elements in the lanthanide series and yttrium were identified as other potential analytes of interest. The most commonly detected rare-earth elements were yttrium, neodymium, and lanthanum, with detection ratios of 0.15, 0.12, and 0.11 respectively (n = 186). As with the other metal and metalloid analytes investigated the concentration distributions were highly skewed, median and 80th percentile values for all rare-earth elements were <LOA. Within the lanthanide series maximum concentrations ranged from 1 – 26 µg/L, while the maximum concentration of yttrium was substantially higher, at 261 µg/L (Table 2).

3.1.3.3 Non-metal toxicants and physico-chemical stressors

There were five detections of total petroleum hydrocarbons expressed as the sum of the >C10 – C40 fraction in the quarry water quality monitoring data set (n = 376). The limit of analysis for the >C10 – C40 fraction was 100 µg/L. The maximum value recorded was 1670 µg/L.

The salinity of quarry discharge water was relatively low, with a maximum recorded electrical conductivity of 3780 µS/cm, which is equivalent to < 2 PSU. The field recorded pH values in the quarry data set were considered to be mildly to moderately acidic, with a pH range of 4.6 – 6.9 and a median pH of 5.7. In relation to suspended solids, up to 844 mg/L had been recorded with a median of 5.5 mg/L, while the associated turbidity recordings were a maximum of 3230 NTU, with a median of 5.5 NTU.

Dissolved nutrient levels in the discharge water were variable. In general nitrogen including total nitrogen and nitrate-nitrogen were consistently high in comparison to their DGVs, with medians of 215 and 211 µg/L for total N and nitrate N respectively, and maximums of 1030 and 951 µg/L. Ammoniacal nitrogen had a more skewed distribution with a substantially lower median of 2.5 (<LOA), although the maximum concentration recorded was similar to total nitrogen at 1040 µg/L. Phosphorous levels were assessed both as phosphate and total phosphorus, both analytes had medians below the LOA, maximum phosphate was approximately half that of total phosphate with concentrations of 9 and 23 µg/L respectively (Table 3).

3.2 *Review of Historical Marine Monitoring Data set*

3.2.1 Summary of data set

The provided marine water quality monitoring data set was derived from the MEMP, with data spanning the period between 2013 – 2022. It is important to note that the marine water quality monitoring data set was collected during annual water quality sampling which occurred at approximately the same time each year (neaps tides of October – December), and as such is only representative of late dry season water quality in the region. The data set provided contained data that was not relevant to the current project including sediment, beach seep, and sewage outfall analyte concentration data. Filtering to the relevant data resulted in a final data set of 13 802 observations from 8 control sites and 12 port sites.

Assessment of the marine water quality data set was limited to analytes identified as potential analytes of interest in the quarry discharge data set. Many of the analytes which were identified as analytes of interest in the quarry discharge water quality data set were not assessed in the marine water quality monitoring data set and not available for comparison.

3.2.2 Occurrence of analytes of interest in the marine environment

The elements caesium, lithium, and titanium were identified as potential analytes of interest from their presence in detectable amounts in the quarry water quality monitoring data set (Table 1), however they were not present in the marine water quality monitoring data set and so are not included in Table 4 below. Rare-earth elements were not assessed in the marine water quality monitoring program and so were not available in the marine data set.

Analytes which had higher concentrations recorded in the marine water quality monitoring data set than in the quarry discharge water quality monitoring data set included boron, molybdenum, strontium, and tin. A more detailed discussion of these analytes is presented in Section 3.3.2. The remainder of the metal and metalloid analytes in the marine monitoring data set had low concentrations relative to the quarry discharge data. When assessing the 80th percentile (used to set site-specific TVs) the only other elements which had concentrations above their respective LOAs were arsenic, barium, iron, and manganese, which had 80th percentile concentrations of 1.8 µg/L, 7 µg/L, 5.4 µg/L, and 4.2 µg/L respectively (Table 4).

3.2.2.1 Non-metal toxicants and physico-chemical stressors in the marine environment

Substantially fewer physico-chemical stressor analytes were measured in the marine water quality monitoring data set in comparison to the quarry discharge water quality monitoring data set. This resulted in marine receiving environment reference data for only four of the 10 analytes identified as potential non-metal toxicants or physico-chemical stressors in the quarry discharge data set.

The 80th percentile for hydrocarbons (<C10 – C40 fraction) was <LOA, with only 3 detections above the LOA, this was a similar distribution of concentration values as observed in the quarry discharge data, where 5 observations >LOA were recorded. Due to the acidity of the discharge water, the 20th percentile pH is the more relevant value, this was 7.65 pH. Turbidity was surprisingly low for the Gulf Region, with a maximum recorded value of 8.82 NTU and an 80th percentile of 5.44 NTU, this is likely due to the timing of the annual marine water quality sampling with low turbidity expected at the end of the dry season in comparison to the wet season.

Table 4. Concentrations of metals and metalloids in the marine water quality monitoring data set which were also detectable in the quarry discharge water quality monitoring data set. Concentrations are in µg/L. Ratio represents the number of detections compared to the number of samples for each analyte. Graphs outlining the distribution of each analyte concentration are presented in Appendix 6.

Analyte	Number of Samples	Detections above LOA	Ratio	Min	Quantile				Max
					20 th	50 th	80 th	95 th	
Aluminium	179	20	0.11	2.50	2.50	2.50	2.50	22.00	87.00
Antimony	13	0	0.00	0.25	0.25	0.25	0.25	0.25	0.25
Arsenic	171	171	1.00	0.60	1.30	1.50	1.80	2.15	2.50
Barium	179	179	1.00	4.00	6.00	7.00	7.00	8.00	12.00
Boron	164	164	1.00	2780	3820	4180	4630	4905	5110
Cadmium	171	0	0.00	0.05	0.10	0.10	0.10	0.10	0.10
Chromium	171	0	0.00	0.25	0.25	0.25	0.25	0.25	0.25
Cobalt	144	12	0.08	0.05	0.10	0.10	0.10	0.20	0.30
Copper	171	8	0.05	0.50	0.50	0.50	0.50	0.50	3.00
Iron	179	42	0.23	2.50	2.50	2.50	5.40	31.00	72.00
Manganese	187	170	0.91	0.25	1.00	1.80	4.20	7.01	10.90
Molybdenum	48	48	1.00	8.90	9.80	10.40	10.90	11.17	11.80
Nickel	171	15	0.09	0.25	0.25	0.25	0.25	1.00	1.40
Silver	48	0	0.00	0.05	0.05	0.05	0.05	0.05	0.05
Strontium	40	40	1.00	6950	7400	7660	8466	8662	8760
Tin	13	1	0.08	2.50	2.50	2.50	2.50	6.30	12.00
Zinc	187	2	0.01	2.50	2.50	2.50	2.50	2.50	7.00

Table 5. Non-metal toxicants and physico-chemical stressors present in the marine water quality data set. Concentrations are in µg/L unless otherwise specified. Graphs outlining the distribution of each analyte concentration are presented in Appendix 7.

Analyte (Unit)	Number of Samples	Detections above LOA	Ratio	Min	Quantile				Max
					20 th	50 th	80 th	95 th	
>C10 - C40 Fraction (sum)	187	3	0.016	50	50	50	50	50	780
pH – Field (pH units)	148	148	1	7.41	7.65	8.03	8.09	8.17	8.2
Suspended Solids (mg/L)	187	136	0.73	0.5	2	3	7	32.1	48
Turbidity (NTU)	144	144	1	0	2.66	3.55	5.44	6.52	8.82

3.3 Development of Marine Trigger Values for Analytes of Interest

3.3.1 Literature Review

3.3.1.1 ANZG Default Guideline Values

The current ANZG (2018) default guideline values for marine waters were assessed. Table 1 below outlines the suggested national default guideline values for dissolved metals and metalloids included in a direct export of the DVG CSV file from ANZG on the 06/07/2023, in addition to the suggested application for slightly to moderately disturbed marine waters.

Table 6. ANZG default guideline values for dissolved concentrations of metals and metalloids in marine waters. Table represents all metal/metalloid analytes present in the export DVG data set available from ANZG (2018). Concentrations are in µg/L. LOSP = level of species protection. Note 99 % LOSP values used for bioaccumulating analytes as per ANZG (2018).

Analyte	TV Reliability	99% LOSP	95% LOSP	ANZG Recommended Use
Cadmium	Very High	0.7	5.5	99% LOSP
Chromium (Cr III)	Low	7.7	27	95% LOSP
Chromium (Cr VI)	Very High	0.14	4.4	95% LOSP
Cobalt	High	0.005	1	95% LOSP
Copper	Very High	0.3	1.3	95% LOSP
Lead	Low	2.2	4.4	95% LOSP
Manganese	Unknown			See below
Mercury (inorganic)	Very High	0.1	0.4	99% LOSP
Nickel	Very High	7	70	99% LOSP
Silver	Moderate	0.8	1.4	95% LOSP
Thallium	Unknown			See below
Tributyltin	High	0.0004	0.006	95% LOSP
Vanadium	Moderate	50	100	95% LOSP
Zinc	Very High	3.3	8.0	95% LOSP

In addition to the analytes listed in Table 6 above the ANZG (2018) guidelines also provide low reliability guidelines for several other metal and metalloid analytes:

Aluminium:

There is not currently sufficient data available to calculate a reliable marine trigger value for aluminium. A low reliability marine trigger value is provided of 0.5 µg/L based on an assessment factor of 200 using 11 acute

data points (ANZG 2018). We note that this value is below the generally available limit of analysis for aluminium in marine waters.

Antimony:

There is not currently sufficient data available to calculate a reliable marine trigger value for antimony. A low reliability marine trigger value for Antimony (III) is provided of 270 µg/L which was derived using an assessment factor of 1000. However, caution is advised when exceeding the freshwater trigger value of 9 µg/L due to uncertainty due to limited data (ANZG 2018).

Arsenic:

ANZG (2018) provides low reliability trigger values for Arsenic (III) and Arsenic (V). Arsenic (III) is the more toxic form but is less common in marine water. For As (III) an environmental concern level (low reliability TV) of 2.3 µg/L was derived using an AF of 100. For As (V) a low reliability TV of 4.5 µg/L was derived using an AF of 200 (200 used because impact data was chronic rather than acute).

Manganese:

While manganese was included in the table of DVGs exported from ANZG (2018), the only trigger value listed for marine water is a low reliability trigger value of 80 µg/L. A proposed ANZG DVG for manganese in marine water is currently under review (see Section 3.3.1.3).

Molybdenum:

There is not currently sufficient data available to calculate a reliable marine trigger value for molybdenum. Data is only available for one species of diatom and one species of dinoflagellate. A low reliability trigger value of 23 µg/L is suggested based on an AF of 200 (ANZG 2018).

Thallium:

There is not currently sufficient data available to calculate a reliable marine trigger value for thallium. A low reliability marine trigger value for thallium of 17 µg/L is suggested based on an AF of 20 for toxicity data from two species of crustacean (ANZG 2018).

Tin:

There is not currently sufficient data available to calculate a reliable marine trigger value for inorganic tin. Currently a low reliability trigger value of 1 µg/L is available which is based on an AF of 200 applied to diatom data. No toxicity to fish or crustaceans has been found below the saturation level of 35 µg/L, indicating that 1 µg/L may be too conservative. A recommended value of 10 µg/L which is used in the United Kingdom is suggested as an alternative low reliability marine trigger level (ANZG 2018).

Rare-earth elements:

No marine data is available for lanthanum or other rare-earth elements. The only data for lanthanum presented by ANZG (2018) was for freshwater *Daphnia*. From this a low reliability trigger value/ environmental concern level of 0.04 µg/L was derived using an AF of 1000. No marine data was available. As this trigger value is below the practical limit of analysis it is suggested that any detection of lanthanum may warrant investigation (ANZG 2018).

Physico-chemical stressors with ANZG (2018) DVGs:

ANZG (2018) provides additional physical and chemical stressor default guideline values derived from data collected over each of 59 marine ecoregions based on the Integrated Marine and Coastal Regionalisation of Australia (IMCRA 4.0) as the best possible representation of Australia's coastal waters. This represents a finer spatial scale for the DVGs than previously implemented in ANZECC & ARMCANZ (2000), however a slightly different suite of physico-chemical stressors is assessed between the two documents, so ANZECC & ARMCANZ recommendations remain current for some analytes (see below).

Nitrate:

ANZG (2018) guidelines provide seasonal DVGs for nitrate-nitrogen derived from the 80th percentile of water quality for each season. As expected for the wet-dry season tropical climate, the summer and autumn (wet season) and the winter and spring (dry season) DVGs are very similar to each other. The maximum 80th percentile was observed in autumn and the lowest in spring. The DVGs were provided as 0.347 µmol/L and 0.196 µmol/L for autumn and spring respectively, which when converted using a molar mass for nitrate of 62.0049 g/mol, is equivalent to 12.15 – 21.51 µg/L.

Phosphate:

ANZG (2018) guidelines provide seasonal DVGs for phosphate derived from the 80th percentile of water quality for each season. Unlike the nitrate DVGs, phosphate had the lowest 80th percentile concentration in autumn, and the maximum in summer. The DVGs were provided as 0.098 µmol/L and 0.238 µmol/L for autumn and summer respectively, which when converted using a molar mass for phosphate of 94.9714 g/mol, is equivalent to 9.31 – 22.6 µg/L.

Salinity:

ANZG (2018) provides 80th percentile DVGs for seasonal salinity for the Groote IMCRA region online. However, given the discharge water is known to be of lower salinity, the 20th percentile is the appropriate value to use as the DVG in this case. The salinity percentiles data table should contain the appropriate values however the access link for this file download is inoperable (accessed 19/07/2023) (ANZG 2018).

Turbidity:

The turbidity DVG provided at the IMCRA mesoscale level in ANZG (2018) is presented in units of K_d490 , a measurement of light attenuation per metre at a wavelength of 490nm. To facilitate monitoring and comparison with discharge water data we consider the previous turbidity DVG of 20 NTU for tropical marine waters outlined in ANZECC & ARMCANZ (2000) to be also applicable.

Other physico-chemical stressors which are not included in the updated ANZG (2018) IMCRA marine bioregion scale DVGs but are listed in the ANZECC & ARMCANZ (2000) guidelines for tropical marine waters include:

Total Phosphorous:

A total phosphorous DVG is outlined in ANZECC & ARMCANZ (2000), DVGs are provided for inshore and offshore waters, the inshore DVG of 15 $\mu\text{g/L}$ is applicable for the proposed discharge point. This DVG for total phosphorous falls in the centre of the range provided by ANZG (2018) for phosphate phosphorous, which indicates that this DVG may be more conservative than the high range phosphate DVG provided in ANZG (2018).

Total Nitrogen:

A total nitrogen DVG is outlined in ANZECC & ARMCANZ (2000), there was no difference in DVGs between onshore and offshore marine sites. The DVG for total nitrogen was 100 $\mu\text{g/L}$. This was substantially higher than the nitrate-nitrogen DVG provided in ANZG (2018).

Ammoniacal Nitrogen:

The ammoniacal nitrogen DVG outlined in ANZECC & ARMCANZ (2000) was for ammonia. The DVG for inshore tropical marine waters was a range between 1-10 $\mu\text{g/L}$. The guidance provided for this range indicates that lower values should be used for clear coral dominated waters, while the higher end of the range should be used for turbid macro-tidal systems. As such the applicable DVG for the proposed discharge point is 10 $\mu\text{g/L}$.

pH Lower Limit:

ANZECC & ARMCANZ (2000) provide an offshore lower pH DVG of 8.0 and an upper pH DVG of 8.4. In the context of the proposed dewatering discharge, the pH of the discharge water is uniformly lower than the marine receiving environment. As such, the lower pH DVG is the appropriate DVG for use to assess the impact of the dewatering discharge on the marine environment.

3.3.1.2 GEMCO MEMP trigger values currently in use

As detailed in Section 3.2 above, as part of GEMCO's annual MEMP a variety of analyte concentrations in the receiving environment surrounding the port are monitored annually. Analyte concentrations are compared against a range of trigger values approved within the GEMCO MMP. Table 2 below outlines the trigger values for metal and metalloids in marine water used in the GEMCO 2022 MEMP.

Table 7. Trigger values currently employed by GEMCO for the potential marine discharge area, as presented in the GEMCO 2022 MEMP.

Analyte	Trigger Value (µg/L)
Cadmium	5.5
Chromium (Cr VI)	4.4
Cobalt	1.0
Copper	1.3
Lead	4.4
Manganese	140
Mercury (inorganic)	0.4
Nickel	70
Silver	1.4
Vanadium	100
Zinc	8.0

The current list of analytes for which there are trigger values currently assessed at the proposed discharge site includes 11 elements. The majority of the trigger values used are derived from the ANZG default guideline values for slightly to moderately disturbed ecosystems. Seven of the analytes are the recommended 95 % level of species protection (LOSP) DVGs. These are:

- Chromium (Cr VI)
- Cobalt
- Copper
- Lead
- Silver
- Vanadium
- Zinc

Three analytes are also the 95 % LOSP DVGs, however following the ANZG guidelines these are less protective than recommended for slightly to moderately disturbed ecosystems. As discussed, the GEMCO MEMP classes the receiving environment, the waters surrounding the port facility, as a slightly to moderately disturbed ecosystem. This is considered appropriate for a port with low levels of development. GEMCO in the MEMP also follows the default guidance of using the 95 % LOSP values for slightly to moderately disturbed ecosystems. However, the 95 % LOSP is not the recommended DVG for slightly to moderately disturbed ecosystems for several analytes which are known to bioaccumulate, including cadmium, mercury, and nickel. The guidance for these metals indicates that the 99 % LOSP value should be used as the DVG for slightly to moderately disturbed ecosystems such as the receiving environment considered here (ANZG 2018). The analytes for which the GEMCO MEMP currently uses an insufficiently protective DVG are:

- Cadmium
- Mercury
- Nickel

Analytes using non-ANZG trigger values:

As discussed in Section 3.3.1.1 above, the manganese trigger value provided by ANZG (2018) of 80 µg/L is considered a low reliability trigger value. In consideration that manganese was likely to be the major metal contaminant input from GEMCO operations, GEMCO sought approval for an increased manganese trigger value. A trigger value of 140 µg/L manganese was approved by the NT EPA via the ANZECC Steering Committee (GEMCO MEMP 2022).

In the GEMCO Marine Environment Monitoring Program there are no trigger values for non-metal/ metalloid analytes in marine water. While there are hydrocarbon trigger values recommended by AIMS (Trott 2012) for sediment concentrations none have been included for marine waters. Currently the quarry water quality monitoring program employs a trigger value for total recoverable hydrocarbons for discharge to bushland. The trigger value for discharge to bushland is 0 µg/L for sum of the >C10 – C40 fractions.

3.3.1.3 Analyte trigger values suggested from literature

When assessing water quality guidelines which were obtained from the literature and not an accepted ANZG (2018) DVG, preference was given for publications which followed the Australian accepted best practice for DVG derivation. Where such publications were unavailable, we assessed general ecotoxicological publications for any guiding information available for trigger value justification.

Aluminium

Water quality guidelines for aluminium in marine waters were found to vary in the literature. Golding *et al.* (2014) developed a 95 % species protection water quality guideline value of 24 µg/L of aluminium in marine waters using data derived from 11 species. In contrast, in a more recent study van Dam *et al.* (2018) suggested

a 95 % species protection guideline of 56 µg/L for aluminium, derived using sensitivity data for 17 species. In consideration that neither aluminium guideline value has been designated as an ANZG (2018) DVG, we suggest that the lower guideline value should be employed as a precautionary approach.

Arsenic:

Golding *et al.* (2022) used chronic toxicity data for 13 species to derive a species sensitivity distribution for Arsenic (V) in marine waters. The 95 % species protection level was determined to be 12 µg/L, however due to a relatively poor fit of the model the guideline value reliability was classified as moderate.

Barium:

Barium does not currently have a trigger value for fresh or marine waters in the ANZG (2018). However unlike in freshwater, barium in marine water tends to precipitate as barite. The equilibrium concentration of barium with barite in marine water is approximately 37 µg/L so if water containing higher values is discharged to the ocean the barium is expected to rapidly precipitate as barite (Neff *et al.* 1995). This indicates that barium is not a contaminant of concern for the marine receiving environment. Average seawater barium concentrations are approximately 13 µg/L (Bolter *et al.* 1964), with a range of between 4 – 12 µg/L recorded in the historical MEMP data.

Caesium:

Very little information on caesium toxicity was found during the literature review. Caesium may naturally occur at levels of ~ 0.37 µg/L in marine water (Folsom *et al.* 1964).

Gallium and molybdenum:

In addition to the proposed aluminium guideline, van Dam *et al.* (2018) also proposed marine water quality guidelines for gallium and molybdenum. These were based on sensitivity data for 6 and 14 species for gallium and molybdenum respectively. The proposed guideline values for 95 % species protection were 800 µg/L for gallium, and 3880 µg/L for molybdenum.

Lithium:

There is no ANZG (2018) DVG for lithium in marine waters, and lithium was not measured in the marine reference data set. However, a recent review of lithium in the marine environment highlights that average ocean lithium concentrations are ~ 180 µg/L, and that negative impacts on marine species require substantially higher concentrations ~ 500 – 500 000 µg/L (Barbosa *et al.* 2023).

Manganese:

Acute and chronic toxicity data for 18 species was used to model a species sensitivity distribution for manganese in marine waters (Golding *et al.* 2023). This data included adult coral which are known to be some of the most sensitive marine species to manganese. The 95 % species protection water quality limit for marine manganese derived from this data was 300 µg/L, which was substantially higher than the low reliability ANZG guideline (80 µg/L) or the currently approved manganese trigger value for GEMCO's MEMP (140 µg/L).

Nickel:

A review of the nickel guideline value was performed using additional chronic toxicity data for a number of tropical as well as temperate species. There was little difference observed between the sensitivities of tropical and temperate species and the combined data set (n = 40 species) was used to derive an updated nickel DVG of 6 µg/L for 95% species protection (Gissi *et al.* 2020).

Rare-earth elements:

The rare-earth elements (REEs) are a group of 17 heavy metals including the 15 lanthanides in addition to scandium and yttrium. Despite the name, the elements are relatively abundant in the earth's crust. There is a lack of data on the ecotoxicity of the rare-earth elements. As discussed in Section 3.3.1.1 there is no ANZG (2018) default guideline value for any of the rare-earth elements in marine waters, with the suggestion that any detection of lanthanum warrants investigation.

The literature on the toxicity of rare-earth elements to humans is relatively sparse but negative impacts including developmental impacts to foetuses, hypertension and heart disease, and digestive issues have been identified. Rare-earth elements may also be transferred to humans by consumption through the trophic chain (Brouzotis *et al.* 2022).

There is little data available on the ecotoxicology of any rare-earth element to marine organisms, however low concentrations of various REE have been shown to have substantial negative impacts. Cerium concentrations of 1.4 µg/L resulted 100% mortality of sea urchin embryos, and the same concentration of lanthanum resulted in 100% developmental defects in the same species. Additionally, mitotoxic (damage to mitochondria) effects occurred at concentrations between 14 – 420 ng/L (Oral *et al.* 2010). In fish, exposure of eels (*Anguilla anguilla*) to very low levels of lanthanum (120 ng/L) resulted in evidence disruption to acetylcholine (a neurotransmitter) binding (Figueiredo *et al.* 2018). In a summary of the available marine ecotoxicological studies for rare-earth elements de Brito (2019) concludes that the majority of studies so far have assessed terrestrial or freshwater species and due to scarce data for marine organisms further studies are necessary to understand the effects of these elements across trophic levels.

There is some evidence of similarity between the toxicity of rare-earth elements which may be due to their similar physico-chemical properties, however there is no consensus in the literature (Lachaux *et al.* 2022). Due

to the potential for toxicity at very low concentrations in the marine environment, and the lack of sufficient evidence to derive accurate species protection guideline limits, we suggest that the approach outlined in ANZG (2018) for lanthanum be followed for all rare-earth elements and that the trigger value be set at 0 µg/L to be practically implemented as <LOA.

Rubidium:

Little information on rubidium toxicity in marine waters was found during the literature review. However, natural rubidium concentrations in sea water are 125 µg/L, which is substantially higher than recorded in the quarry discharge water quality data set (Bolter *et al.* 1964).

Titanium:

Titanium has been identified as an emerging contaminant of concern due to the increasing use of titanium dioxide nano particles in industrial applications (Dedman *et al.* 2021). There is little available research on the toxicity of dissolved titanium but its concentration in marine water is extremely low (Orians *et al.* 1990). While not dissolved, concentrations of nanoparticles used in toxicity studies are very high in comparison to the concentrations recorded in the quarry discharge water (~ 10 mg/L) and there is little evidence of impact at environmentally relevant concentrations (Dedman *et al.* 2021).

3.3.2 Reference site method

A reference site approach uses background concentrations at unimpacted reference sites to derive locally relevant guideline values. In general, the ANZG (2018a) guidelines for the development of a local reference value recommend using the 80th percentile of the reference site concentrations to set as the trigger value. We considered the background concentrations of the receiving environment (presented in Section 3.2) when assessing the appropriateness of each trigger value (See Tables 4-5).

Of the analytes present in the quarry discharge water quality monitoring data set, four of the metals and metalloids which were selected as potential analytes of interest were found to have higher maximum concentrations in the marine reference water quality data set than in the quarry discharge water quality data set. These analytes were boron, molybdenum, strontium, and tin (Section 3.2.2). The sample distribution of the concentrations of these analytes was then assessed. We compared the 80th percentile of the marine reference data set with the maximum concentration of the quarry discharge data set. The 80th percentile was chosen as this is the level recommended by ANZG (2018) for use in setting site specific trigger values using reference site data. In general, this 80th percentile site specific trigger value is then compared with the median value of the monitoring point / or the discharge data in this case. Instead of using the median, we compared 80th percentile reference site value with the maximum value in the quarry discharge data. This conservative approach minimizes the risk that the historical water quality monitoring data set is not reflective of future discharge analyte concentrations.

Boron, molybdenum, and strontium all had 80th percentile concentrations in the marine reference data set that were substantially higher than the maximum concentrations in the quarry discharge data set. 80th percentile concentrations were 4630 µg/L for boron, 10.9 µg/L for molybdenum, and 8466 µg/L for strontium, while their respective maximum concentrations in the discharge data set were 170 µg/L, 3 µg/L, and 285 µg/L respectively. In contrast, while the maximum concentration of tin in the reference data was higher than in the quarry discharge data, the reference 80th percentile was <LOA while the maximum concentration in the discharge data was 3 µg/L. Following this assessment, we considered trigger values for boron, molybdenum, and strontium to be unnecessary, while a proposed trigger value was included for tin.

As discussed in Section 2.1.2 there was little identifiable difference in analyte concentrations between marine reference sites and potential impact sites, and all monitoring data was used to define the overall reference condition of the proposed discharge site. Three analytes, molybdenum, selenium, and strontium were identified as having higher concentrations in the potential impact area immediately surrounding the port as compared to the reference sampling sites to the north and south of the port. Comparison of the sampling distributions of the concentrations of these analytes between the marine monitoring data set and the quarry water quality monitoring data set indicates that this difference will have no impact on the implementation of trigger values for these analytes.

For these three analytes, the maximum concentrations detected in the quarry discharge water quality monitoring data set were substantially lower than the minimum concentrations detected in the marine water quality monitoring data set. Both selenium and strontium are relatively common in the marine environment, and it is not anticipated that quarry discharge water will negatively increase the concentrations of these elements (Tables 1, 4). As such no trigger value is recommended, and the higher concentrations observed at the port monitoring sites will have no impact as a trigger value from reference data is not required. The maximum concentration of molybdenum in the quarry discharge water quality monitoring data set was 3 µg/L. In contrast, the minimum concentration in the marine water quality monitoring data set was 8.9 µg/L and the literature suggested trigger value is 3880 µg/L.

3.3.3 Suggested Trigger Values

Table 8 below outlines the suggested trigger values for discharge of GEMCO quarry water to the marine environment. Trigger values were derived from a synthesis of relevant default guideline values, reference site data, and published literature providing either 95 % guideline values from species sensitivity distributions, or where they were not available, direct ecotoxicological research.

Table 8. Suggested trigger values for metals and metalloids for dewatering discharge to the marine environment. Concentrations are µg/L unless otherwise specified. Superscript on recommended TVs indicates source. Number of samples above TV is the number of exceedances of the proposed trigger value in the quarry discharge water quality monitoring data set, note that this reflects point source exceedances and does not assess the impact of a mixing zone.

Analyte	ANZG/ ANZECC DVG (Reliability level)	Literature suggested TV	80 th percentile of reference data set	Recommended TV	Number of samples above TV	95 th percentile of discharge data set	Maximum concentration in discharge data set
Aluminium	0.5 (Low)	24	<LOA	24 ^d	77	464	2920
Antimony	270 (Low)	-	<LOA	270 ^a	0	0.5 (<LOA)	2
Arsenic	4.5 (As V) (Low)	12 (As V)	1.8	12 ^e	0	0.5 (<LOA)	5
Cadmium	0.7 (Very high)	-	<LOA	0.7 ^a	0	0.5 (<LOA)	0.2
Chromium (Cr VI)	4.4 (Very high)	-	<LOA	4.4 ^a	0	0.5 (<LOA)	2
Cobalt	1 (High)	-	<LOA	1 ^a	3	0.5 (<LOA)	5
Copper	1.3 (Very high)	-	<LOA	1.3 ^a	8	1	10
Iron	-	-	5.4	5.4 ^c	387	25 (<LOA)	1040
Lead	4.4 (Low)	-	0.4	4.4 ^a	0	0.5 (<LOA)	<1 (<LOA)
Manganese	80 (Low)	300	4.2	300 ^f	22	314	8020
Mercury (inorganic)	0.1 (Very high)	-	<LOA	0.1 ^a	0	0.05 (<LOA)	<0.1 (<LOA)
Nickel	7 (Very high)	6	<LOA	6 ^g	3	4	13
Silver	1.4 (Moderate)	-	<LOA	1.4 ^a	1	0.5 (<LOA)	2
Thallium	17 (Low)	17	<LOA	17 ^a	0	0.5 (<LOA)	<1 (<LOA)
Tin	1 (Low)	10 (ANZG Recommendation)	<LOA	10 ^a	0	0.5 (<LOA)	3
Vanadium	100 (Moderate)		2.5	100 ^a	0	0.5 (<LOA)	<1 (<LOA)
Zinc	8 (Very high)		<LOA	8 ^a	43	24	196
Rare-earth elements	0.04 (Lanthanum) (Low)	<LOA (ANZG Recommendation)	Not measured	0 or <LOA ^h	166	Range: 0.5 (<LOA) - 35	Overall max: 261 (yttrium) Lanthanum max: 19

Analyte	ANZG/ ANZECC DVG (Reliability level)	Literature suggested TV	80 th percentile of reference data set	Recommended TV	Number of samples above TV	95 th percentile of discharge data set	Maximum concentration in discharge data set
>C10 – C40 Fraction (sum)	-	0 (<LOA)	<LOA	0 or <LOA ⁱ	5	50 (<LOA)	1670
Ammoniacal Nitrogen	10	-	Not measured	10 ^b	11	112	1040
Nitrate Nitrogen	12.15 – 21.51	-	Not measured	12.15 – 21.51 ^a	44	684	951
Total Nitrogen	100	-	Not measured	100 ^b	30	881	1030
Phosphate	9.31 – 22.6	-	Not measured	9.31 – 22.6 ^a	0	6.9	9
Total Phosphorus	15	-	Not measured	15 ^b	1	14	23
Salinity (PSU)		-			-	37 µS/cm (5 th Percentile)	~0 PSU (23 µS/cm) (Min)
Turbidity (NTU)	20	-	5.44	20 ^b	75	223	3230
pH Lower Limit (pH)	8.0	-	7.65 (20 th percentile)	7.65 ^c	48	5.03 (5 th percentile)	4.6 (Min)

- a) ANZG 2018
- b) ANZECC & ARM CANZ 2000
- c) Site specific: 80th percentile of reference sites
- d) Golding *et al.* 2014
- e) Golding *et al.* 2022
- f) Golding *et al.* 2023
- g) Gissi *et al.* 2020
- h) Derived from ANZG recommendation and literature review
- i) GEMCO discharge to bushland approved value

3.4 Assessment of Discharge Water Data Set Against Suggested TVs

As outlined in Table 8, the quarry discharge water quality monitoring data set was then compared to the proposed trigger values to determine the number of exceedances of each trigger value. The number of exceedances represents the potential for constraint to the discharge operation and for environmental impact. However, it should be noted that this measure of the number of exceedances is a comparison of point source discharge to the proposed trigger values and as such, is inherently conservative as compared to realistic operational procedures which will likely include dilution in a mixing zone prior to comparison to the trigger values.

Metals and metalloids:

In total, 8 of the 17 metal and metalloid analytes which have proposed trigger values had exceedances in the historical quarry water quality monitoring data set.

Iron had the most exceedances of its proposed trigger value of any metal. All ($n = 387$) measurements of iron concentrations in the quarry discharge data set exceeded the proposed $5.4 \mu\text{g/L}$ site-specific trigger value. This would represent a possible constraint to discharge, however it is likely a data artefact due to the high LOA used for the iron analysis in quarry discharge data set. The LOA used for the marine monitoring analysis was $5 \mu\text{g/L}$ for iron, while the LOA used in the quarry discharge water analysis was $50 \mu\text{g/L}$. This caused all quarry samples to exceed the proposed trigger value as half the LOA ($25 \mu\text{g/L}$) is used where values are below the LOA. Only 15 samples in the quarry discharge data set were above the $50 \mu\text{g/L}$ LOA, based on the level of skew in other analyte concentrations in the data set, we consider it likely that many of the samples below the LOA would also be below the $5.4 \mu\text{g/L}$, however analysis using a lower LOA is needed for confirmation. Iron concentrations are commonly analysed to an LOA of $1 \mu\text{g/L}$, and this is recommended for future water quality monitoring of the quarry discharge water.

Other metals which had a substantial number of exceedances included aluminium, zinc, and manganese, which had 77, 43, and 22 exceedances of the proposed trigger values respectively. These elements are identified as having the potential to either cause environmental risk or constrain discharge due to the relatively high frequency of exceedances of the proposed TVs and due to the magnitude of exceedances, with maximum concentrations for these analytes exceeding the trigger values by factors of 24 – 122 times.

Copper, cobalt, nickel, and silver had between 1 – 8 exceedances of their trigger values. In addition to the low overall number of exceedances, the magnitude of the exceedances was low for these elements overall (Table 8). Due to the rarity of exceedance and the low magnitude, these elements are unlikely to constrain discharge.

Rare-earth elements:

When assessed together, there were 166 samples which had rare-earth element concentrations above the LOA (between 1 – 27 detections per REE, each with 186 measurements), which is considered to be an exceedance of the proposed 0 or <LOA REE trigger value. While a detailed analysis and description of the concentrations of analytes at each quarry is outside the scope of this document, it is potentially useful to note that the vast majority (95 %) of rare-earth element exceedances detected in the discharge water quality monitoring data set occurred at only two of the 22 quarries monitored. Almost all rare-earth elements detected above the LOA were at the F3 and F3N quarries. If the proposed trigger value of <LOA results in operational constraints to dewatering, it may be beneficial to assess alternative disposal or treatment options for the water originating from these two quarries.

Non-metal toxicants and physico-chemical stressors:

The trigger value for total hydrocarbons measured as the sum of >C10 – C40 fractions was exceeded on 5 occasions out of 376 measurements. This was the same as reported in Indo-Pacific Environmental (2023) when reviewing the trigger values for discharge to bushland. It was concluded that this was unlikely to result in a constraint to dewatering, although that efforts to lower the LOA should be investigated.

In regard to potential physico-chemical stressors, turbidity, pH, and all nitrogen measurements had multiple exceedances of the proposed trigger values. The most commonly exceeded was the turbidity TV of 20 NTU which was exceeded 75 times of 345 measurements. The lower pH TV (20th percentile of reference data) was breached 48 times (48 measurements) with a minimum pH of 4.6 recorded, which was substantially more acidic than the receiving environment. Of the nitrogen trigger values the most commonly exceeded was nitrate-nitrogen which was exceeded 44 times (47 measurements). While the ammoniacal nitrogen TV was exceeded less often (11 times, 43 measurements) the maximum magnitude of the exceedance was higher, at over 100 times the TV for the maximum recorded concentration (Table 8).

We found no lower trigger value for salinity for the Groote region available and there was little suitable data in the marine reference data set. As such there is currently no trigger value recommended, however we note that the discharge water is essentially fresh in comparison to the receiving environment and salinity reduction from the discharge water should be closely monitored.

3.5 Worst Case Scenario Assessment for Hydrodynamic Modelling

As part of the scope of this report GEMCO requested an assessment of the worst case scenarios regarding analyte concentrations within the quarry discharge water quality monitoring data set in order to facilitate the hydrodynamic modelling of analyte concentrations within the mixing zone. A memorandum providing an interim data summary was provided to allow initial modelling to proceed (Indo-Pacific Environmental 2023b). Table 8 provides an updated summary of the data for hydrodynamic modelling with a focus on analytes which have been identified as a potential environmental concern and with a proposed trigger value.

Due to the uniformly skewed analyte concentration distributions, we included only the 95th percentile and maximum concentrations of each analyte in Table 8. We consider these values to provide the best conservative estimate of the risk to the environment when discharging due to lower percentiles often being below the LOA. If other percentiles are required for modelling data may be found in Tables 1 – 3.

4 CONCLUSION & RECOMMENDATIONS

Summary:

The aim of this report was to develop appropriate trigger levels for the discharge of excess water to the marine receiving environment in order to support the GEMCO Excess Water Disposal Prefeasibility Study. A comprehensive review of the quarry discharge water quality monitoring data set revealed a suite of analytes which were consistently detectable in the quarry discharge water. Forty five analytes of interest were initially identified following examination of the quarry discharge water quality data set. This suite of potential analytes of interest was then refined following assessment of baseline analyte concentrations in the marine receiving environment, assessment of the guidance and default guideline values DVGs prescribed in ANZG (2018) and ANZECC & ARMCANZ (2000), and a comprehensive literature review. A final suite of 27 proposed trigger values was established for monitoring of quarry dewatering discharge water to the marine receiving environment of Milner Bay. The proposed trigger values, number of exceedances in the quarry discharge water data set, and the worst case scenarios for hydrological modelling purposes are summarised in Table 8 of this document.

Additional Recommendations:

In addition to the direct stressor line of evidence considered in the development of the proposed toxicant trigger values outlined in this report, consideration should also be given to other lines of evidence including ecosystem receptors. If exceedances occur, additional lines of evidence are critical for assessing the consequences and management responses. Assessing trends in ecosystem receptors such as biodiversity can require multiple samples and benefits from a before-after, control-impact (BACI) design. As such, pre-disturbance and ongoing monitoring is suggested as a vital addition to the trigger values proposed in this report for assessment of the potential discharge dewatering project impact. These additional ecosystem receptor lines of evidence are increasingly being required as part of waste discharge licences in Australian jurisdictions and are necessary in the event of exceedances (ANZG 2018).

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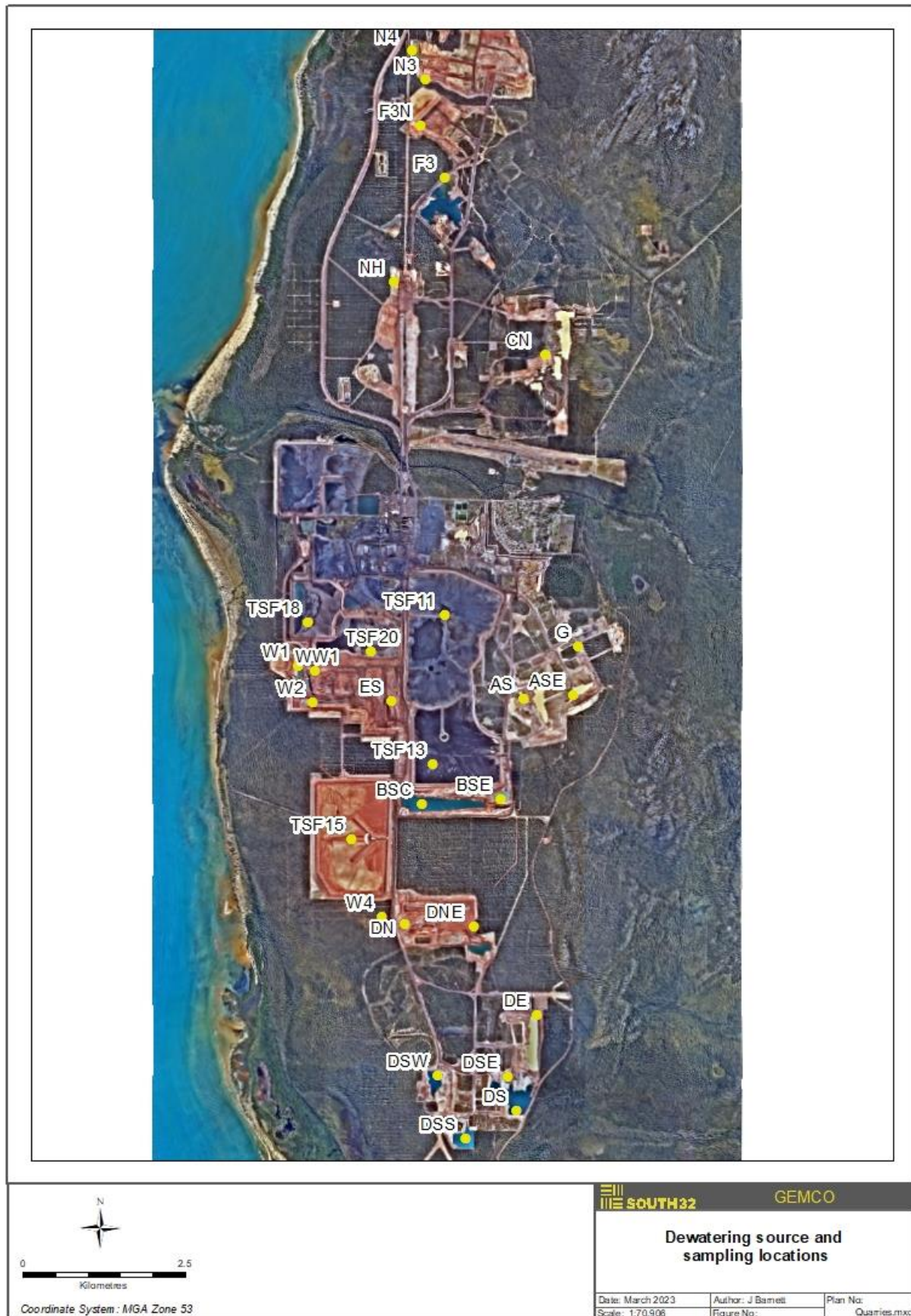
6 Appendix 1: Maps

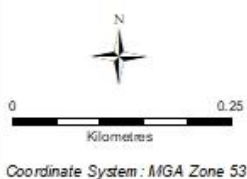
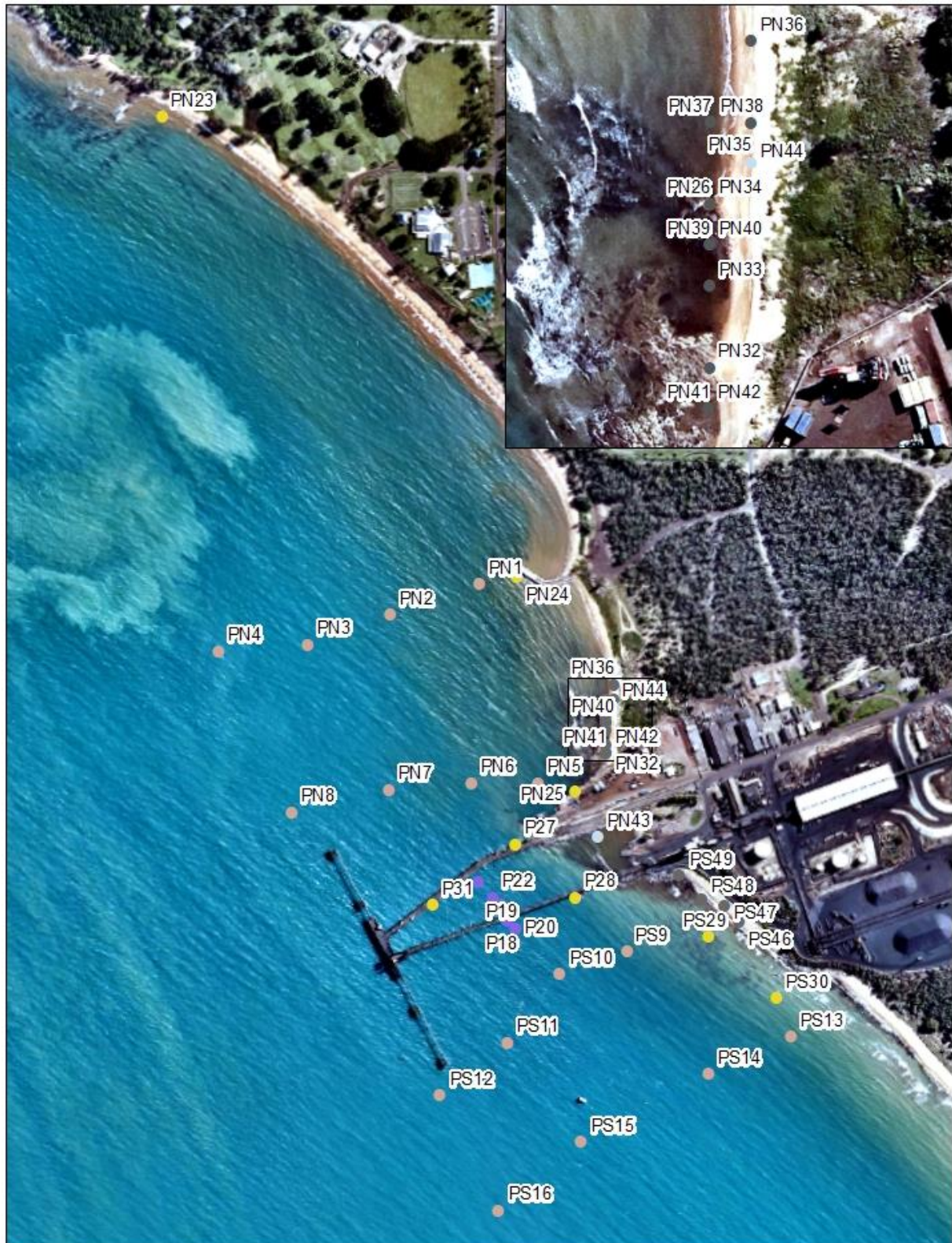
Map 1. Dewatering source and sampling locations. Map provided by GEMCO.

Map 2a. Marine monitoring program sampling locations. Port sites. Map provided by GEMCO.

Map 2b. Marine monitoring program sampling locations. Control sites South. Map provided by GEMCO.

Map 2c. Marine monitoring program sampling locations. Control sites North. Map provided by GEMCO.





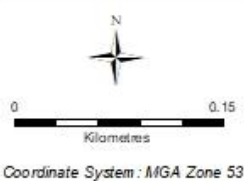
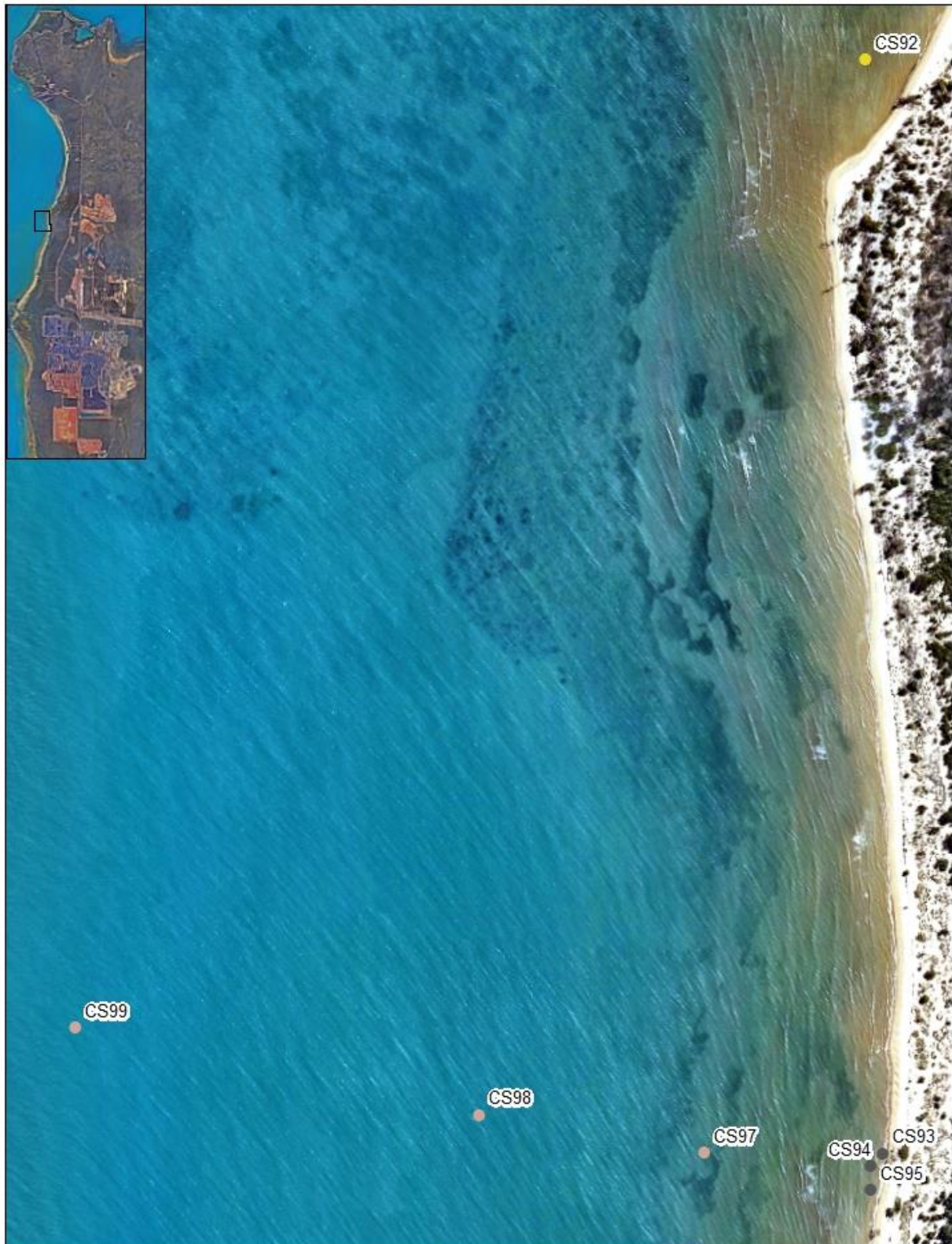
Legend

- Beach Sand
- Beach Seep
- Offshore Water & Sediment
- Oysters
- STP Outfall

SOUTH32 **GEMCO**

Marine Monitoring Locations - Port

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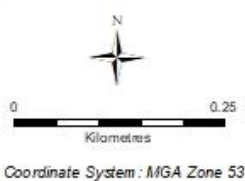
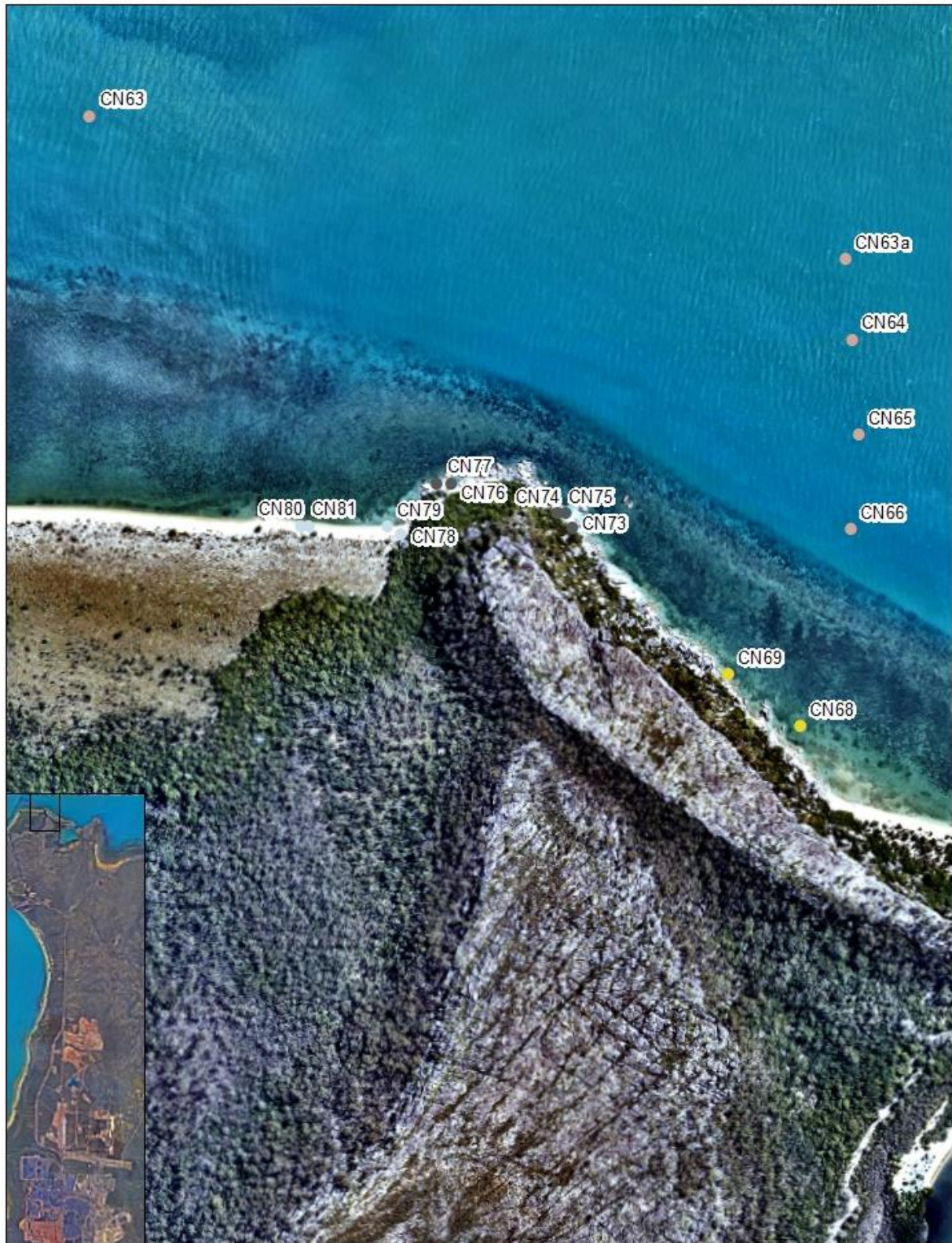
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- Beach Seep & Beach Sand
- Offshore Water & Sediment
- Oysters

SOUTH32 **GEMCO**

Marine Monitoring Locations - South

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- Beach Seep
- Offshore Water & Sediment
- Oysters
- STP Outfall

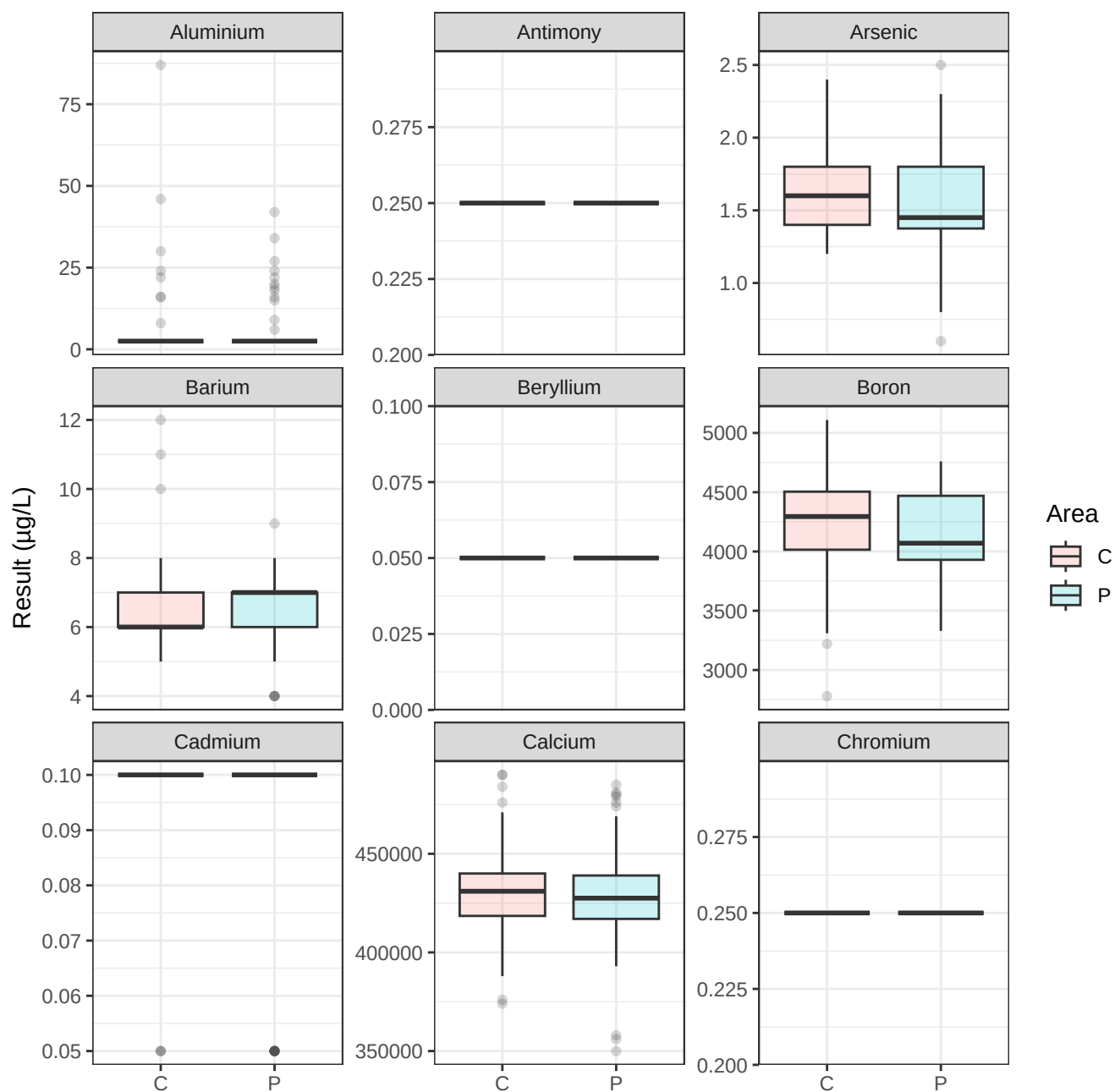
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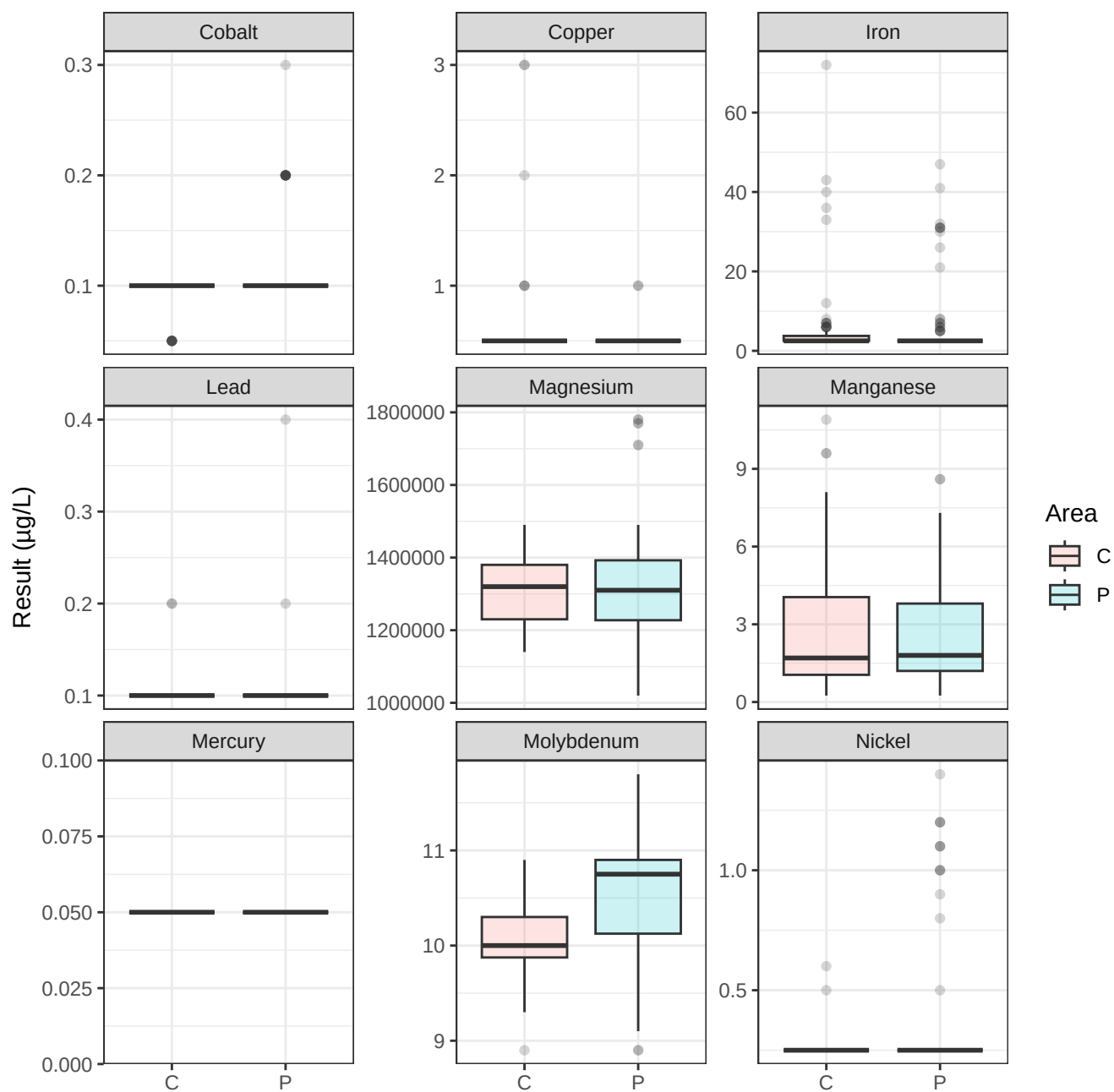
Marine Monitoring Locations - North

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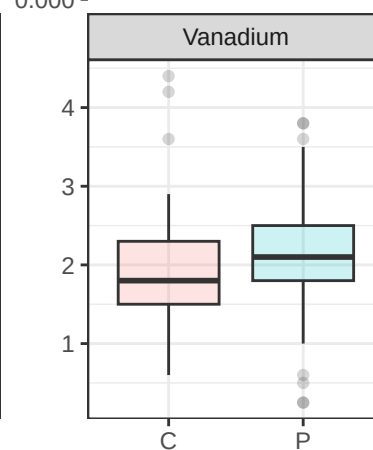
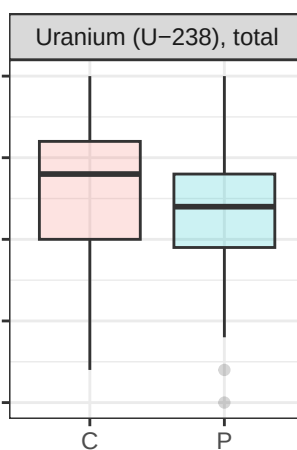
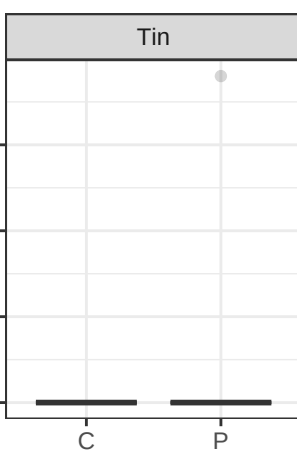
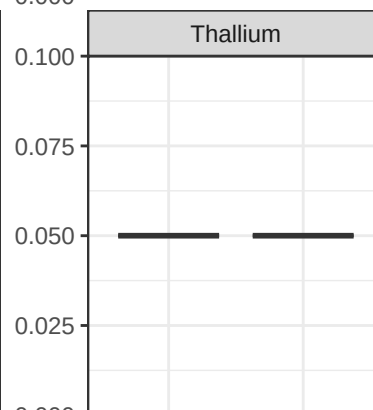
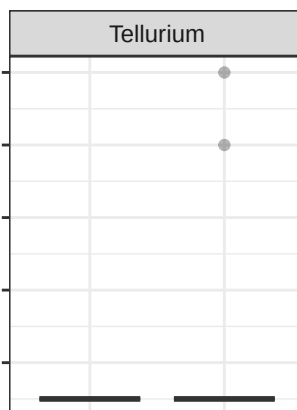
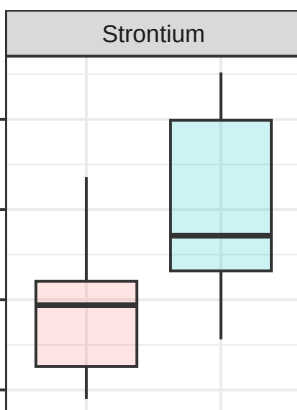
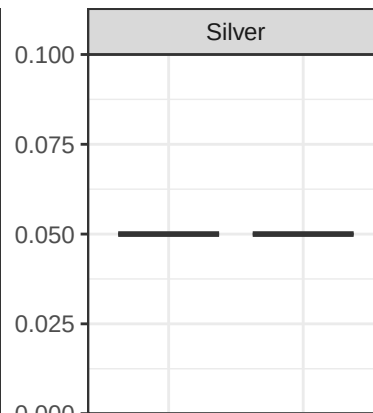
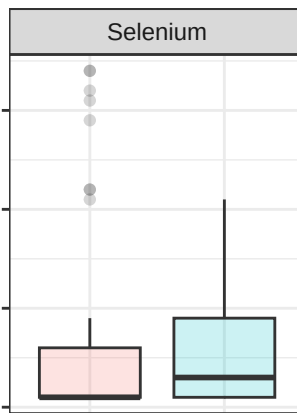
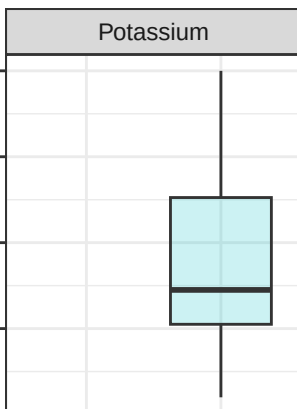
7 Appendix 2: Analyte distribution between marine port and reference sites

Appendix 2 Figure. Distribution of metal and metalloid analyte concentrations in marine receiving waters. Boxplots indicate differences in analyte concentrations between port sites (blue) and control sites (red).





Result (µg/L)



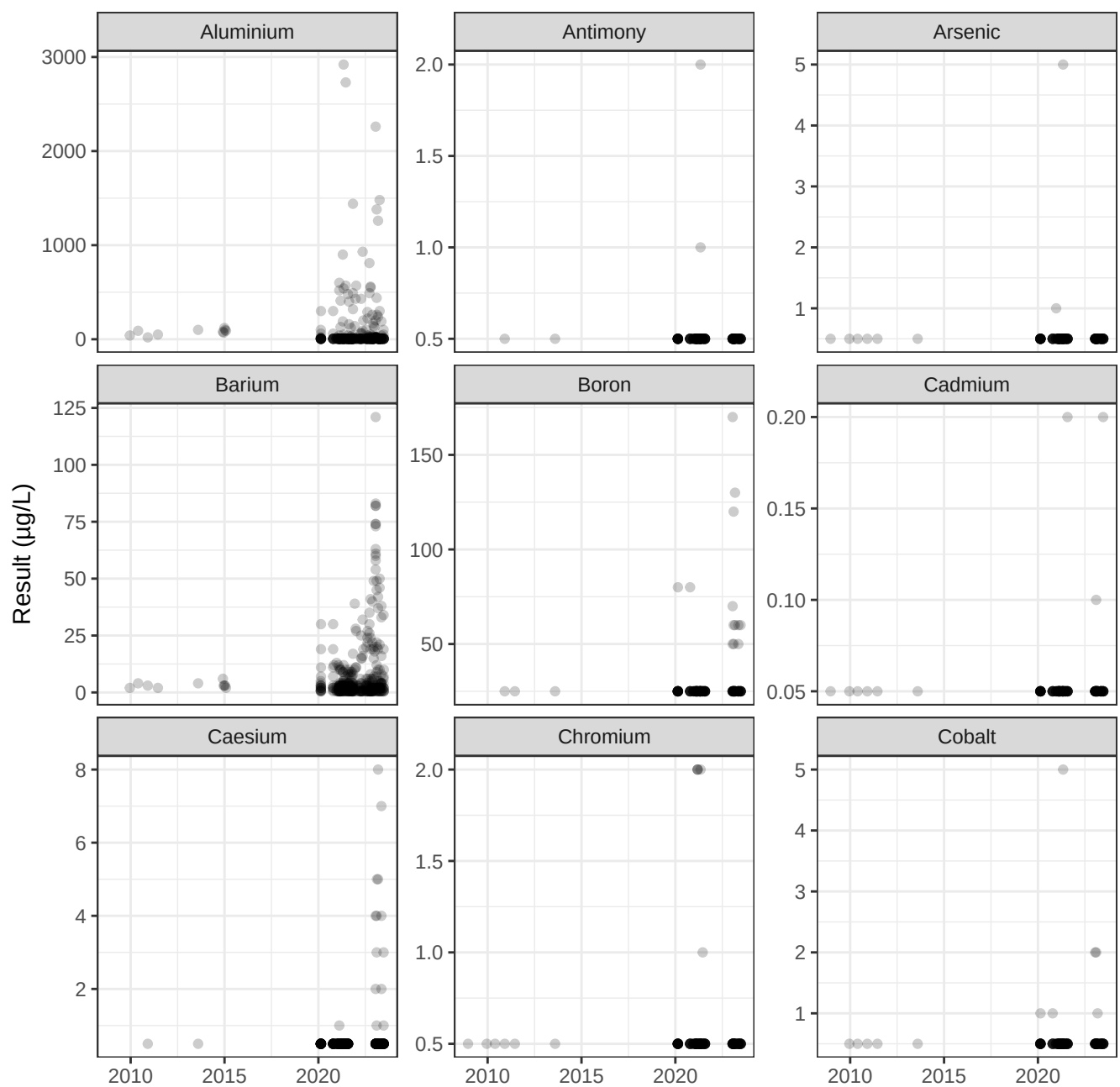
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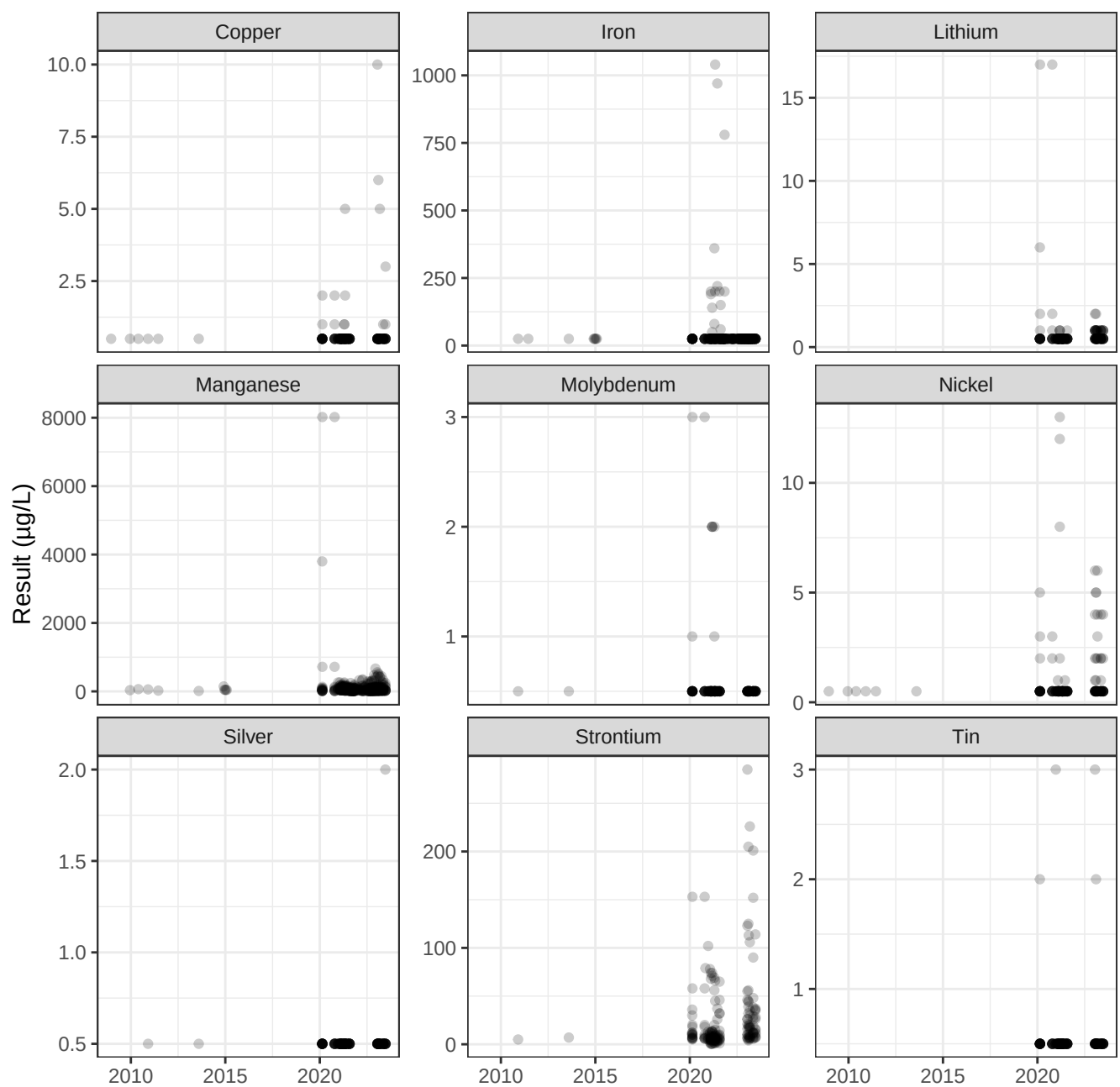




8 Appendix 3: Quarry discharge water metal and metalloid analyte concentrations

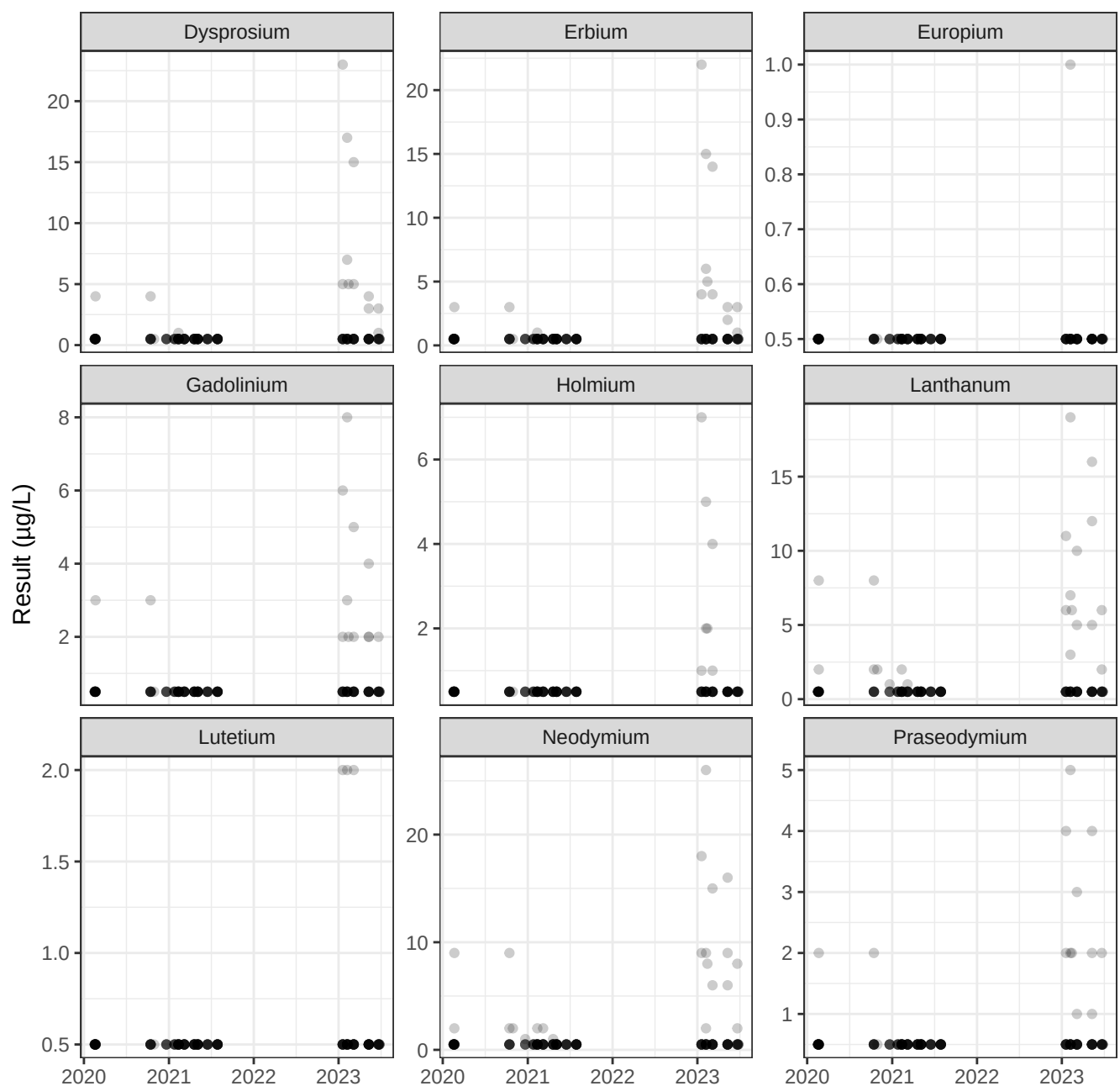
Appendix 3 Figure. Metal and metalloid concentrations in the quarry discharge water quality monitoring data set for the period 2008 – 2023.

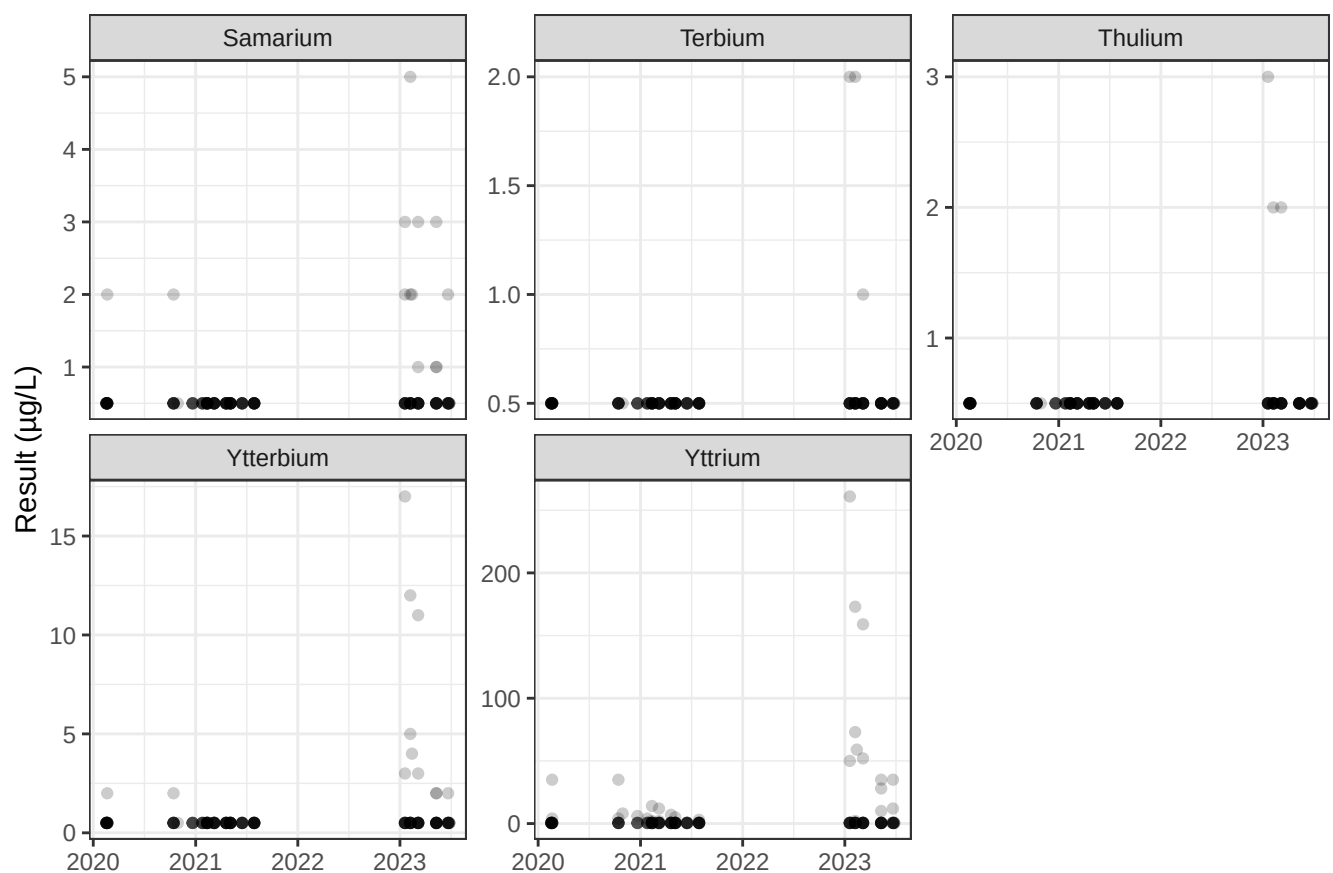




9 Appendix 4: Quarry discharge water rare-earth element analyte concentrations

Appendix 4 Figure. Rare-earth element concentrations in the quarry discharge water quality monitoring data set for the period 2020 – 2023.

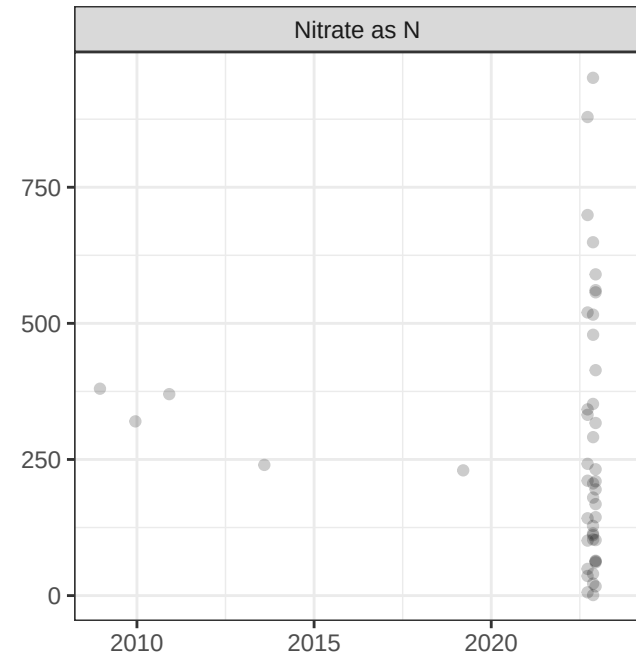
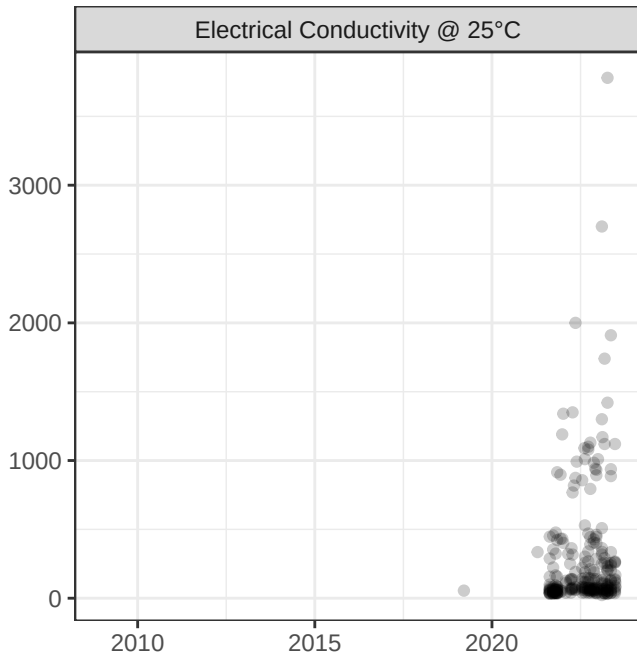
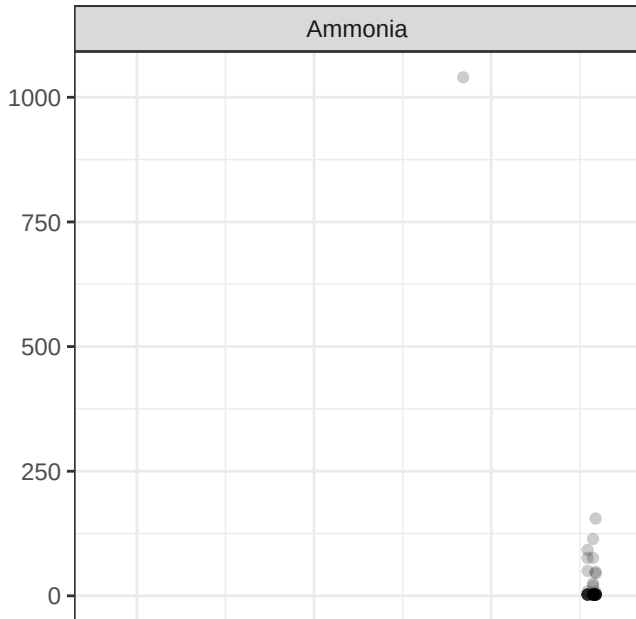
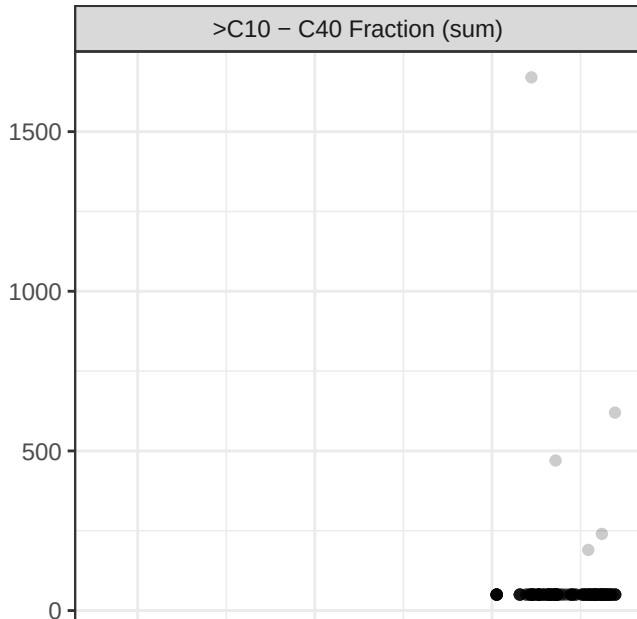


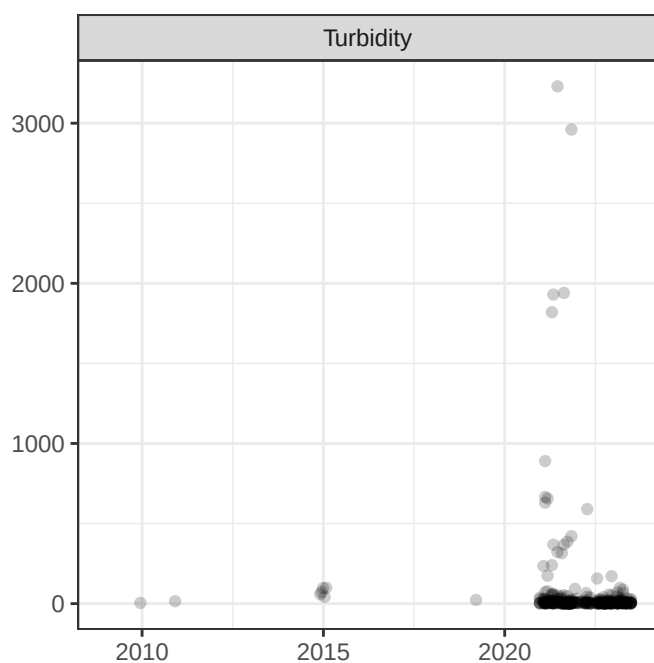
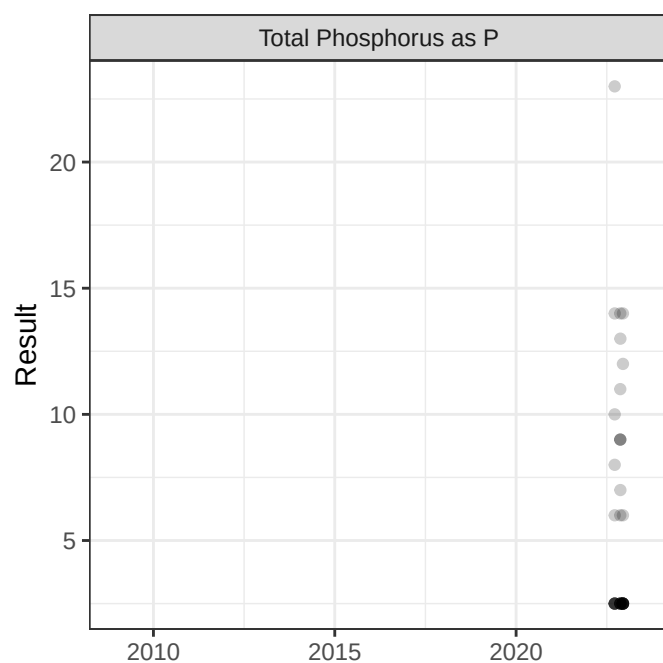


10 Appendix 5: Quarry discharge water non-metal and physico-chemical analyte concentrations

Appendix 5 Figure. Non-metal toxicants and physico-chemical analyte concentrations in the quarry discharge water quality monitoring data set for the period 2008 – 2023. Units are in $\mu\text{g/L}$ except for electrical conductivity ($\mu\text{S/cm}$), pH (pH units), suspended solids (mg/L), and turbidity (NTU).

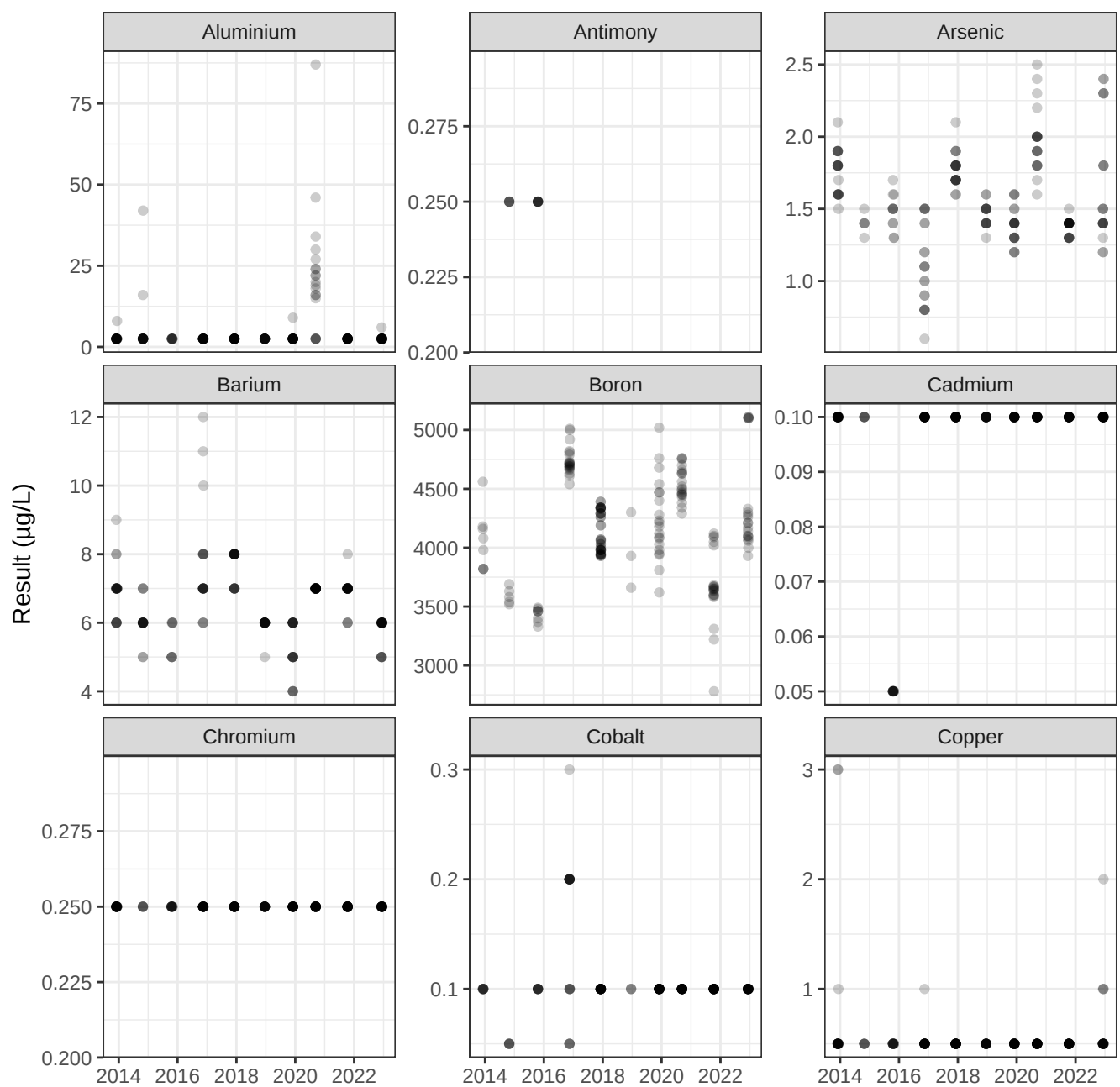
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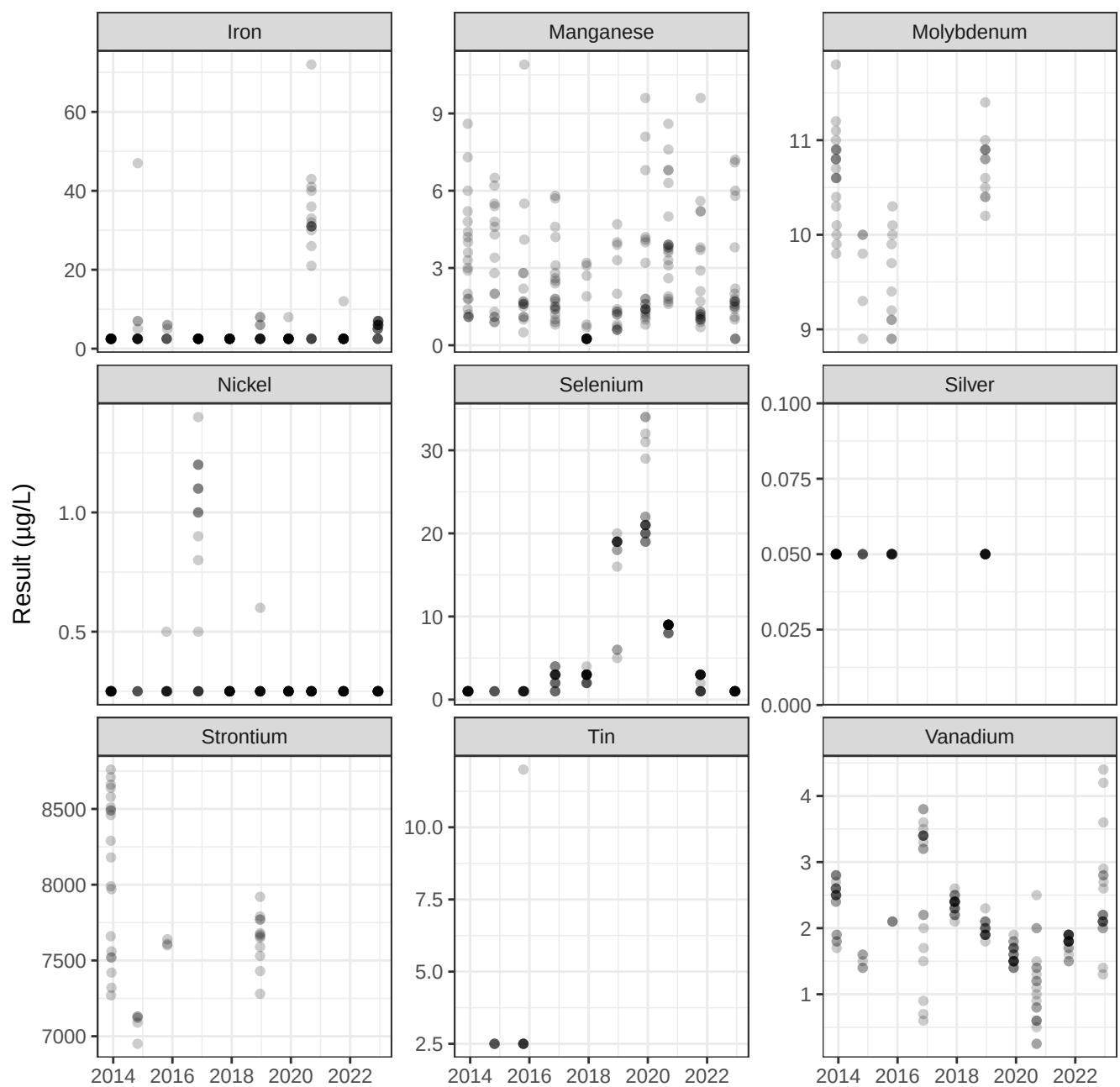


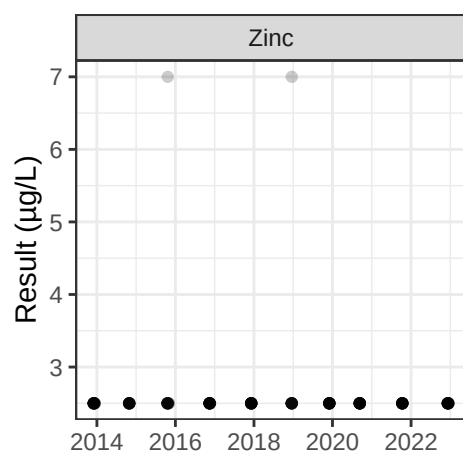


11 Appendix 6: Marine receiving environment metal and metalloid analyte concentrations

Appendix 6 Figure. Metal and metalloid concentrations in the marine receiving environment for the period between 2013 – 2022.







12 Appendix 7: Marine receiving environment non-metal and physico-chemical analyte concentrations

Appendix 7 Figure. Non-metal toxicants and physico-chemical analyte concentrations in the marine receiving environment for the period between 2013 – 2022. Units are in $\mu\text{g/L}$ except for pH (pH units), suspended solids (mg/L), and turbidity (NTU).

End Document

Appendix B: Red Earth Engineering 2024 Report



GEMCO Excess Water Disposal Project

Hydrology and Hydraulic Modelling Report

Prepared for:
South32 – Groote Eylandt Mining Company (GEMCO)

Document Number: J24019-027-RPT

Revision	Details	Reviewed by	Prepared by	Date
A	Issued for client review	Eddie Baker	Ehsan Zadeh	20/09/2024

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1.0 Introduction

1.1 Overview

Red Earth Engineering (REE) were engaged by South32 Major Projects to provide engineering and design support associated with onshore infrastructure for the proposed Excess Water Disposal Project (EWDP) at the existing Groote Eylandt Mining Company (GEMCO) manganese mine.

The EWDP proposes to transfer mine quarry water to the Port at Alyangula for disposal via a marine discharge (refer **Figure 1**). The onshore infrastructure consists of a water transfer system and pipeline (~12 km length) from the northern quarries water storage area to transfer water to the marine discharge system at the Port in Alyangula.

The pipeline alignment is traversed by Ndunga Creek, and Malkala Creek. The pipelines also cross various other coastal catchments, which comprise poorly defined natural drainage features generally flowing in an east to west direction.

The majority of waterways and natural drainage features along the pipeline alignments are highly ephemeral, flowing only for short periods after substantial rainfall. The EWDP's proposed north-south pipelines will intersect the natural east-west surface water flow paths. However, by incorporating appropriate and regular flow paths, such as raised or buried pipeline segments, the project is expected to have minimal impacts on the hydrological regime, causing only minor redirections of overland flows.

The purpose of this hydrology and hydraulic (surface water) modelling report is to assess design considerations for waterway crossings and drainage features, and to evaluate the flood impacts (changes in water levels) resulting from the pipeline installation.

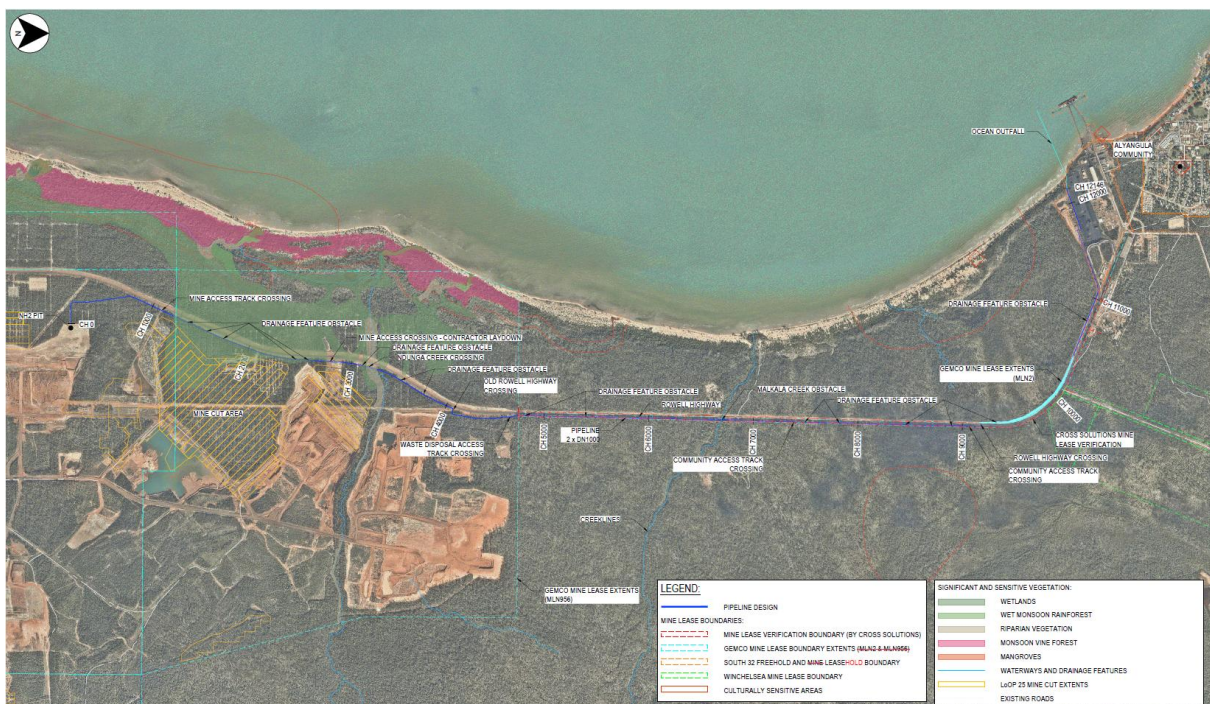


Figure 1: Excess Water Project Overview

1.2 Scope and Methodology

The following methodology was adopted for the EWDP surface water assessment:

- A hydrologic model was developed in RORB to determine the 1:10 AEP critical storm for the study area and watercourse crossings. As the EWDP crosses several watercourses, the hydrologic model was separated accordingly. The critical duration was determined at the outlet of the model.
- A direct rainfall model was developed in TUFLOW HPC to determine design surface water flows and flood impacts along the entire pipeline route. The model was run for a selected critical storm as determined in the hydrologic model.
- As specified in the Australian Rainfall and Runoff (ARR, 2019), the direct rainfall model was validated using a traditional hydrologic-hydraulic linked model.
- Treatment/mitigation options were developed to reduce afflux in line with the nominated afflux criteria.

1.3 Limitations and Assumptions

The following limitations and assumptions are noted:

- Flood evaluations depend on various datasets, assumptions, and factors, some of which are based on experience. As a result, all analyses and findings have some level of uncertainty associated with them. This doesn't mean that the results are incorrect. Instead, this statement indicates that no result is definitive and that the reader should keep this in mind.
- The topographic data is commonly presented using LiDAR, which comes with specified horizontal and vertical accuracies. LiDAR can detect the water surface, but it doesn't provide information about bathymetry, which refers to the underwater features of a water body. It's important to recognise the limitations of the LiDAR data available as it may impact the flood results and analysis conclusions.
- In 2D flood hydraulic assessments like the one discussed herein, the collected LiDAR data is processed by being filtered and condensed into a gridded cell format. Each cell's level represents an average of the LiDAR data for that area, based on a specific gridding algorithm. This method reduces the resolution of the actual ground surfaces in hydraulic models, which means that the simulated flood surface may not accurately reflect real flood conditions.
- The nominated rain design temporal patterns and durations might not lead to critical results at every spot along the pipe alignments. To address this, a rain-on-grid method was adopted and a practical number of runs were completed to achieve a reasonable series of results along the pipe alignment.
- The hydraulic model and model extents incorporate large sections of the mine. Not all data, was available at the time of modelling, and as such represent a limitation in the modelling approach. Where required sensitivity analysis has been undertaken to understand the potential impact of the adopted assumptions.
- To reduce flood afflux, the favoured treatment option for defined drainage pathways was to bury the pipe, to reduce potential flood loading and provide greater capacity during larger flood events. Alternative raised arrangements can also be considered and will be reviewed on an as-needed basis where these are carried forward.

- Flood events larger than the 1:10 AEP have not been assessed, which is in line with the scope of this investigation.
- Supplied LiDAR was adopted for this investigation. It is noted that not all LiDAR is current, as such changes in the terrain post-LiDAR production date may impact flood modelling results.

1.4 Previous Studies

The following studies have provided background information on the catchment data and the point of reference for a review of the modelling approach, parameter selection, and results of this study.

1.4.1 Post-Closure Hydrology Assessment (HATCH 2018)

This hydrology study was undertaken to provide a pre-feasibility assessment of flood behaviour across the GEMCO Western Leases mining area to assist with future mine plans and closure studies. The hydrology models of the area were developed using RORB based on the calibrated RORB model of the Angurugu River at the streamflow gauge. Four scenarios were considered for the hydrology assessment. These scenarios were pre-mine, ultimate operational phase, and two landform scenarios. The design flow hydrographs from the hydrology models in conjunction with the direct rainfall-on-grid were utilized as input to develop the TUFLOW model of the project area, for flood events 1:50 AEP to 1:100 AEP as well as the 1:1,000 AEP event. The hydraulic model was only developed for the pre-mine and ultimate operational phase.

1.4.2 Ndunga Creek Stream Diversion Option Assessment (WRM 2022)

A proposed diversion of Ndunga Creek was assessed to support a pre-feasibility assessment of potential mining of the orebody beneath the natural creek alignment. The proposed alignment extends across the full length of the northern Western Leases mining area.

The hydraulic and geomorphic characteristics of the pre-mining Ndunga Creek channel were used to inform the design of the proposed diversion. Due to the similar cross-sectional shape and hydraulic characteristics of the Ndunga Creek channel, the proposed diversion was expected to perform similarly to the pre-mining creek during runoff events and maintain stability in the long term. The catchment delineation for Ndunga Creek adopted by WRM was not completely considered for this study as there were some changes to the mining area and, therefore, catchments.

2.0 Basis of design

2.1 Design Flood Events

The adopted design flood event was the 1:10 AEP return period. The methodology for determining the critical design storm including the temporal pattern and duration selection is detailed in **Section 0**.

2.2 Afflux Criteria

To ensure consistency between flood assessments, the acceptable flood afflux criteria recently adopted for the GEMCO Northern Haul Road River Crossing Reinstatement (M200.C.19573.100-ENG-BOD-0001) was adopted for this assessment.

The proposed design must not increase the pre-construction flood levels outside the site boundaries and outside any unallocated land by more than is defined in **Table 1** below.

The afflux criterion does not apply to land within the mine lease, however, reasonable measures should be undertaken to reduce flood impact on-site infrastructure.

Table 1: Design criteria for acceptable flood afflux

Land Use	Maximum afflux for peak levels
Public land, including Local Council-owned and managed reserves. This afflux does not apply to any buildings on these lands	100 mm
Private properties (residential and commercial) This afflux does not apply to any buildings on privately owned land.	50 mm
Buildings (irrespective of land ownership)	30 mm
Any area not specified above	100 mm

2.3 Input Data

2.3.1 Climate and Rainfall

Hydrologic and hydraulic models rely upon intensity-frequency-duration (IFD) data. For this study, the 1:10 AEP design rainfall depth was obtained from the Bureau of Meteorology (BOM) online database. Since this IFD data was based on the historical time series of previous decades, all IFD data was adjusted to reflect current conditions to address the impacts of climate change using the method outlined in ARR 2019. The updated design rainfall depths (IFDs) are provided in **Table 2**.

Table 2: Adopted Design rainfall Depth (mm) – Part 1 – (Lat: -13.987, Long: 136.462)

Storm Duration	Rainfall Depth (mm)						
	63.20%	50%	20%	10%	5%	2%	1%
15 min	26.2	28.9	37	42.1	46.9	52.9	57.3
20 min	31.2	34.5	44.1	50.2	55.8	62.9	68.1
25 min	35.5	39.2	50.1	57	63.4	71.4	77.1
30 min	39.1	43.2	55.4	63	70	78.7	84.9
45 min	47.5	52.7	67.7	77.2	85.7	96.1	103
1 hour	53.5	59.5	76.9	87.7	97.6	109	118
1.5 hour	61.4	68.7	89.8	103	115	129	139
2 hour	66.5	74.7	98.7	114	127	144	155
3 hour	72.7	82.2	110	128	145	166	180
4.5 hour	77.8	88.7	122	143	163	189	208
6 hour	81.1	93	129	154	177	207	231
9 hour	85.8	99.1	141	169	198	236	266
12 hour	89.7	104	150	182	214	259	295
18 hour	96.8	113	165	203	242	297	342
24 hour	104	121	179	221	265	328	380

2.3.2 Ground data and aerial imagery

The hydraulic model geometry and catchment delineation for the hydrology model were generally developed based on the 2013 1m lidar survey as base data. The northern mining areas were updated using the 2022 and 2033 survey data.

Aerial imagery of May 2023 was used to extract more topographic and culvert data, where required.

2.3.3 Hydraulic structures

Culvert data including length, diameter, and invert level were obtained from the design drawings (J24019-00-C-0001 to J24019-02-C-3102). For the northern part of the Groote Eylandt Road, a new survey has been done to validate the invert level and diameter (survey completed by Cross Solutions 26-06-2024).

2.3.4 Coordinate Reference System

The coordinate reference system of GDA94 MGA Zone 53 was used to develop the flood models and extracted results.

3.0 Hydrology Model

3.1 Software

Hydrologic modelling was undertaken using RORB (version 6.5.1) to determine design flow rate estimates at model outlets. RORB is a widely used runoff and streamflow routing software that can simulate hydrographs based on user-supplied design rainfalls and catchment characteristics. RORB software is specially designed to conduct an event-based simulation approach as recommended by ARR (2019). Many of the ARR (2019) principles have been adopted for this study.

3.2 Hydrologic Model Build

As the pipeline passes through multiple catchments, the critical storm for each catchment was identified as the one producing the highest peak flow at the model outlet, rather than at individual crossing locations. The results include the critical durations for the catchments intersected by the pipeline.

The following sections provide an outline of the key inputs, methodology, and results of the hydrologic analysis.

3.2.1 Catchment delineation

Sub-catchments were delineated using an automated GIS process and refined visually using aerial imagery and site knowledge i.e. pit locations. Catchments contributing to pits were removed from the hydrologic model. **Table 3** summarises the sub-catchment data, whilst **Figure 2** presents a visual representation of the sub-catchment delineation.

Table 3: Summary of Catchments Incorporating the Pipeline

Catchment Number	Area (km ²)
1	17.59
2	22.87

The rain-on-grid model was run for a series of rainfall durations and temporal patterns to identify storms resulting in the highest water levels along the pipeline alignment.



Figure 2: Catchment Delineation incorporating EWD Pipeline

3.2.2 Initial Loss and Continuing Loss

Rainfall losses are represented using Initial Loss (IL) and Continuing Loss (CL). Regional rainfall loss values, (IL 27 mm and CL 0.8, mm/h) were sourced from the ARR online data hub (ARR 2019) and were adjusted to the current day condition as per recent ARR guidance (ARR 2019). Accordingly, the adjusted losses were IL 28.8 mm and CL 0.84 mm/h.

3.2.3 Area Reduction Factor

Standard values, specific to the catchment area contributing to the EWDP, were extracted from the ARR data hub and used in this study.

3.2.4 Run-Off Routing Parameters

For RORB models the routing of hydrographs through a network with non-linear storage-discharge relationships is defined by two key parameters, K_c and m . As specified in ARR 2019, the non-linear routing coefficient, m , should be 0.8 unless there is strong evidence to support a variance. The storage coefficient, K_c , accounts for the degree of hydrograph attenuation. For this investigation, the K_c value has been estimated using the empirical equation for Australian Catchments (Dyer et al. 1994). The Dyer method is based on the average reach length of the catchment. Previous Groote Eylandt studies have found this relationship to provide a good fit for catchment responses (REE 2020).

$$K_c = 1.14 \times d_{av}$$

Where d_{av} is the mean catchment travel distance (km).

Table 4 presents the adopted RORB parameter values for each catchment. d_{av} values were determined based on the length of RORB reaches.

Table 4: Catchment RORB Parameters

Group	m	Kc
Catchment 1	0.8	3.61
Catchment 2	0.8	3.30

3.2.5 Hydrologic Model Summary

The summary of the Hydrology model is shown in **Table 5**:

Table 5: Summary of Hydrology Model

Parameter	Notes	Reference
Location	Catchment 1 - Lat: -13.875, Long: 136.441 Catchment 2 - Lat: -13.925, Long: 136.441	A central point of the contributing catchment and the hydrologic extent.
Storm Event (AEP)	1:10 AEP	EWDP Basis of Design (GEM-19282-FS-001-BoD-RevA)
Design Event Duration (hrs)	1, 2, 3, 4.5, 6, 12, 24	Standard Industry durations
IFD Data – Rainfall Depth (mm)	Refer Section 2.3.1	Bureau of Meteorology, updated to the current day following ARR, Version 4.2, 2019.
Temporal Pattern	Monsoonal North	ARR 2019
Aerial Reduction Factor	Northern Coastal Region	ARR 2019
Losses	Initial Loss: 28.8 mm Continuing Loss: 0.84 mm/hr	ARR Data Hub, updated to current day following ARR, Version 4.2, 2019

3.3 Hydrology Model Results

3.3.1 Summary of the hydrological modelling results for the pipeline

Based on the above procedures and criteria, critical storm duration and rainfall temporal patterns were determined for each catchment outlet. **Table 6** provides a summary of the hydrological modelling results for the 1:10 AEP flood event.

Table 6: Summary of hydrological modelling results for catchments draining to the Pipeline

Catchment	Outlet	10% AEP event result		
		Critical Storm Duration	Temporal Pattern	Peak Flow (m3/s)
Catchment 1	1	4.5 hr	TP 1	68.95
	2	4.5 hr	TP 6	69
Catchment 2	1	6 hr	TP 5	52
	2	4.5 hr	TP 10	32.16
	3	1.5 hr	TP 9	56.37
	4	4.5 hr	TP 10	42.47
	5	1.5 hr	TP 5	30.98

3.3.2 Comparison to Previous Studies

Ndunga Creek has previously been modelled by HATCH, 2018. Comparison between the results indicates that the peak flow estimated using RORB model is 15% lower than the HATCH results. The difference is likely due to changes in topography, and a reduction in catchment area due to ongoing mining operations.

3.3.3 Sensitivity Analysis

Sensitivity analysis was undertaken to assess the importance of key climate change impacts, particularly the impact of climate change on critical rainfall. The findings reveal the adjusted IFDs resulted in similar duration and temporal patterns and will unlikely impact treatment options. The increase in peak flow was in the order of approximately 9%.

4.0 Hydraulic Assessment

4.1 Software

The hydraulic assessment was completed using TUFLOW HPC model software version 2023-03-AD. TUFLOW is a computational engine that provides one-dimensional (1D) and two-dimensional (2D) solutions of the free-surface flow equations to simulate flood and tidal wave propagation. TUFLOW is industry-accepted software and is deemed appropriate for this study.

4.2 Hydraulic Model Setup

The hydraulic model was established following the below method:

- Terrain data from the 2013 survey was used as the base topography model, with the mining areas updated using the 2022 and 2023 surveys (see **Section 2.3.2**).
- The model extent was designed to fully encompass the pipeline, extending upstream and downstream to capture floodplain inundation.
- Aerial imagery from 2023 was utilized to determine the distribution of the roughness coefficient. Each land use type—categorized as light and dense vegetation, roads, water bodies, and industrial zones—was assigned a layer in TUFLOW linked to the material file.
- Terrain modifiers (z-shape layers) were used to adjust the pipeline's vertical alignment to represent the above-ground sections. Where the pipeline was buried, no terrain modification was applied. This method was also employed for treatment options where the pipeline needed to be buried in areas with afflux exceeding the specified criteria.

A summary of the model components is presented in **Table 7**:

Table 7: General Configuration for Hydraulic Model

Item	Configuration
Topography and Aerial Imagery	• 2013 1m LiDAR survey as base data. • The northern mining areas were updated using the 2022 and 2023 survey data. • Aerial imagery captured in May-2023 was used to extract more topographic and culvert data.
2D model mesh extent	Sufficient to fully encompass the pipeline, extending upstream and downstream to capture floodplain inundation
2D model mesh grid size	5m

Item	Configuration												
Model roughness	Manning's values were adopted to represent the overall roughness of the ground surface inundated by flood flows. The table below indicates the manning's value used in this study. <table> <tr> <th>Land use Type</th><th>Manning's Value</th></tr> <tr> <td>Light vegetation</td><td>0.04</td></tr> <tr> <td>Dense vegetation</td><td>0.08</td></tr> <tr> <td>Roads</td><td>0.022</td></tr> <tr> <td>Industrial/ mining zones</td><td>0.1</td></tr> <tr> <td>Water body</td><td>0.03</td></tr> </table>	Land use Type	Manning's Value	Light vegetation	0.04	Dense vegetation	0.08	Roads	0.022	Industrial/ mining zones	0.1	Water body	0.03
Land use Type	Manning's Value												
Light vegetation	0.04												
Dense vegetation	0.08												
Roads	0.022												
Industrial/ mining zones	0.1												
Water body	0.03												
Upstream boundary condition	Upstream boundary conditions included the following: • 2d BC polygons for catchments upstream of the model extent • 2d RF for rain-on-grid model extents.												
Downstream boundary condition	Outflow boundaries were assigned along the downstream boundary of the 2D model mesh to allow water to leave the model. Model boundaries were located sufficiently far away so as not to influence the location of interest.												
Hydraulic structure configuration	Culverts were modelled using a 1D network (1d_nwk) component linked to the 2D model domain.												
EWDP representation	The on-ground laid pipeline was modelled using topography modifiers (2d_zsh) based on the pipeline's vertical alignment.												

4.3 Hydraulic Modelling Results

The following sections present key outcomes for existing and design conditions along the completed EWDP route.

4.3.1 Existing Conditions

The existing condition model was run for 1:10 AEP flood events to provide baseline conditions, and to determine the critical design storm. **Table 8** provides a summary of the design storm, including the adopted critical duration and temporal pattern for each pipeline. Depth and velocity results for existing conditions are shown in **Appendix A**.

Table 8: Critical rainfall for on-ground pipelines

Critical Duration	Temporal Pattern
360 min	TP 05

For Pipeline NH2 to Port, the RORB model was used to determine the critical duration for the catchments incorporating the EWDP. Due to multiple outlets in each catchment, several critical durations were identified based on the outlets. The scenario was designed to reflect the worst-case conditions, which had the most significant impact, as determined by the TUFLOW model outputs.

4.3.2 Model Validation

As specified in ARR 2019, rain-on-grid model performance should be validated using traditional hydrologically coupled hydraulic models. Peak flow hydrographs from both methods were compared in three sections for the first catchment incorporating the pipeline, as shown in **Figure 3** and **Figure 4**. It's evident that the two models show similar water levels at each location and as such the rain-on-grid methodology was deemed appropriate for this study.

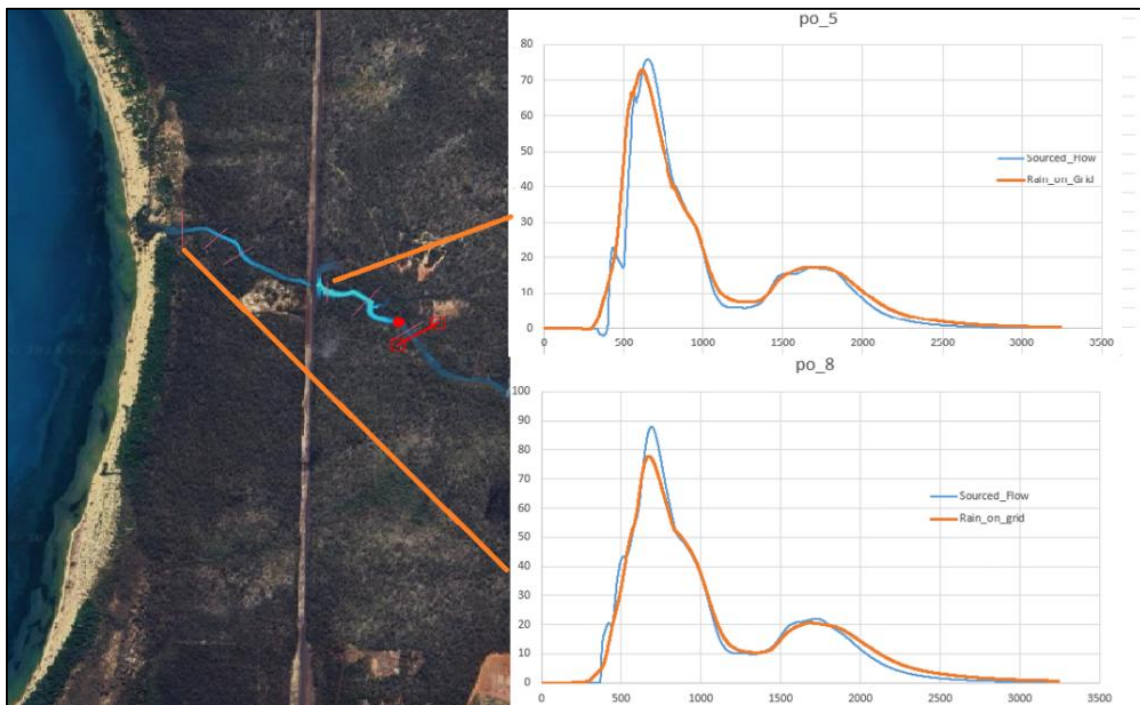


Figure 3: Validation of rain-on-grid model with source model –midstream and downstream sections

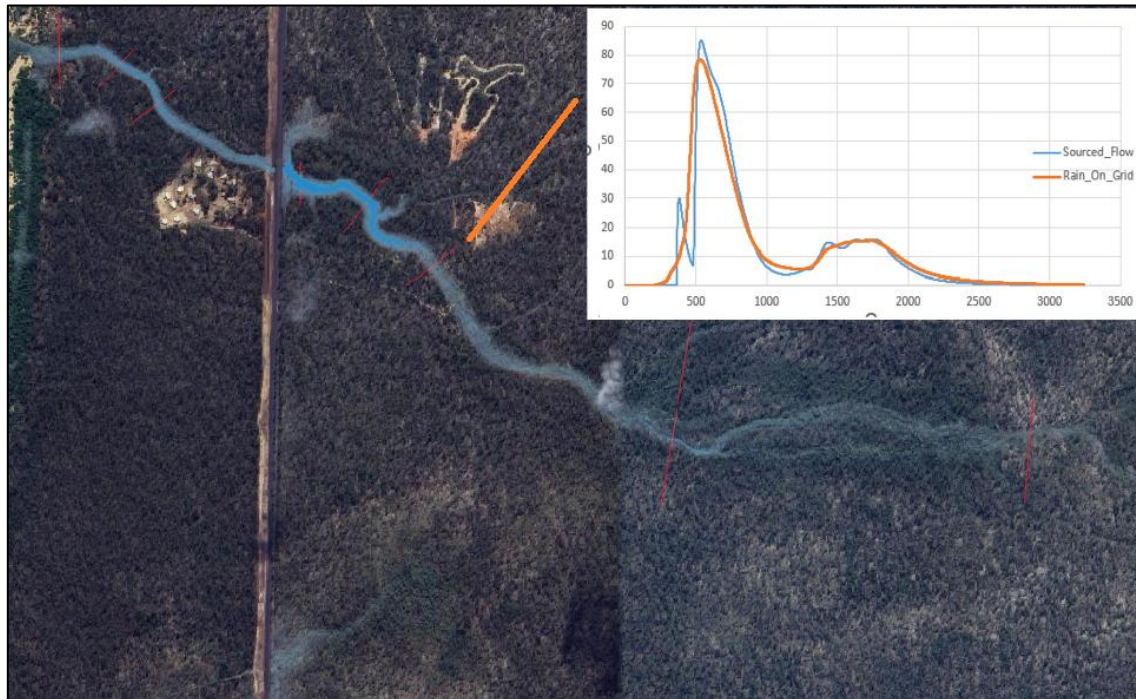


Figure 4: Validation of rain-on-grid model with source model – Upstream section

4.3.3 Design Conditions

The design model, which includes the EWDP, was developed for the 1:10 AEP flood event (refer to **Appendix A**). A comparison of baseline and design conditions (see **Appendix B**) identified several locations along the pipeline where the afflux exceeds 100 mm. **Figure 5** provides an example of the flood afflux caused by the pipeline, with further details available in the pre-mitigation results.

For this assessment, pre-mitigation results refer to the baseline design alignment, and post-mitigation results refer to the results considering additional mitigation/treatment.

Although treatment upstream of culverts and access tracks was included by default in the design conditions (Pre-mitigation), the results indicate that additional treatment is necessary to reduce afflux (post-mitigation). New treatment areas were incorporated (details in **Appendix C**), and the models were re-run to assess post-treatment/mitigation afflux. The updated results show a significant reduction in afflux, meeting the desired conditions outside the mine lease for the modelled event. An example of the treatment outcome is shown in **Figure 6**, with further analysis in **Appendix B**.

In all cases, the preferred treatment option is to bury the pipeline. This approach minimises flood impact loading on the pipeline and addresses blockage risks during larger flood events.

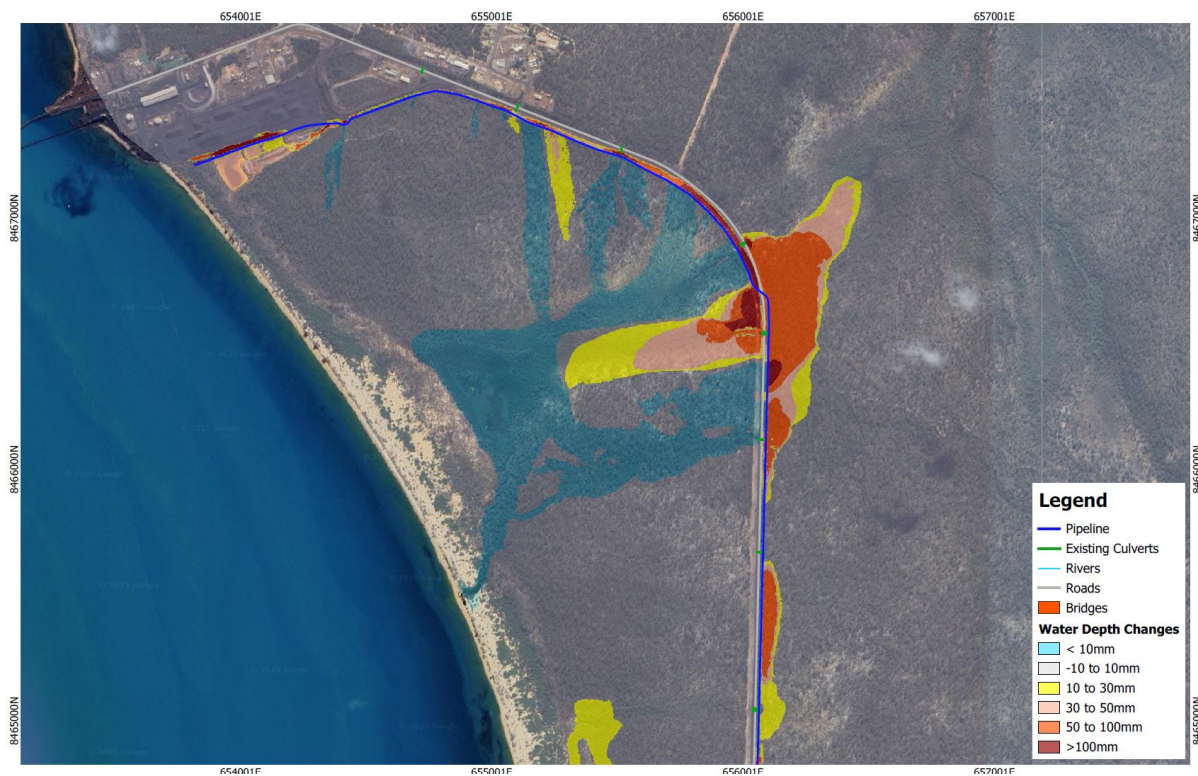


Figure 5: Flood Depth Afflux – Pre-Mitigation Scenario

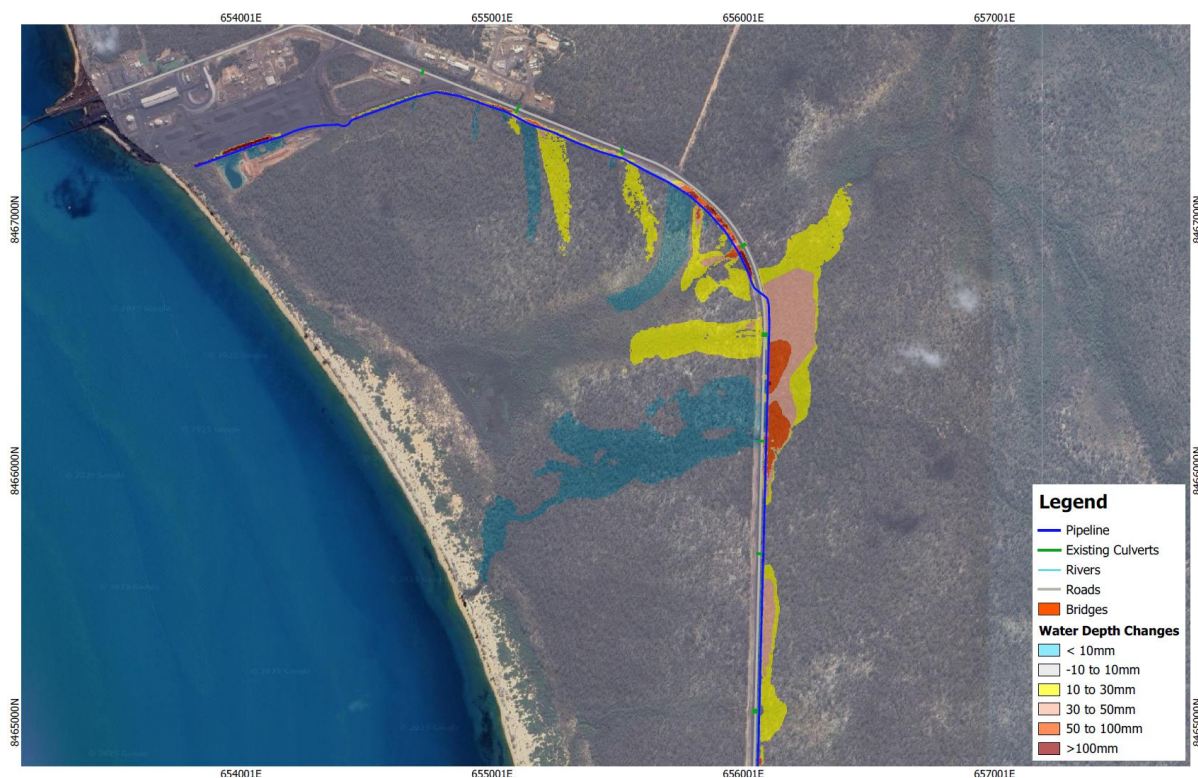


Figure 6: Flood Depth Afflux – Proposed Mitigation Scenario

4.3.4 Design Notes

The flood investigation does not cover the upgrade work at the primary haul road crossing of the Angurugu River. It is known that the assessment of flood impacts related to the enhancements of the main haul road crossing of the Angurugu River was conducted during the crossing design upgrades, resulting in minimal afflux impacts, refer to 302406-ST-RPT-002 (ARUP 2024).

5.0 Conclusion

The analysis of the pipeline route under both existing and design conditions has provided valuable insights into the hydraulic performance and required mitigation measures for the pipeline.

For existing and design conditions, a rain-on-grid model was used to estimate the 1:10 AEP flood characteristics, identifying critical storm durations and temporal patterns for each pipeline. This model was validated against traditional hydrologically coupled hydraulic models, with both methods showing similar peak flows within the selected catchment, confirming the rain-on-grid model's reliability.

The design model (pre-mitigation) identified several locations where afflux exceeded 100 mm, indicating the need for additional mitigation. Post-mitigation results which incorporate additional treatment at various locations along the alignment, showed a significant reduction in afflux, meeting the desired conditions outside the mine lease. The preferred mitigation/treatment strategy was to bury the pipeline, reducing potential flood impact loading and minimizing blockage risks for larger flood events.

For larger events, temporary inundation above the criteria may occur, though this is consistent with the effects on other mine infrastructure. At mine closure, the pipeline is expected to be removed, restoring the pre-development flood regime.

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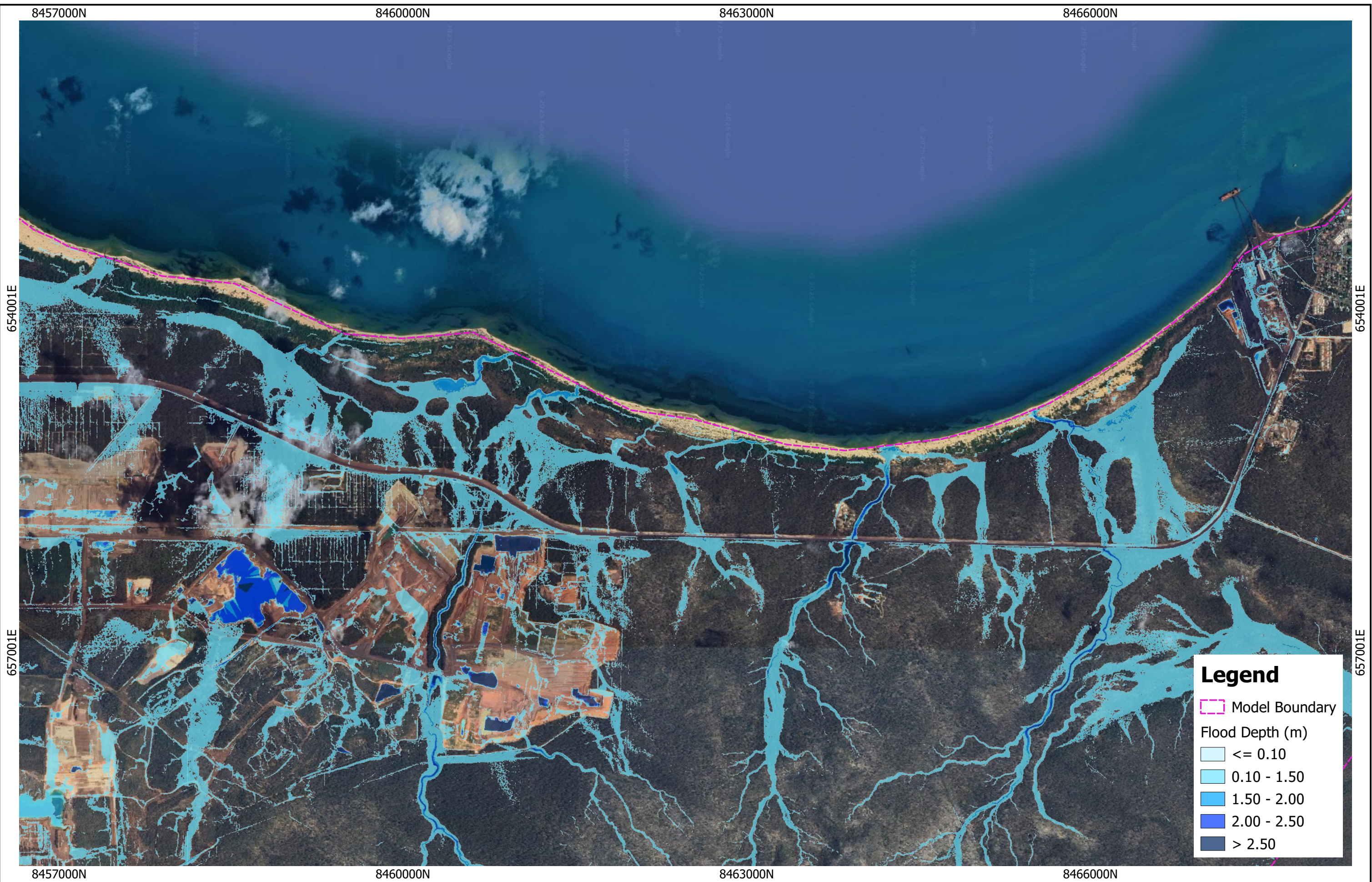
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Appendix A

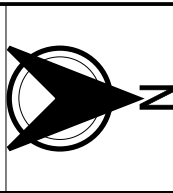
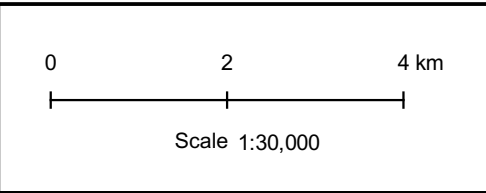
Flood Inundation Maps

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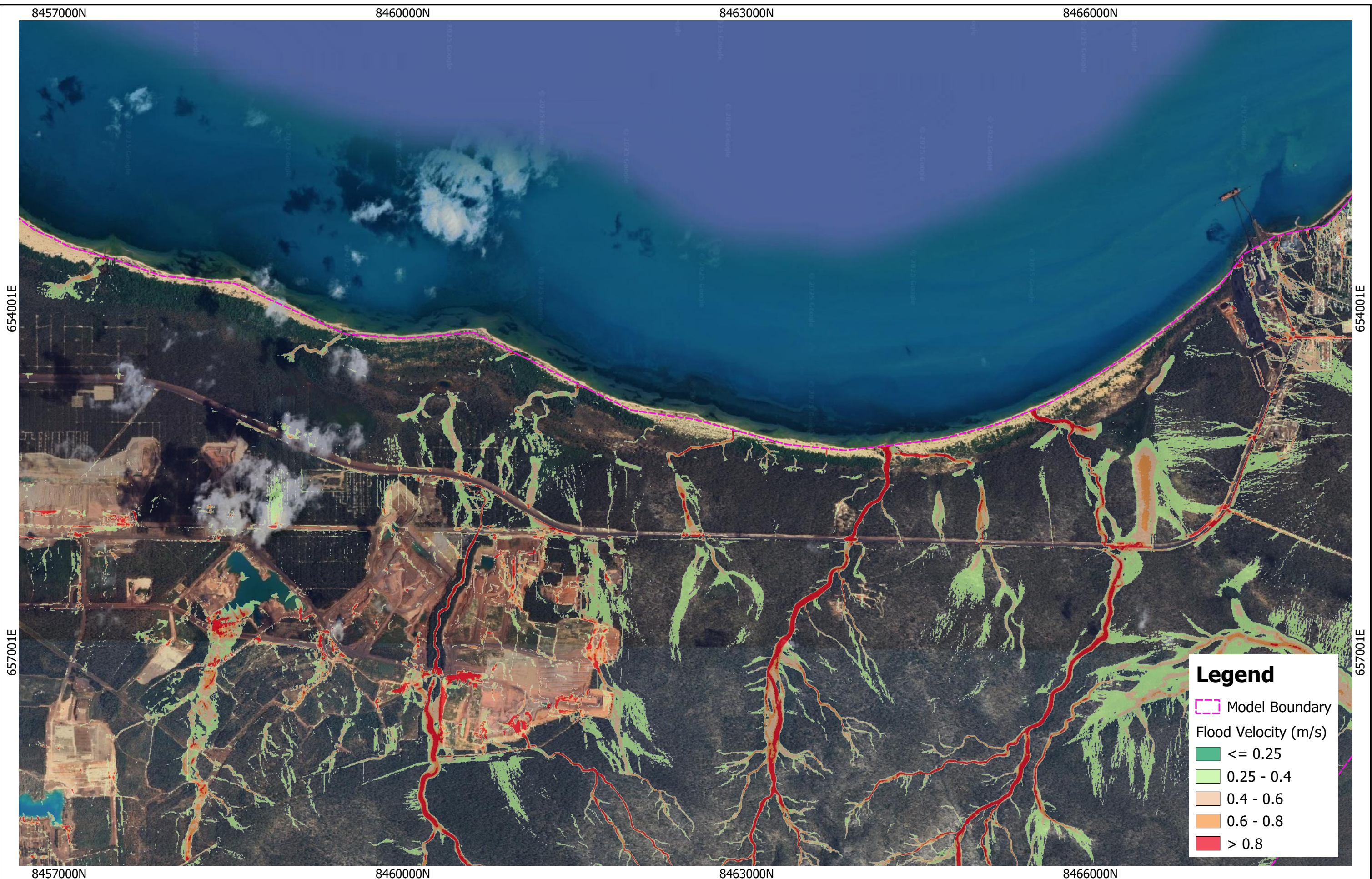
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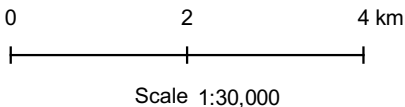
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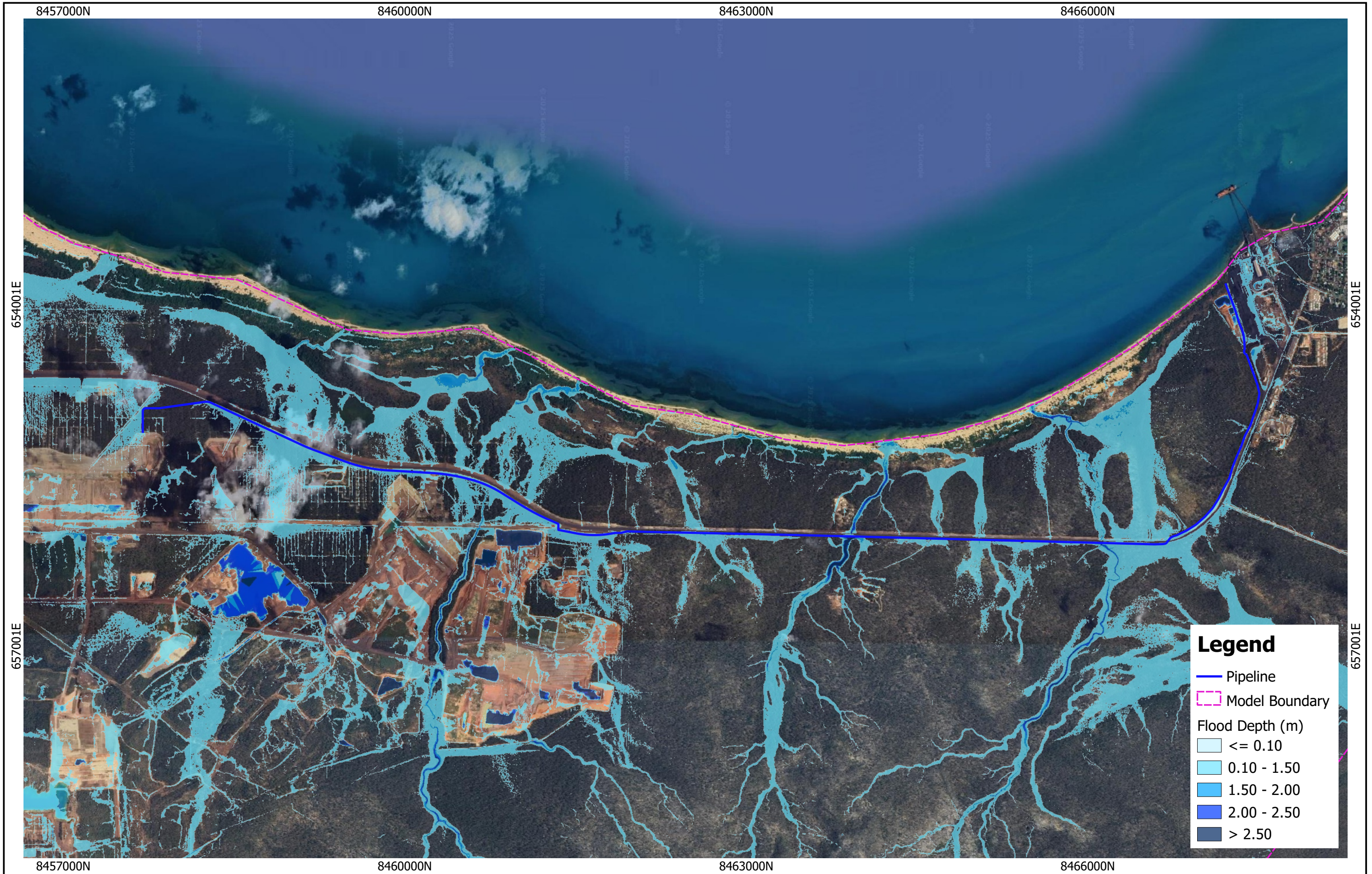
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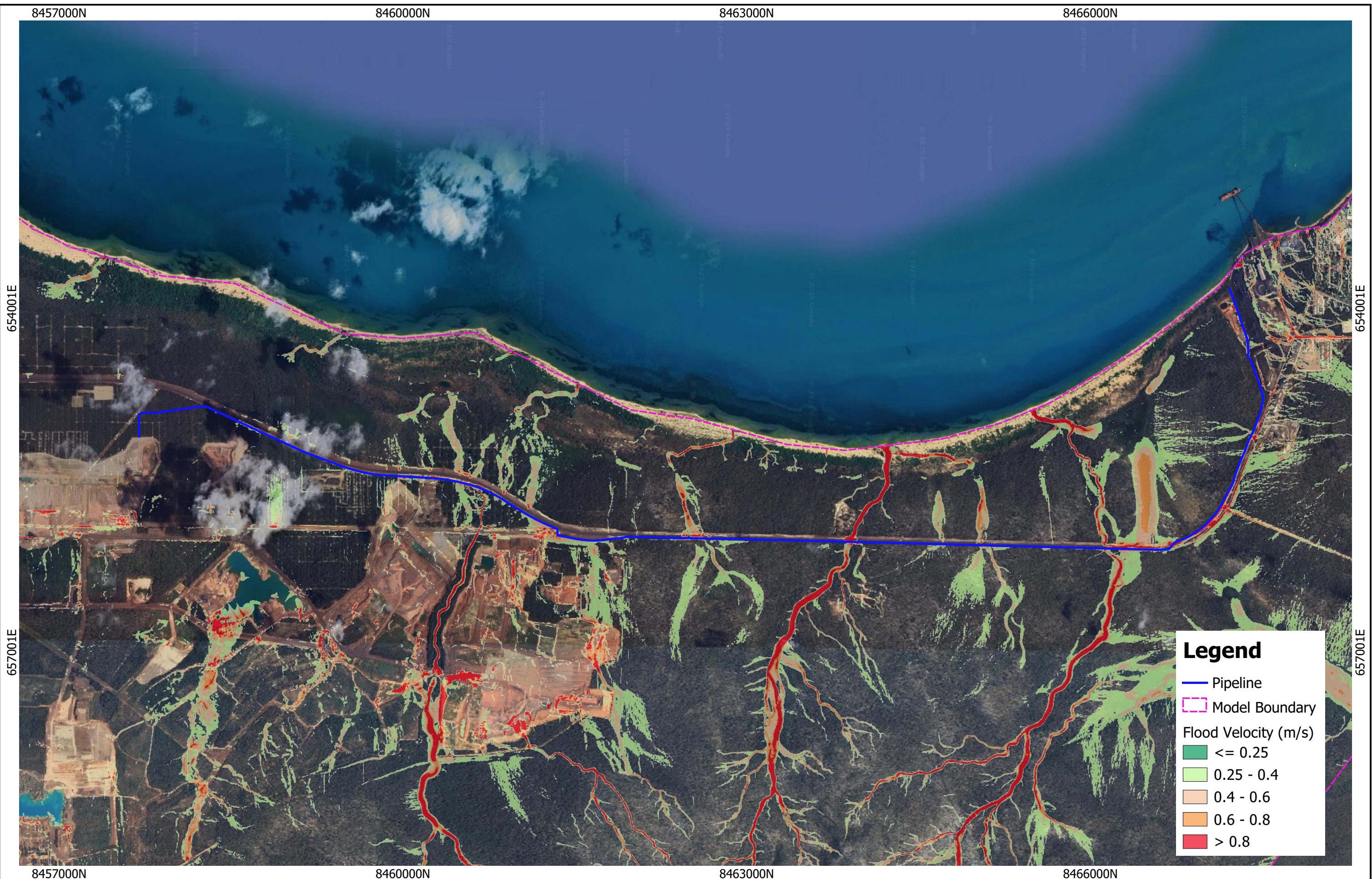
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A3	Figure: Figure A3					

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Legend

— Pipeline

- - - Model Boundary

Flood Velocity (m/s)

- ≤ 0.25
- 0.25 - 0.4
- 0.4 - 0.6
- 0.6 - 0.8
- > 0.8

Project: GEMCO Excess Water Disposal PFS Support	
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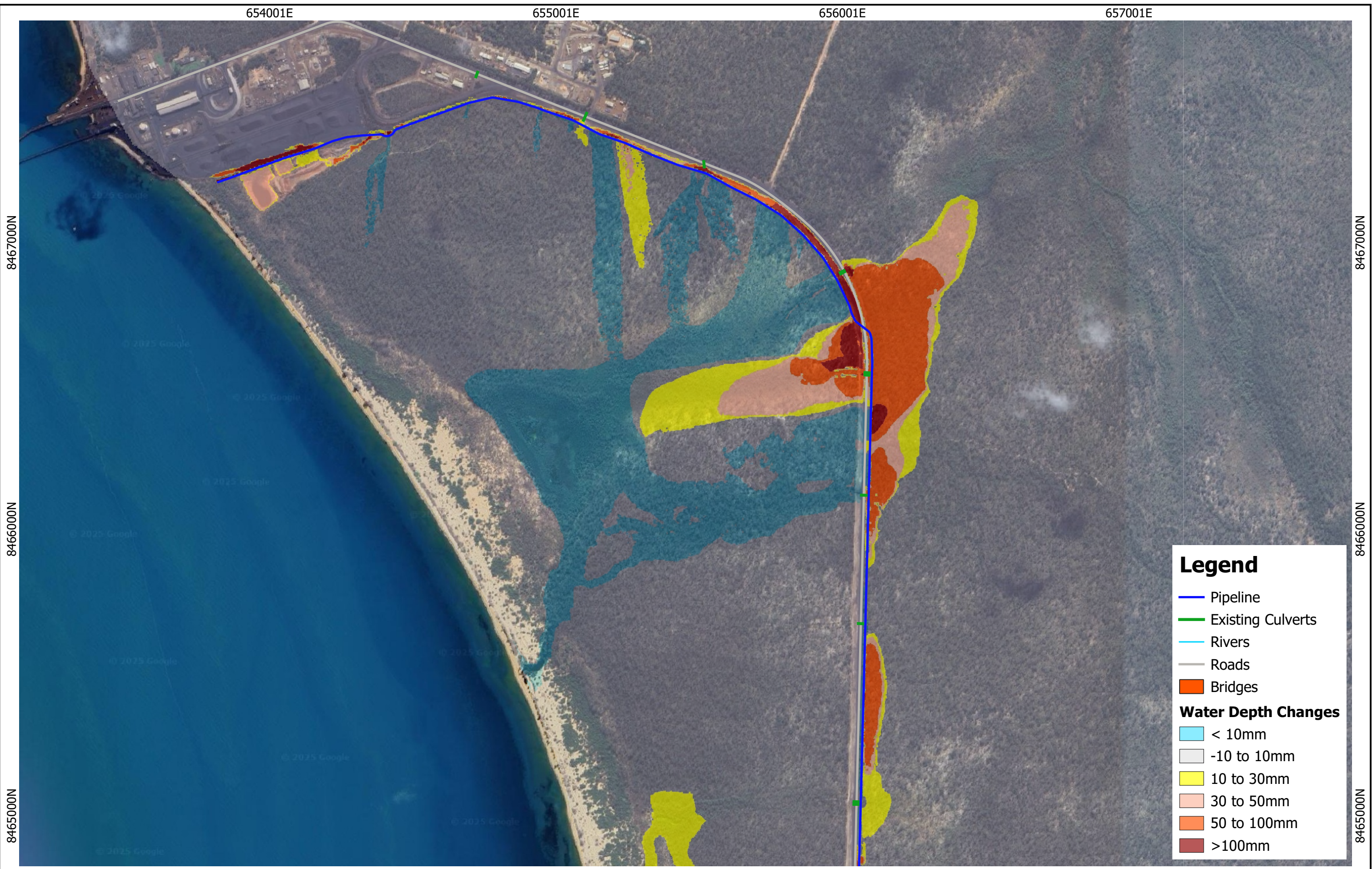
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Appendix B

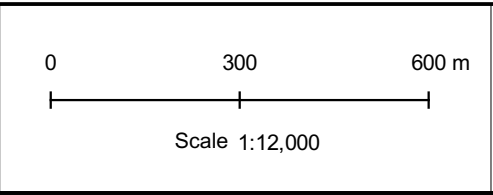
Flood Afflux Maps

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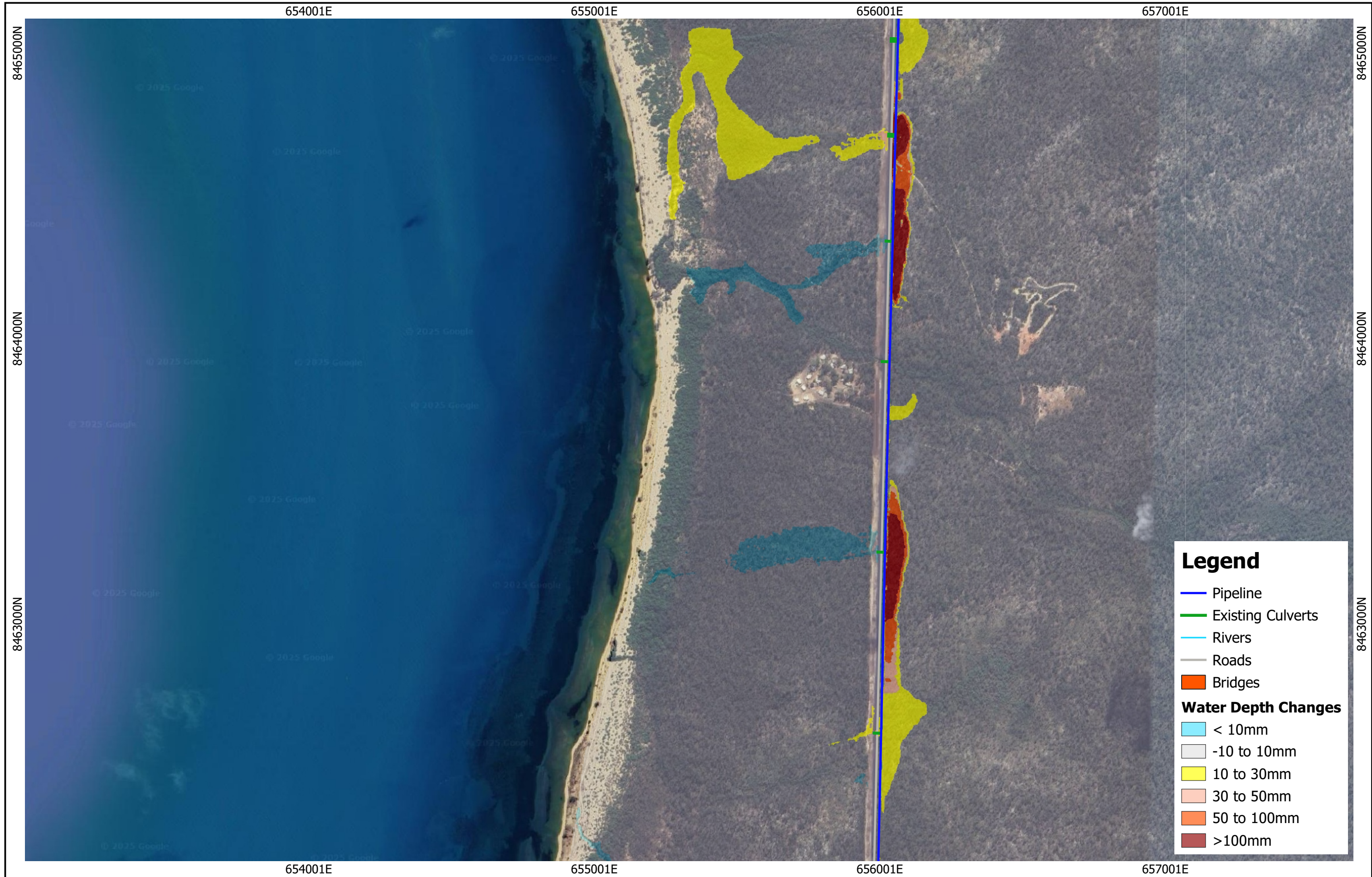
Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Depth Afflux Pre Mitigation			
A3	Figure: Figure B1	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



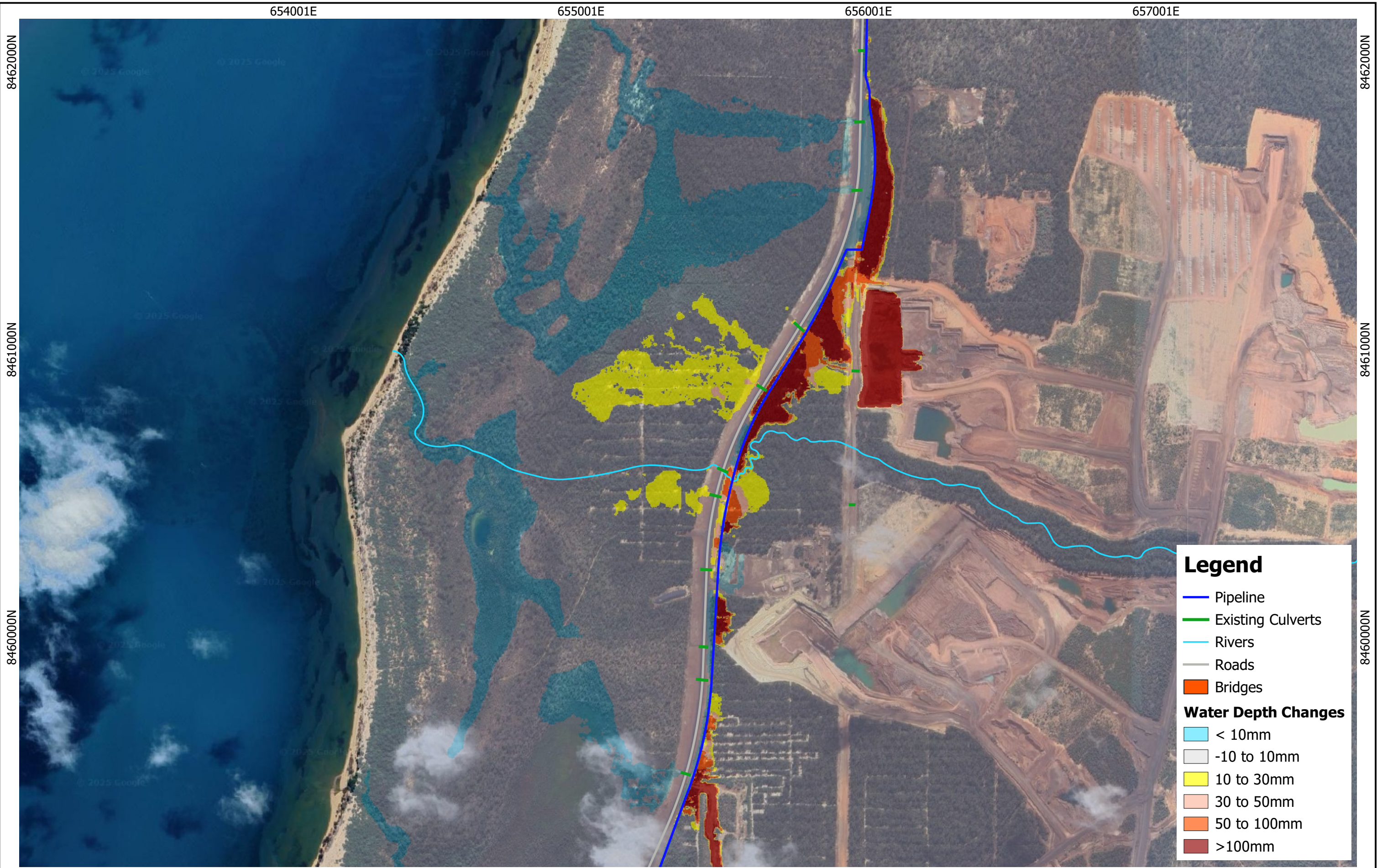
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admin@redearthengineering.com.au
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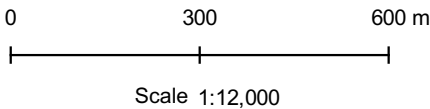
Project: GEMCO Excess Water Disposal PFS Support				Horizontal Datum: GDA94 / MGA zone 53	0300600m Scale 1:12,000			Red Earth Engineering Pty Ltd ABN: 17 136 007 746 Phone: +61 7 3173 1714 admin@redearthengineering.com.au 70/74 Bowen Street, Spring Hill, QLD 4000
Title: 1:10 AEP Flood Depth Afflux Pre Mitigation								
A3	Figure: Figure B2	Version: A	Date: 18/09/2024					

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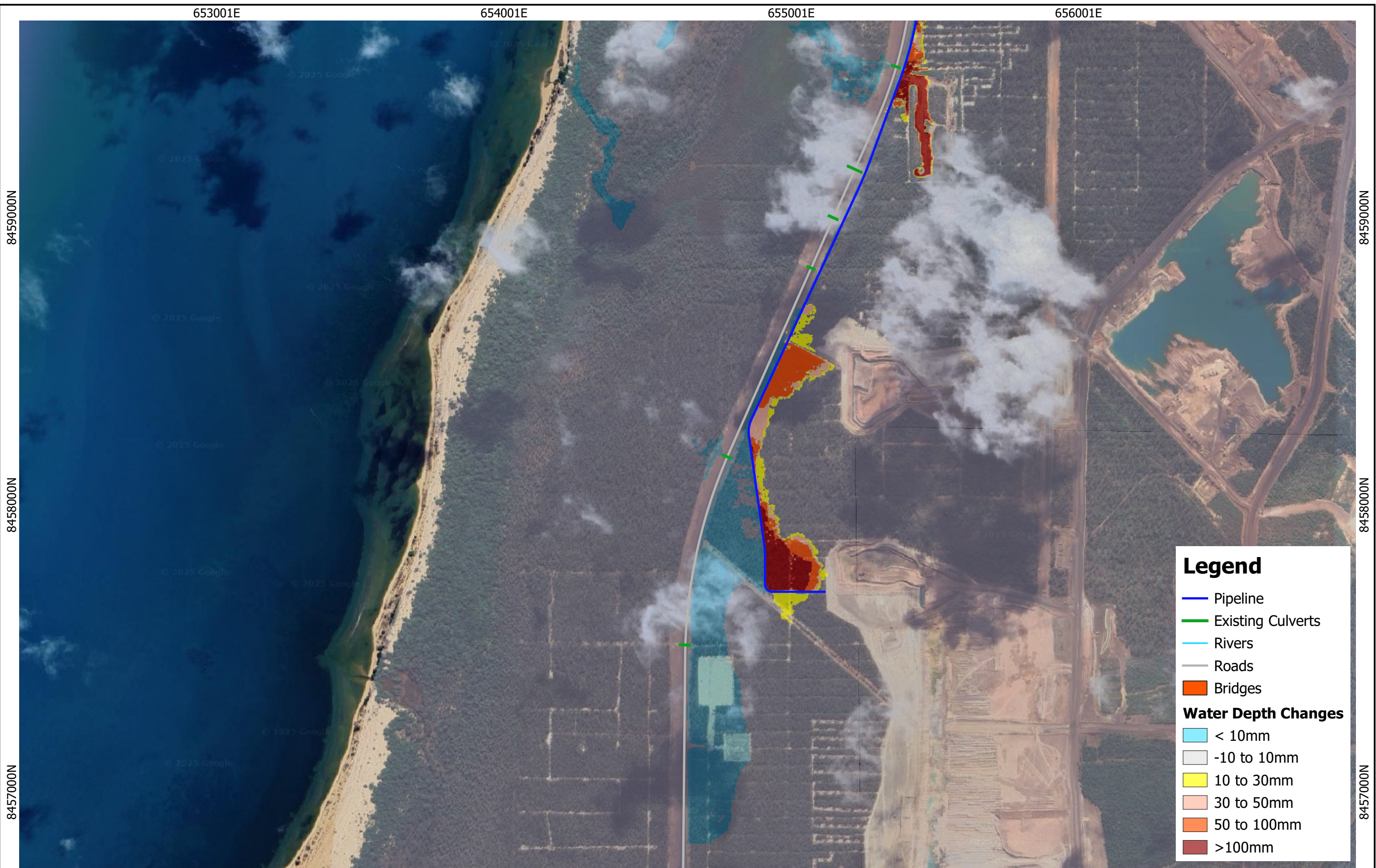
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Title:	1:10 AEP Flood Depth Afflux Pre Mitigation		
A3	Figure: Figure B3	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



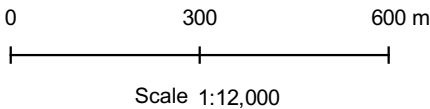
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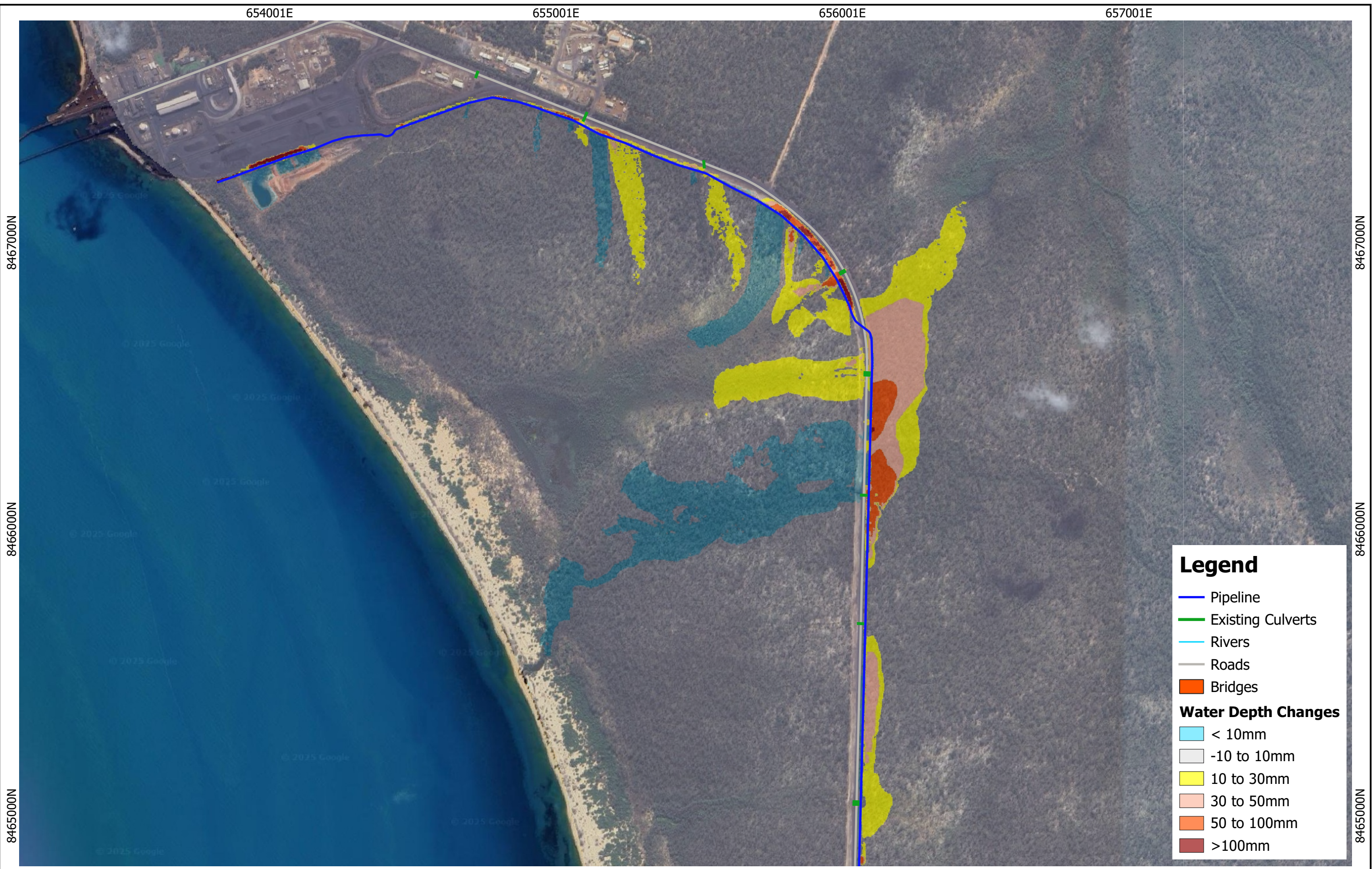
Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Depth Afflux Pre Mitigation			
A3	Figure: Figure B4	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



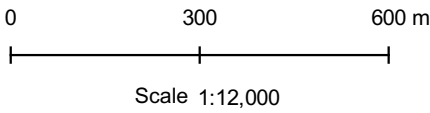
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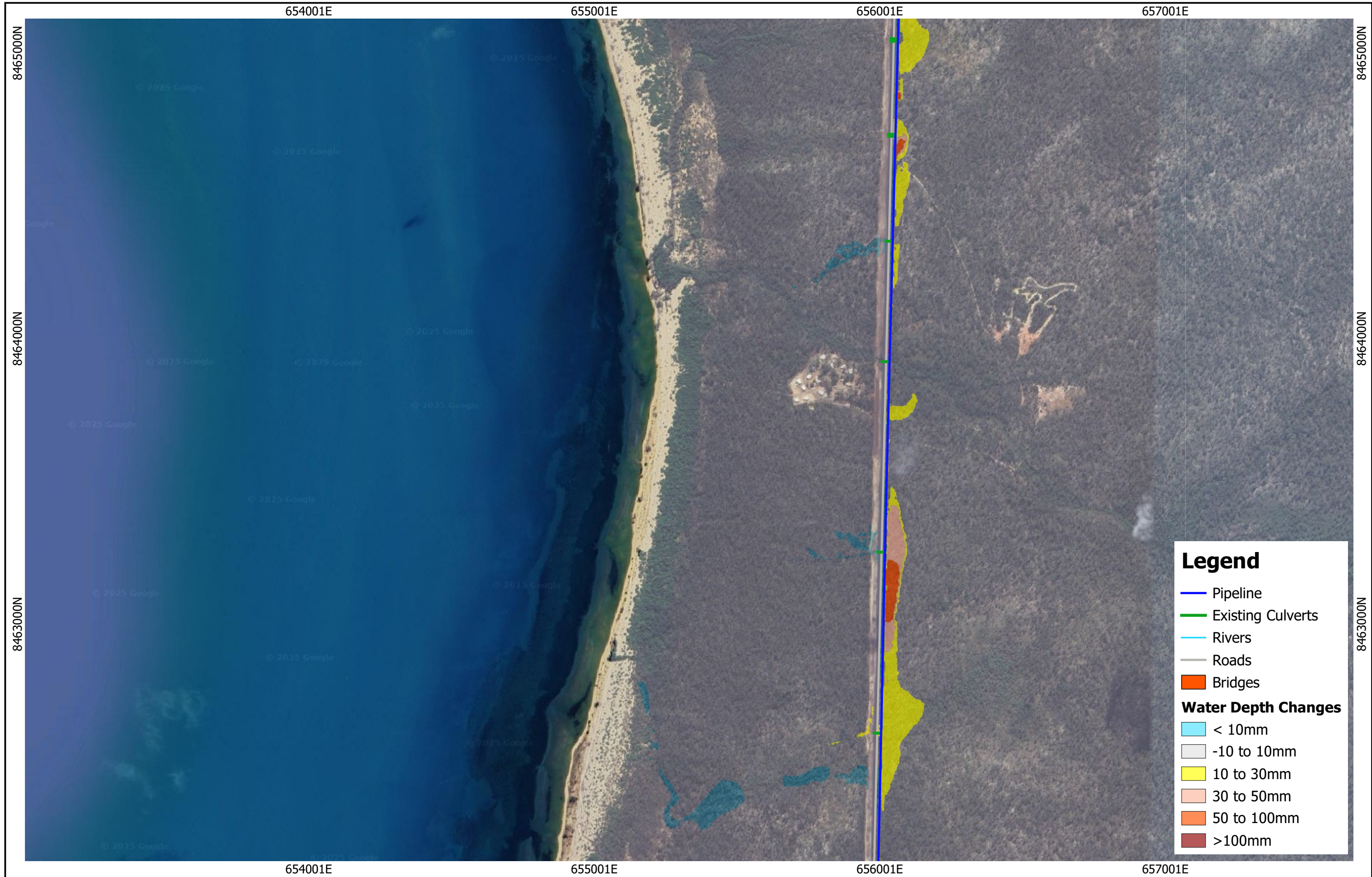
Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Depth Afflux Proposed Mitigation			
A3	Figure: Figure B5	Version: A	Date: 18/09/2024

Horizontal Datum:
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Project: GEMCO Excess Water Disposal PFS Support				Horizontal Datum: GDA94 / MGA zone 53	0300600m Scale 1:12,000			Red Earth Engineering Pty Ltd ABN: 17 136 007 746 Phone: +61 7 3173 1714 admin@redearthengineering.com.au 70/74 Bowen Street, Spring Hill, QLD 4000
Title: 1:10 AEP Flood Depth Afflux Proposed Mitigation								
A3	Figure: Figure B6	Version: A	Date: 18/09/2024					

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Project: GEMCO Excess Water Disposal PFS Support		Horizontal Datum: GDA94 / MGA zone 53	0300600 Scale 1:12,000			Red Earth Engineering Pty Ltd ABN: 17 136 007 746 Phone: +61 7 3173 1714 admin@redearthengineering.com.au 70/74 Bowen Street, Spring Hill, QLD 4000
Title: 1:10 AEP Flood Depth Afflux Proposed Mitigation						
A3	Figure: Figure B7					

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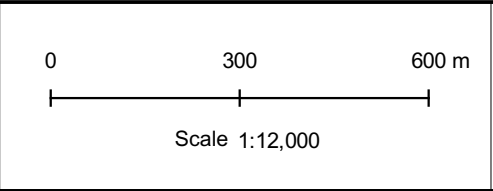
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8459000N



8457000N
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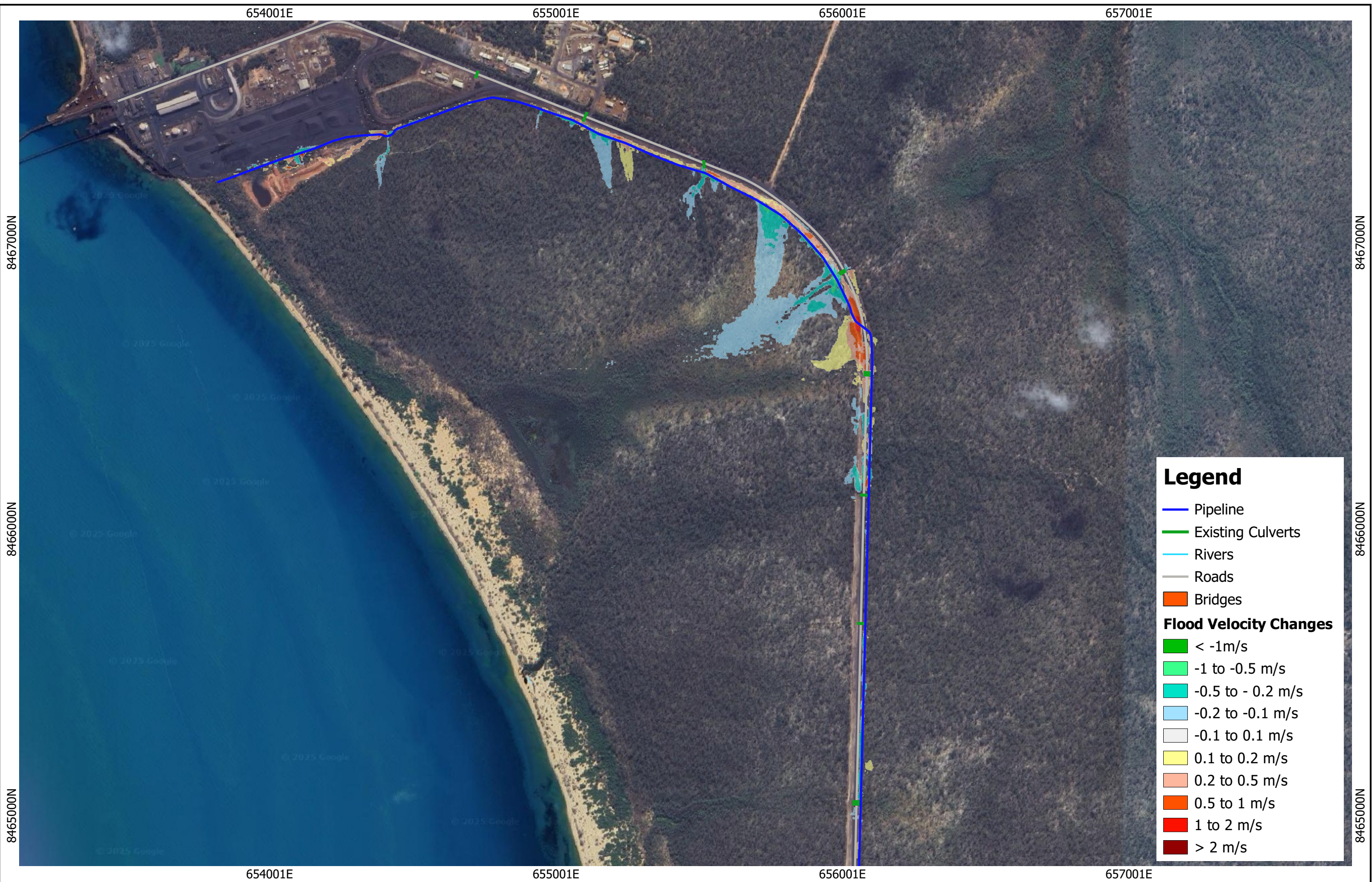
Project:	GEMCO Excess Water Disposal PFS Support		
Title:	1:10 AEP Flood Depth Afflux Proposed Mitigation		
A3	Figure: Figure B8	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



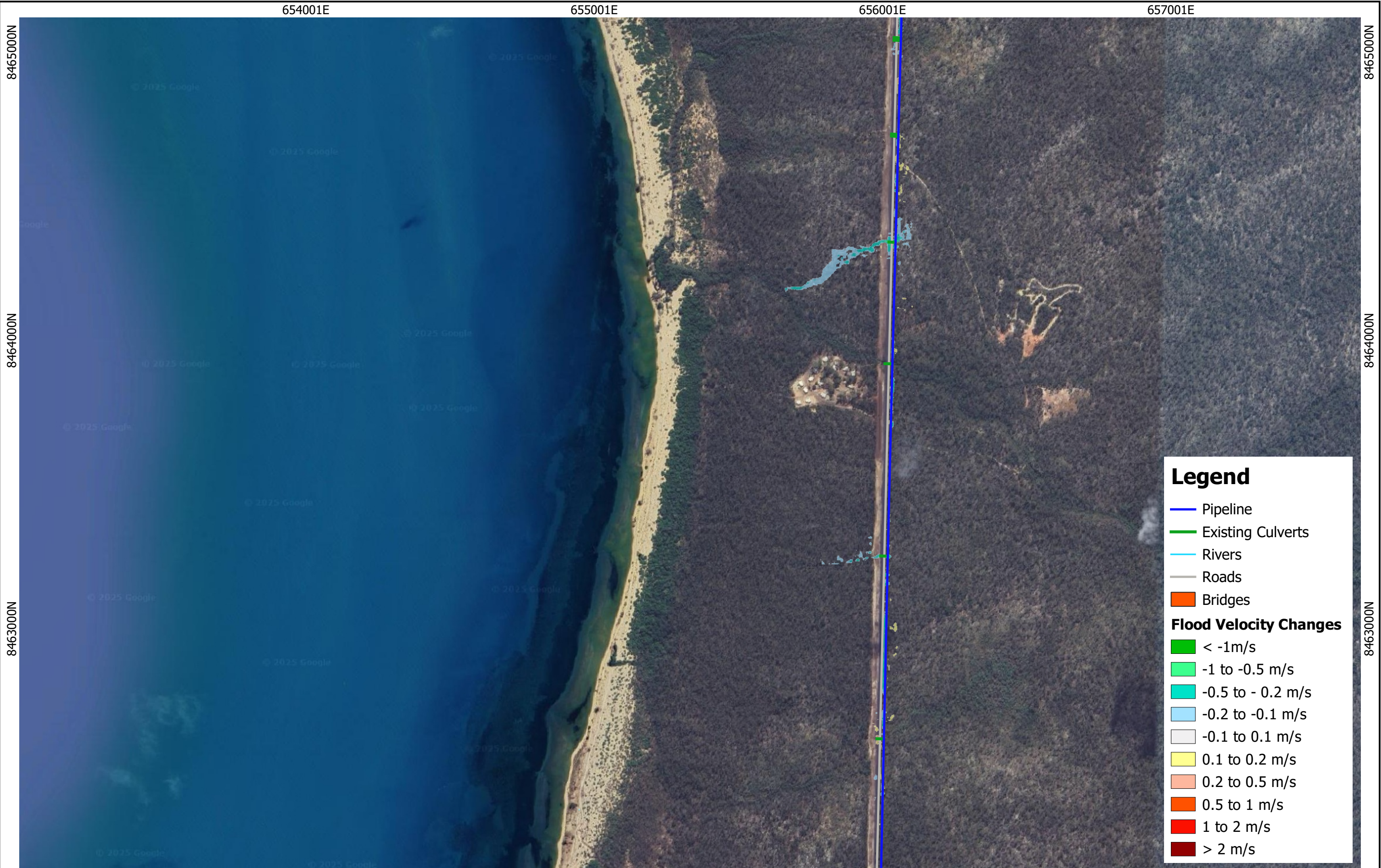
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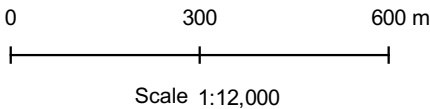
Project: GEMCO Excess Water Disposal PFS Support				Horizontal Datum: GDA94 / MGA zone 53	0300600 Scale 1:12,000	N	red earth engineering	Red Earth Engineering Pty Ltd ABN: 17 136 007 746 Phone: +61 7 3173 1714 admin@redearthengineering.com.au 70/74 Bowen Street, Spring Hill, QLD 4000					
Title: 1:10 AEP Flood Velocity Afflux Pre Mitigation													
A3	Figure: Figure B9	Version: A	Date: 18/09/2024										

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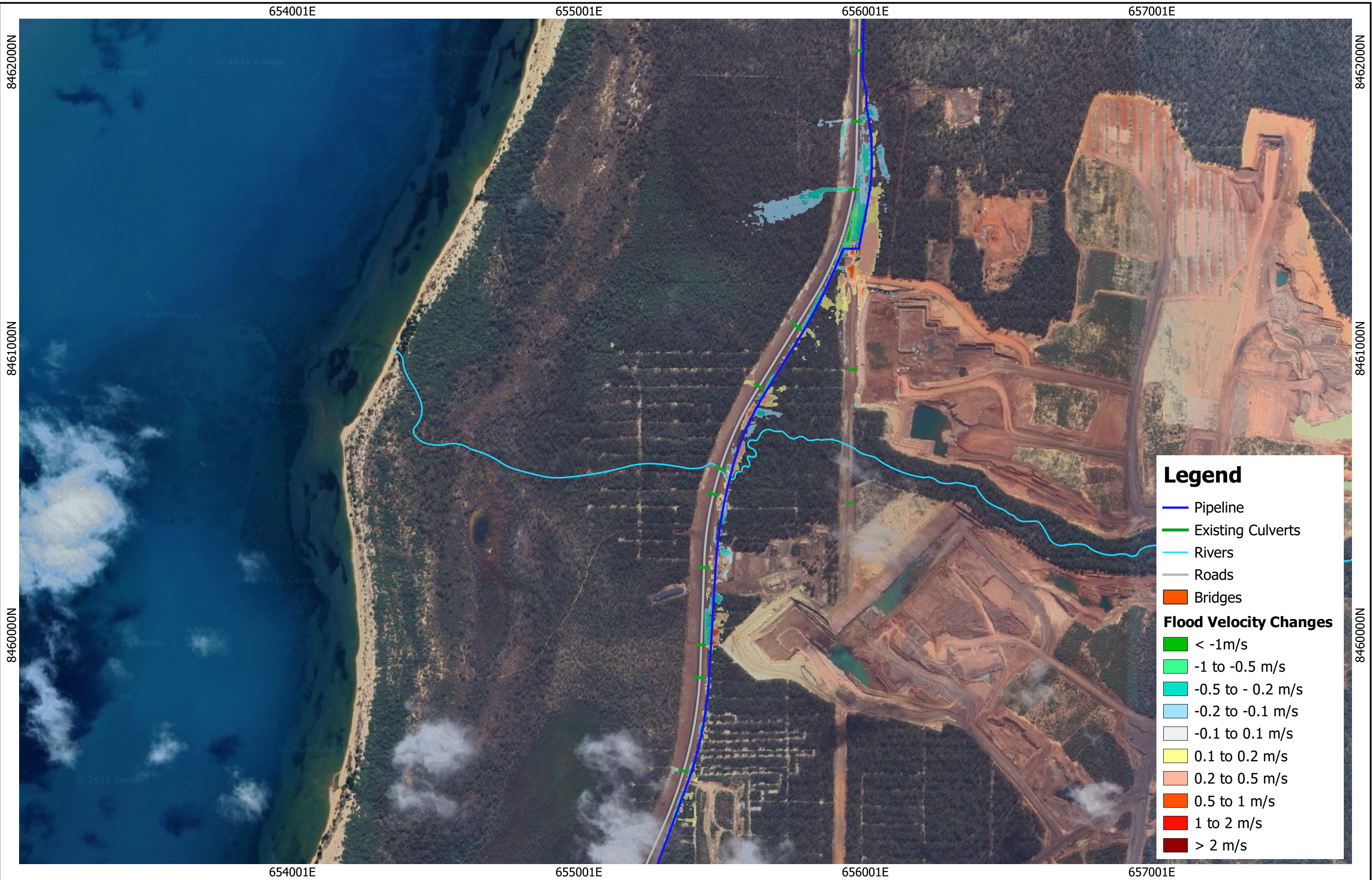
Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Velocity Afflux Pre Mitigation			
A3	Figure: Figure B10	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



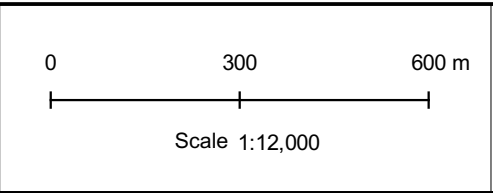
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Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Velocity Afflux Pre Mitigation			
A3	Figure: Figure B11	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



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8459000N

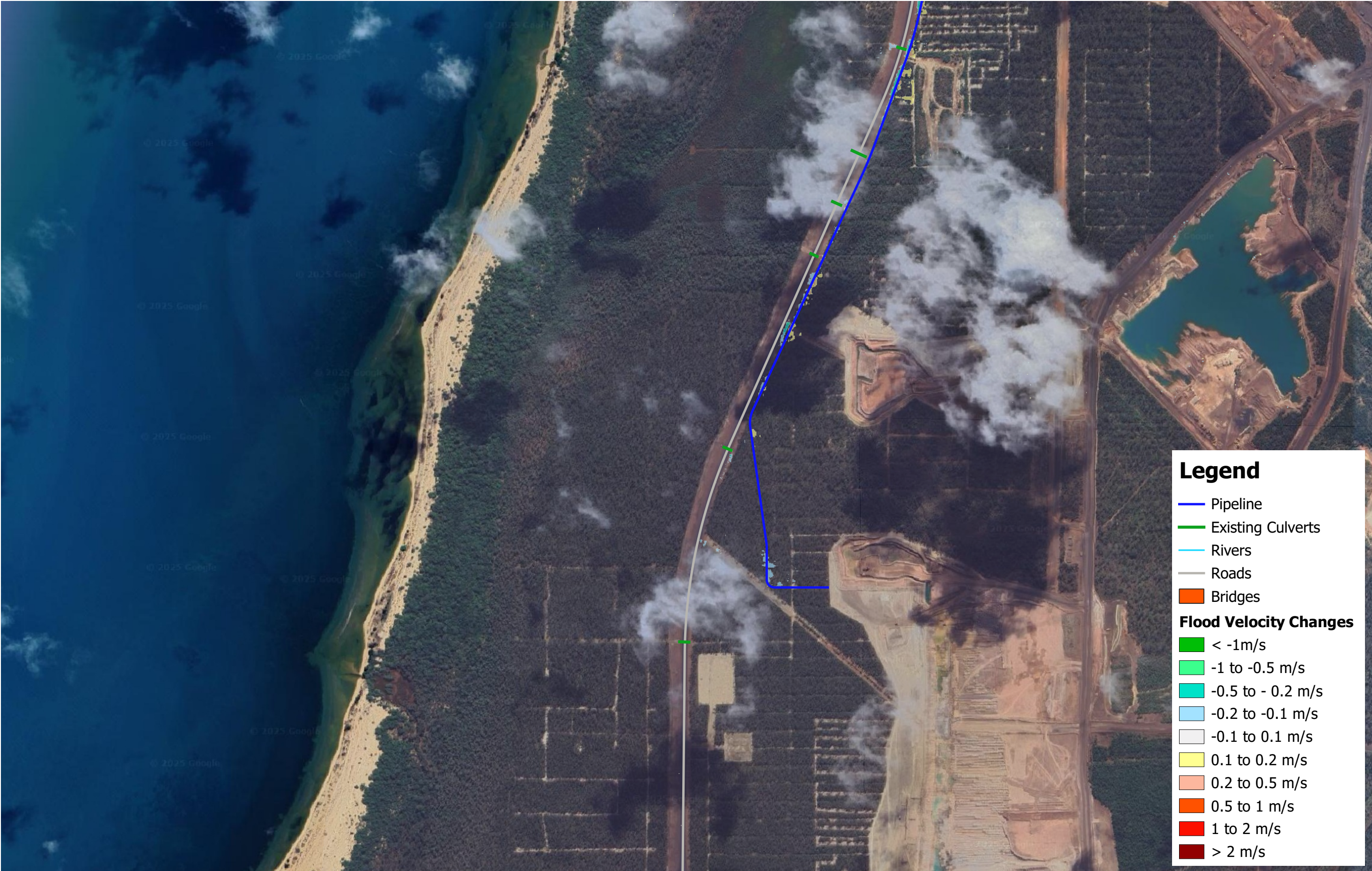
8458000N

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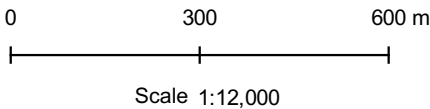


Project: GEMCO Excess Water Disposal PFS Support

Title: 1:10 AEP Flood Velocity Afflux
Pre Mitigation

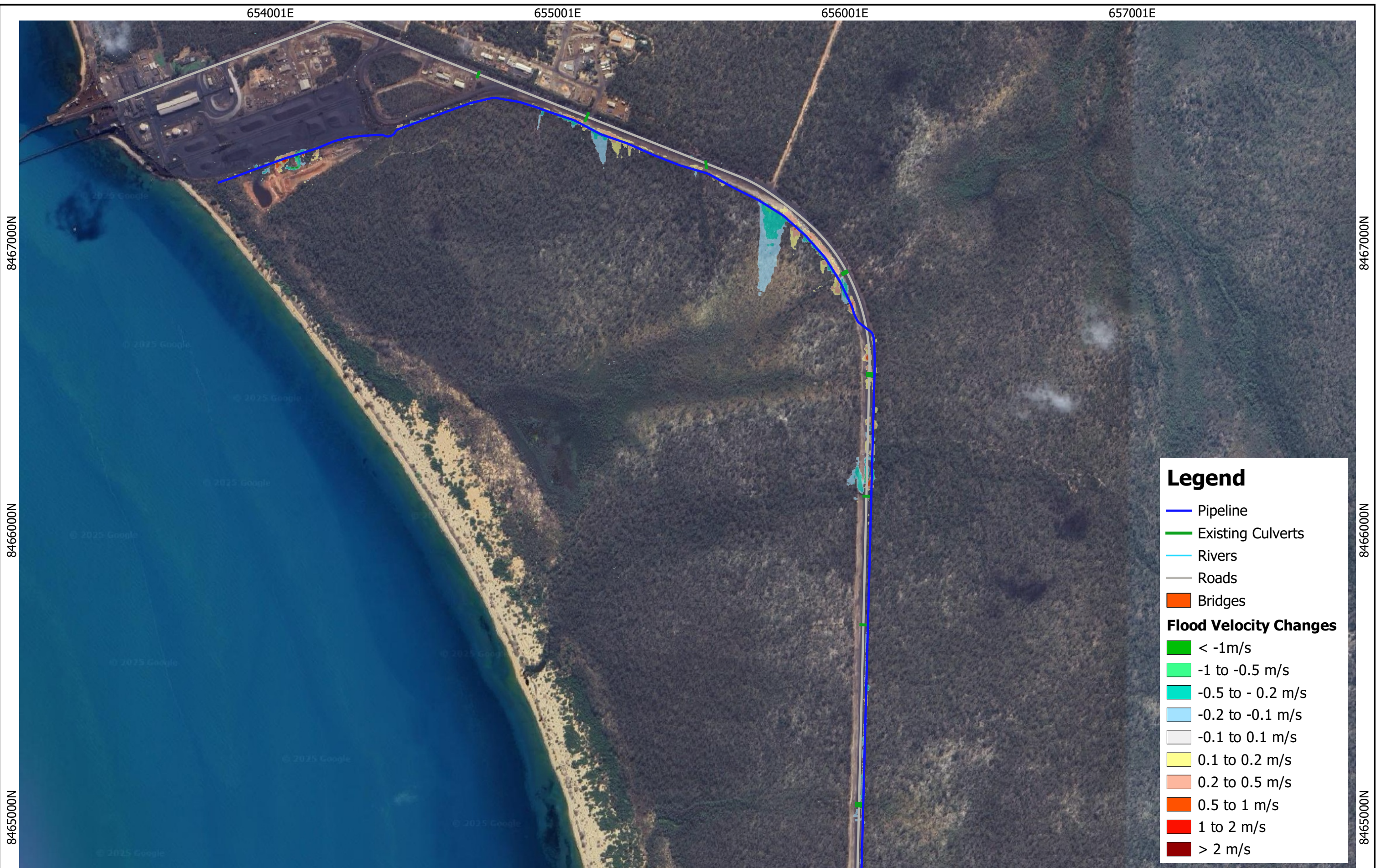
A3 Figure: Figure B12 Version: A Date: 18/09/2024

Horizontal Datum:
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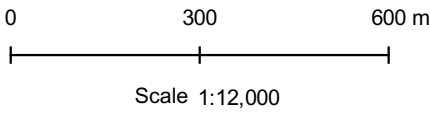
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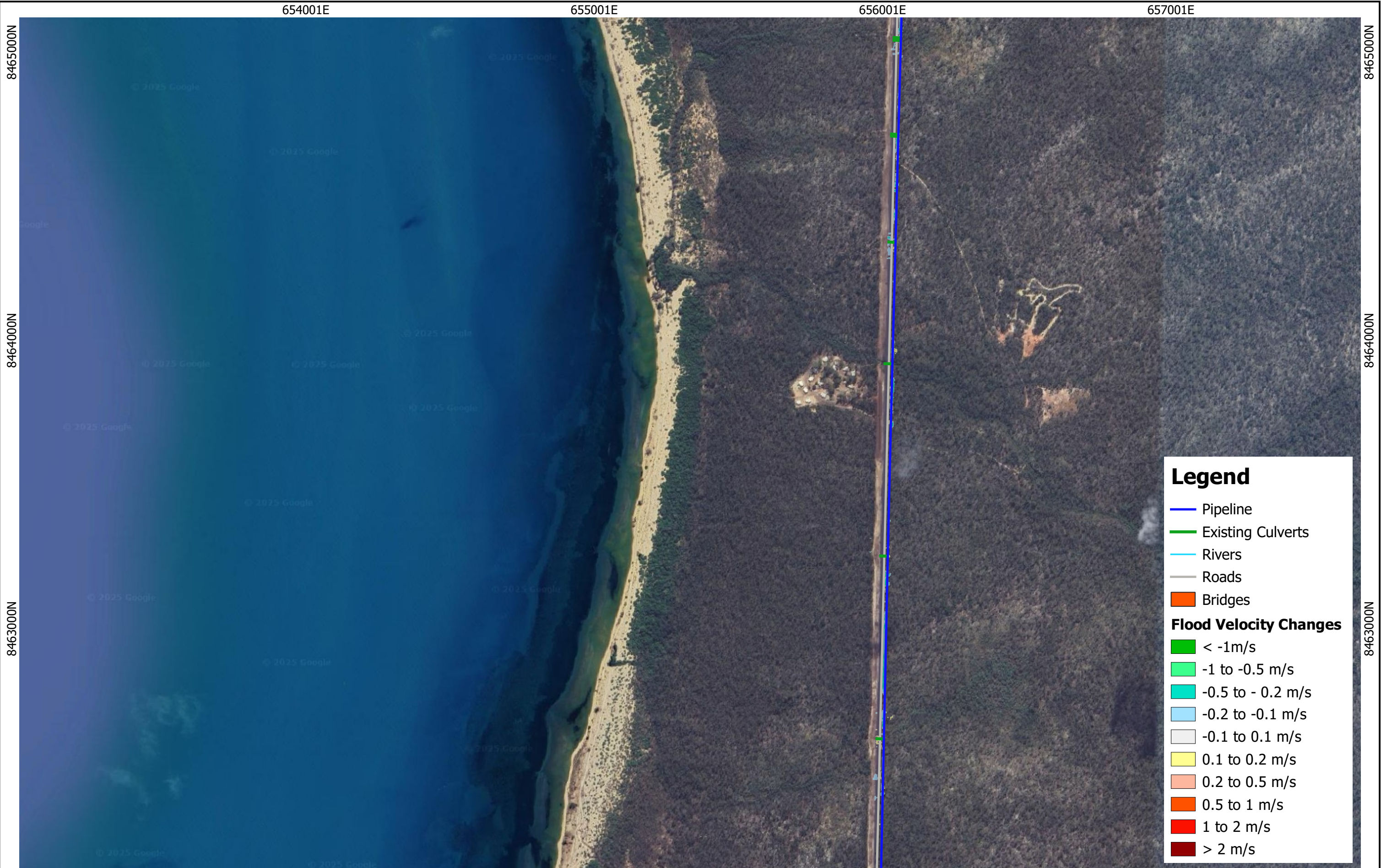
Project:	GEMCO Excess Water Disposal PFS Support			
Title:	1:10 AEP Flood Velocity Afflux Proposed Mitigation			
A3	Figure: Figure B13	Version: A	Date: 18/09/2024	

Horizontal Datum:
GDA94 / MGA zone 53



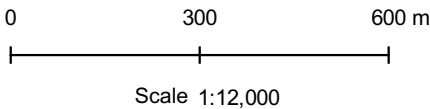
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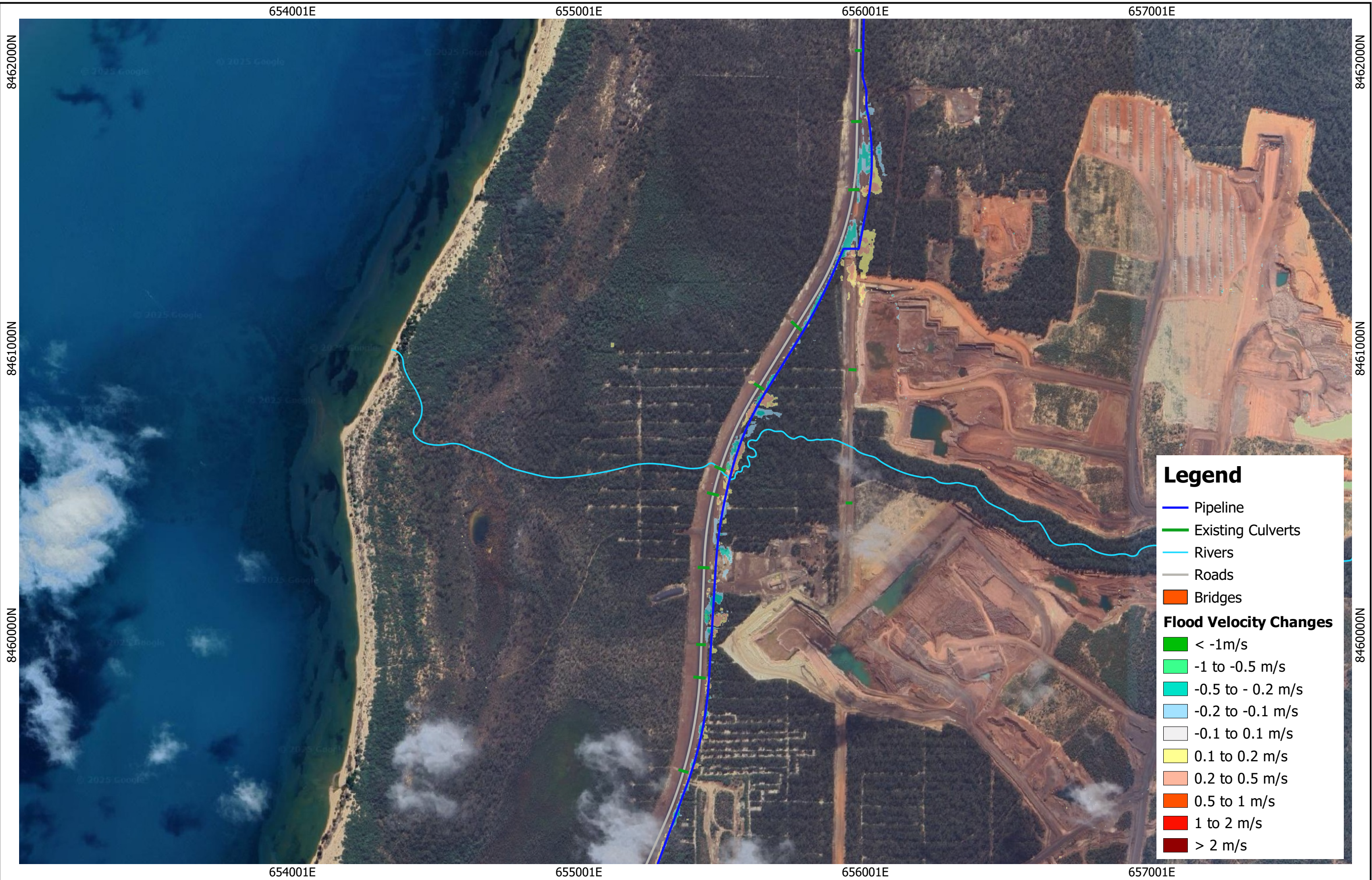
Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Velocity Afflux Proposed Mitigation			
A3	Figure: Figure B14	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



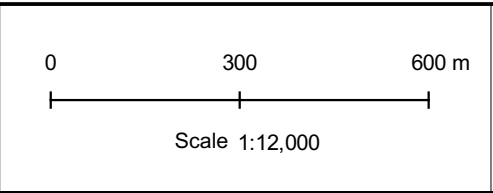
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Project: GEMCO Excess Water Disposal PFS Support			
Title: 1:10 AEP Flood Velocity Afflux Proposed Mitigation			
A3	Figure: Figure B15	Version: A	Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53



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8459000N

8458000N

8457000N

8459000N

8458000N

8457000N



Project: GEMCO Excess Water Disposal PFS Support

Title: 1:10 AEP Flood Velocity Afflux
Proposed Mitigation

A3 Figure: Figure B16 Version: A Date: 18/09/2024

Horizontal Datum:
GDA94 / MGA zone 53

0 300 600 m
Scale 1:12,000



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Appendix C

Surface Water Treatment Locations

Pipeline NH2 to Port – Surface Water Treatment Locations		
Location (Chainage)	Length of Treatment (m)	Comment
1150	50	Current Design
1360	30	Current Design
1550	35	Proposed to Add
1740	25	Current Design
2120	50	Proposed to Add
2460	25	Current Design
2570	30	Current Design
2660	15	Proposed to Add
2760	40	Current Design
3000	15	Proposed to Add
3100	25	Current Design
3150	55	Current Design
3500	50	Proposed to Extend
3750	45	Proposed to Extend
4060	65	Current Design
4340	20	Proposed to Add
4570	20	Proposed to Add
4650	35	Current Design
4810	20	Current Design
5400	25	Current Design
6040	50	Proposed to Add
6120	50	Proposed to Add
6700	50	Current Design
7400	30	Current Design
7500	50	Proposed to Extend
7820	30	Current Design
8180	25	Proposed to Add
8450	40	Current Design
8910	45	Proposed to Extend
9040	55	Current Design
9150	25	Proposed to Add
9310	35	Current Design
6450	70	Current Design
9580	25	Proposed to Add
9700	50	Proposed to Add

Pipeline NH2 to Port – Surface Water Treatment Locations		
9950	20	Proposed to Add
10280	20	Proposed to Add
10650	20	Proposed to Add
10750	30	Current Design
11460	75	Proposed to Extend
11870	50	Proposed to Add