PROJECT

SUPPLEMENTARY WATER QUALITY REPORT – MINIMAL IMPACT CONSIDERATIONS TWEED SAND PLANT EXPANSION CUDGEN, NEW SOUTH WALES

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SYNOPSIS This supplementary report reviews surface water and groundwater quality data to address the 'Minimal Impact Considerations' of the NSW Aquifer Interference Policy 2012 with respect to the proposed expansion of Hanson Construction Material's Tweed Sand Plant located in Cudgen, New South Wales. It also provides a detailed assessment of iron and salinity results recorded in the site's surface and groundwater as requested by the NSW DPIE Water and NRAR submission dated 18 June 2021. This report augments previous water quality reporting as contained in the Surface and Groundwater Assessments contained in the Tweed Sand Plant Expansion EIS, 2021.

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SUMMARY

In March 2021 Hanson Construction Materials Pty Ltd (Hanson) submitted an Environmental Impact Assessment (EIS) for the proposed expansion of its Tweed Sand Plant (TSP) operation located in Cudgen, New South Wales. Hanson commissioned Gilbert & Sutherland (G&S) to prepare a number of technical reports contained within the EIS, including a Groundwater Assessment.

The EIS went on Public Exhibition from 22 April 2021 until 20 May 2021, following which a total of 13 submissions were received. This supplementary report was prepared in response to the submission received from the Department of Planning, Industry and Environment's Water Department (herein 'DPIE Water') and the Natural Resource Access Regulator ('NRAR'), which requested the Proponent address the 'Minimal Impact Considerations' of the NSW Aquifer Interference Policy relating to high priority groundwater dependent ecosystems, and also respond to specific queries relating to iron and salinity concentrations recorded in the site's ground and surface waters.

This supplementary report responds to the NRAR/DPIE Water submission items 3.1 a), b) and c). It provides information and assessment directly addressing the relevant minimal impact considerations, and responds to the requests relating to iron and salinity in the site's waters. Summary findings of the assessments undertaken to address the submission are provided below.

Minimal Impacts Considerations

Water levels – Impacts to GDE's have been assessed for the existing TSP site and expansion area and are clearly defined in this report and the Supplementary Groundwater Model Report, Tweed Sand Plant Expansion, Cudgen, New South Wales, October 2021 (herein the Supplementary GWM Report). A review of the relevant Water Sharing Plan Mapping for high-priority Groundwater Dependent Ecosystems (GDEs) does not indicate any of these ecosystems in close proximity to the site (the closest being 2km away). The outcomes of numerical MODFLOW modelling indicates there will be no impacts to the high-priority GDEs mapped in the 'Water Sharing Plan NCCSGS' and thus the AIP 2012 Level 1 minimal impact criterion for water levels is satisfied.

With respect to high priority culturally significant sites, the WSP does not indicate the presence of such sites within proximity to the TSP expansion or within the footprint of the predicted changes to the groundwater table. The Level 1 minimal impact criterion with respect to culturally significant sites is thus also satisfied.

Water pressure – Numerical MODFLOW groundwater modelling was completed to assess changes in groundwater level (i.e. changes to pressure head) as a result of the proposed TSP expansion. Groundwater level changes resulting from the development are shown on Drawing 12035-SUPP_GWM_006, which shows that there will be no changes to groundwater level (i.e. pressure head decline) within proximity to any of the known registered bores. This indicates that the Level 1 minimal impact threshold for water pressure is met by the proposed expansion.

Water quality – The potential for the development to alter groundwater quality (beyond 40 m from the activity) to a degree that would alter the aquifer's beneficial use category or affect the health of nearby GDEs has been considered in this report with reference to the findings of the Supplementary GWM Report. The beneficial uses of the groundwater at the site and immediate locale are limited to the categories of aquatic ecosystem values, industrial uses and irrigation. Each of these categories could be affected by changes in salinity, pH or iron concentrations.

The impact of the proposed development on water table elevations which could lead to changes in water quality have been assessed through preparation of a numerical MODFLOW groundwater model. Drawing 12035_SUPP_GWM_006 provides an overview of the changes in groundwater table elevation likely to be caused by the development.

Anticipated groundwater level changes due to the development are minimal, predominantly occurring within the footprint of the extraction lake with no or low changes outside of the lot boundaries. The changes in groundwater elevation predicted by the model are brought about by the changes in topography caused by extraction of sand. Essentially, reducing the land elevation and removing the substrate that contains the groundwater results in an associated lowering of the immediate groundwater table as it equilibrates with the surface water level of the extraction lake.

Groundwater drawdown outside of the lot boundaries is modelled to range to a maximum of 0.5 m. Whilst recognising that a lowering of the groundwater table in acid sulfate soils can impact groundwater quality, long term groundwater level monitoring at the site demonstrates that the predicted change in groundwater levels is within the natural variation experienced in this locale. Accordingly, changes to groundwater quality due to drawdown are unlikely.

To further explore the Project's potential impacts on groundwater quality, with a specific focus on salinity and iron concentrations, a range of statistical assessments have been undertaken. The findings of these analyses are summarised below.

Salinity

Various statistical analyses of salinity in the extraction lake and groundwater environment were undertaken to assess the potential salinity risks of the project. The analyses indicated that:

- Electrical Conductivity (EC) concentrations and long-term trends within the extraction lake are well defined.
- EC levels within the extraction lake are stable with one of the three monitoring locations indicating a decreasing EC trend.
- It is well established that the elevated salinity in the site's deep (~20 m) groundwaters is associated with regional estuarine conditions in the Tweed River and ultimately the Pacific Ocean.
- As the TSP lake expands it will continue to assimilate shallow and deep groundwaters into the waterbody.
- The stable EC trends observed over the long history of monitoring at the site are anticipated to continue throughout the expansion of the site. Monitoring and ongoing assessment of EC is proposed to continue at all surface and groundwater monitoring locations throughout the site and expansion area.

Dissolved iron

With respect to dissolved iron concentrations in the groundwater and associated risks, the data analysis detailed herein indicates:

- There are no consistent patterns or correlations between the presence of dissolved iron in the groundwater and the conditions encountered within the TSP extraction lake, nor can any temporal changes in iron concentrations be attributed in a definitive way to the ongoing dredging and sand processing activities at the site under present and/or historical conditions.

- There appears to be no link between the chemical characteristics of the lake and the surrounding shallow groundwater in the monitoring bores.
- These findings are supported by the G&S report entitled 'Revised Water Balance Modelling, Tweed Sand Plant Expansion, Cudgen, New South Wales October 2021', which indicates that the extraction lake typically operates as a groundwater recharge window whereby waters seep from the lake to the groundwater environment rather than groundwaters seeping into the lake.
- The expansion of the lake will intercept the dissolved iron within the groundwater as the works proceed. The historical surface water and groundwater data indicates that the site has experienced pervious time periods where dissolved iron was present in the groundwater with no associated change in the iron concentrations of the lake. The performance of the lake chemistry thus far indicates that the lake is of sufficient size to buffer/mitigate any changes in dissolved iron in the landform without significantly altering the water chemistry of the extraction lake.
- As the proposed expansion will continue to extract and process sand in much the same way as the existing TSP operation, the past environmental performance of the area provides a robust indication of the ongoing behaviour of the surface and groundwater environments into the future.
- Regarding potential impacts on GDE's, the magnitude of likely drawdown within the small area of mapped low-potential terrestrial GDE on the site's south-western boundary is within the range of natural seasonal variation. Significant changes to groundwater chemistry in the locale are therefore unlikely.
- In addition, the site's comprehensive water quality data set and the statistical analyses presented in this report indicate that the size of the current lake, and by extrapolation, the proposed expanded lake, is such that it acts as a stabilising feature to the local surface and groundwater environments and buffers/mitigates against significant changes in water chemistry.

Long term site observations and other environmental assessments at the site indicate that:

- Iron staining or associated evidence of iron toxicity (such as fish kills) have not been observed at the TSP site.
- Recent aquatic macroinvertebrate studies (including electrofishing) within the TSP extraction lake indicated that the aquatic macroinvertebrate and fish assemblages in the TSP extraction lake were relatively diverse and abundant and represented a healthy aquatic ecological community.

A comprehensive environmental monitoring regime, including surface and groundwater monitoring and inspections of the success of site rehabilitation plantings, is proposed for the TSP expansion project. These monitoring programs would readily identify increased iron concentrations caused by the expansion works and any secondary indicators such as fish kills or vegetation stress.

The proposed Soil and Water Management Plan for the TSP Expansion includes a comprehensive program of surface and groundwater monitoring throughout the site. The water quality objectives proposed in that report have been based on the ANZECC Water Quality Guidelines for Fresh and Marine Environments (where available). The SWMP also includes contingency measures should monitoring indicate trends in water quality that could impact the health of the extraction lake, surrounding groundwater and its dependent ecosystems (where present).

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DRAWING NO.	DESCRIPTION
Z19163 – F19 and F120	Concept Development Phasing
12035-003	Monitoring Locations
12035-104	High Priority Groundwater Dependant Ecosystems
12035-501	Registered Groundwater Bores
12035 – SUPP_GWM_006	Change in modelled groundwater elevation (Existing to Developed Site Conditions) Tweed Sand Plant only

1 Introduction

In March 2021, Hanson Construction Materials Pty Ltd (Hanson) submitted an Environmental Impact Study (EIS) for the proposed expansion of its Tweed Sand Plant (TSP) operation located in Cudgen, New South Wales. Hanson engaged Gilbert & Sutherland Pty Ltd (G&S) to prepare a number of technical reports contained within the EIS including a Groundwater Assessment.

Following public exhibition of the EIS from 22 April 2021 until 20 May 2021, 13 submissions were received. This supplementary report was prepared in response to the submission received from the Department of Planning, Industry and Environment's Water Department (DPIE Water) and the Natural Resource Access Regulator (NRAR) which requested the Proponent address the minimal impact considerations of the NSW Aquifer Interference Policy relating to high priority groundwater dependent ecosystems and also respond to specific queries relating to iron and salinity concentrations recorded in the site's ground and surface waters.

1.1 Scope of this report

The DPIE and NRAR submission dated 18 June 2021 requested additional information be provided in respect of the groundwater assessment[1] within the EIS. Key items from the DPIE Water and NRAR submission to be addressed in this supplementary report are reproduced below in italic text:

> ***3.0 Minimal Impact Considerations***
>
> ***3.1 Pre-approval Recommendations***
> *The proponent should:*
>
> a) *present a supplementary report addressing the 'minimal impact considerations' of the NSW Aquifer Interference Policy (2012) with consideration of all high priority GDEs, DPIE Water's observation on salinity and iron concentrations and potential impacts,*
> b) *analyse and report on lake salinity risks post closure,*
> c) *quantify the risk of water quality changes and their impact on GDEs, including the increase in soluble iron.*
>
> ***Explanation***
> *The EIS does not address the NSW AIP assessment criteria directly as requested in the DPIE Water submission to the SEARs. However, the EIS does provide information on GDEs, water quality and groundwater levels.*
>
> ***Groundwater dependent ecosystems (GDEs)***
> *The EIS has identified GDEs using the Bureau of Meteorology (BoM) GDE Atlas. Low potential GDEs are reported along the southern boundary of the expansion area. Groundwater modelling predicts 0.5m drawdown at the BoM low potential GDEs. A small strand of high potential GDEs within the expansion footprint exists towards the northern boundary. The identified high potential GDEs will be removed subject to project approval.*
>
> *The proponent's EIS has not referenced the Water Sharing Plan for the 'North Coast Coastal Sands Groundwater Sources 2016' to identify 'high priority' GDEs.*
>
> *DPIE data shows 'high priority' GDEs located along the southern boundary of the existing extraction area. These GDEs have not been referenced in the EIS. The groundwater model drawdown contours*

[1] Gilbert & Sutherland, March 2021, 'Groundwater Assessment, Tweed Sand Plant Expansion, Cudgen, New South Wales' (Appendix C of EIS).

presented in the Groundwater Assessment show water table impact as a change from the already developed site conditions. The drawdown contours present no predicted change in water table at the location of the 'high priority' GDEs identified in this review. The AIP GDE impact criteria is cumulative impact and impacts from the existing site development along with the project expansion must be considered.

Acid Sulphate Soils and Water Quality

The project operates within a known area of high probability acid sulfate material. Field testing pH results range from 1.2 up to 7.1 with an average result of 4.8. The proponent has undertaken water quality monitoring since 2001. An acid sulfate management plan requires returning PASS fines to the dredge pond at a depth below the water table to limit oxidation. The pH within the existing lake and groundwater is reported to have remained relatively stable.

The Acid Sulfate Soil Assessment makes two key statements:

> *"No lime treatment of extracted sands has been required at the site owing to the sand resource's high ratio of acid neutralising capacity (ANC) compared to its acid generating potential (AGP)";*

and

> *"...the existing approved approach to ASS Management will also be adopted for operations within the proposed expansion area. This methodology has proven successful over the life of the TSP operations with stable pH levels maintained in the lake and no evidence of the occurrence of acidic reactions in the in-situ material surrounding the lake,"*

DPIE Water acknowledges pH concentrations appear to be relatively stable since 2001. However, there is elevated and erratic fluctuations in iron concentration measured in the shallow groundwater observation bores peaking recently at just under 100 mg/L at one site. Several deeper observation bores are also showing erratic fluctuations in iron concentration in recent years.

Without a geochemical assessment to determine the cause of elevated iron concentration in shallow groundwater, DPIE Water disagrees that there is "no evidence of the occurrence of acidic reactions in the in-situ...". The iron fluctuations could be caused by evaporative processes, introduced from the oxidation of acid sulfate soil material, a combination of the two or another process. An analysis of ion ratios such as chloride to iron and chloride to sulfate may identify the process causing high iron concentrations. DPIE Water seeks further geochemical work to understand these processes and assess if project expansion will exacerbate the release of iron.

The iron concentrations in the shallow aquifer exceed Tweed River Water Quality Objectives, ANZECC Water Quality Guidelines and NHRMC Recreation Water Quality Guidelines for primary contact recreation. As no lime dosing has been undertaken to date, and the cause of elevated iron in the shallow groundwater is unknown, it is unclear if iron concentrations can be mitigated. The elevated iron concentrations compromise groundwater beneficial use with potential for ecological impacts to the enveloping GDEs along the project boundary and other water assets.

There is also evidence of high salinity (>15,000 mg/L) in deeper groundwater associated with sea water intrusion across the broader monitoring network. Low salinity groundwater occurs in the shallow sand aquifer. The extraction to a depth of -20m risks mixing of groundwater in the shallow and deep aquifers. The resulting lake water quality for salinity has not been predicted. Data shows a rising EC trend in the deeper observation bores indicative of a landward progression shift in the saltwater interface. The impact risk would increase as extraction progresses westward towards the tidal Tweed River.

There is a clear omission in the discussion about the mixing of deep and shallow groundwater and the resulting influence on lake water quality. There is no salinity performance measure reported for groundwater or surface water in the Soil and Water Management Plan. Whilst electrical conductivity is *reported to be collected, there is no rationale presented for this omission. It is unknown if the lake is becoming more saline.*

This supplementary report was prepared to respond to items 3.1 a), b) and c) of the NRAR/DPIE Water submission. It provides further information and assessments to directly assess the relevant minimal impact considerations and respond to the queries relating to iron and salinity within waters at the site.

2 Minimal impact considerations

The DPIE and NRAR submission dated 18 June 2021 requested in item 3.1a) that the minimal impact considerations of the NSW Aquifer Interference Policy 2012 ('AIP 2012' or 'the Policy') be addressed directly. In response, the AIP 2012 was reviewed with respect to the proposed TSP Expansion. It is understood that the Policy requires the Proponent to ensure that '*no more than minimal harm will be done to any water source, or its dependent ecosystems, as a consequence of its being interfered with in the course of the activities to which the approval relates'*.

Table 1 of the AIP 2012 establishes a set of minimal impact considerations for different types of water sources (including Coastal Sands Water sources) to be addressed with respect to an aquifer interference activity such as the proposed TSP Expansion. For ease of reference, the relevant minimal impact considerations of the AIP 2012 which relate to Coastal Sands Water Sources have been reproduced in the following sub-sections.

2.1 Water table

The AIP 2012 provides the following Level 1 minimal impact threshold with respect to the water table in coastal sands water sources:

1. *Less than or equal to 10% cumulative variation in the water table, allowing for typical climatic "post-water sharing plan" variations, 40m from any;*
   a) High priority groundwater dependent ecosystem; or
   b) High priority culturally significant site;
      i listed in the schedule of the relevant water sharing plan.
      Ii A maximum of a 2m decline cumulatively at any water supply work

With respect to an assessment of impacts on High Priority GDE's, the Groundwater Assessment contained in Appendix C of the EIS was prepared by suitably qualified specialists with a demonstrable record of assessing hydraulic and hydrologic changes capable of affecting Groundwater Dependent Ecosystems (GDEs). The report provided a detailed assessment of the proposed expansion's potential impacts on GDEs and included a review of the following data sources to investigate the presence and characteristics of wetlands and GDEs located within and nearby the proposed expansion footprint:

- NSW Wetlands vector dataset, Office of Environment and Heritage, State Government of NSW and Department of Planning, Industry and Environment 2010;
- State Environmental Planning Policy (Coastal Management) 2018; and
- NSW Environmental Data, the Bureau of Meteorology's Groundwater Dependant Ecosystems Atlas.

The NRAR/DPIE Water submission states that the Groundwater Assessment did not reference the Water Sharing Plan for the North Coast Coastal Sands Groundwater Sources 2016 ('Water Sharing Plan NCCSGS') to identify 'high priority' GDEs. The submission notes that there are 'high priority' GDEs located along the southern boundary of the existing extraction area that have not been considered in the assessment for the TSP expansion.

A further review of the 'high-priority' GDE Map contained within the Water Sharing Plan was undertaken to determine the proximity of any high-priority GDEs to the subject site. Although there are several of these GDEs mapped along the coastline, it does not appear that there are any GDEs along the southern boundary of the site as indicated in the NRAR/DPIE submission. A search of NSW SEED online mapping was completed to confirm the distance between the TSP site and any of the mapped high-priority GDEs within proximity. The closest high-priority GDE's (as mapped by the Water Sharing Plan) to the site are the 'Blacks Creek Swamps' to the south being approximately 2 km away, and the 'Cudgen Creek Swamps' to the east being approximately 5 km from the site. G&S drawing 12035-104 contained in Appendix 1 shows the site in its regional context and its proximity to the high priority GDEs mapped in the Water Sharing Plan NCCSGS.

The impact of the proposed development on the water table within and surrounding the TSP expansion site was assessed through preparation of a numerical MODFLOW groundwater model. An overview of the changes in groundwater table elevation likely to be caused by the development is provided in Drawing 12035_SUPP_GWM_006.

Minimal change to groundwater levels are anticipated as a result of the development and where changes are predicted they are predominantly within the footprint of the extraction lake, with only minor excursions outside of the lot boundaries. As stated above, the WSP Mapping does not indicate any high-priority GDE's in close proximity to the site (the closest being 2 km away). The outcomes of numerical MODFLOW modelling indicate there will be no impacts to the high-priority GDEs mapped in the 'Water Sharing Plan NCCSGS' and thus the AIP 2012 Level 1 minimal impact criterion for water levels is satisfied in part. The Supplementary Groundwater Model Report[2] (herein the Supplementary GWM Report) should be referred to for full details of water table impacts.

With respect to high priority culturally significant sites, the WSP does not indicate the presence of such sites within proximity to the TSP expansion or within the footprint of the predicted changes to the groundwater table. The Level 1 minimal impact criterion with respect to culturally significant sites is thus also satisfied.

2.2 Water pressure

The AIP provides the following Level 1 minimal impact threshold with respect to water pressure in coastal sands water sources:

1. *A cumulative pressure head decline of not more than a* 2m *decline, at any water supply work.*

A search was conducted using the Bureau of Meteorology's Australian Groundwater Explorer[3] to determine the presence of groundwater bores/ existing groundwater users (i.e. water supply works) in close proximity to the TSP site. Drawing 12035-501 in Appendix 1 shows the location of the various registered bores with respect to the site and the registered classification of each.

Bores located within the boundary of the existing TSP site are monitoring bores installed and monitored by TSP. There are no groundwater bores currently registered within the footprint of the expansion area.

To the north of the existing TSP operation there are three bores located within the footprint of the Kingscliff Wastewater Treatment Plant and these are registered for the purposes of dewatering and monitoring.

To the immediate east of the existing TSP operation there is one bore registered for Commercial and Industrial use for the adjacent Cudgen Lakes Sand extraction.

There are two registered bores to the west of the proposed expansion area located on the western side of the M1. These are registered as monitoring and Irrigation bores.

Numerical MODFLOW groundwater modelling was completed to assess changes in groundwater level (i.e. changes to pressure head) as a result of the proposed TSP expansion.

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[2] Supplementary Groundwater Model Report, Tweed Sand Plant Expansion, Cudgen, New South Wales, October 2021.

[3] Australian Groundwater Explorer, Australian Government Bureau of Meteorology, 2000. http://www.bom.gov.au/water/groundwater/explorer/

Groundwater level changes due the development are shown on Drawing 12035_SUPP_GWM_006. The drawing shows that there will be no changes to groundwater level (i.e. pressure head decline) within proximity to any of the known registered bores. This indicates that the Level 1 minimal impact threshold for water pressure is met by the proposed expansion.

2.3 Water quality

The AIP provides the following Level 1 minimal impact threshold with respect to water quality in coastal sands water sources:

1. *A change in the groundwater quality should not lower the beneficial use category of the groundwater source beyond 40 m from the activity.*

The beneficial uses of the groundwater at the site and immediate locale are limited to the categories of aquatic ecosystem values, industrial uses and irrigation. Each of these categories could be affected by changes in salinity, pH or iron concentrations.

The potential for the development to alter groundwater quality (beyond 40 m from the activity) to a degree that would alter the aquifer's beneficial use category have been considered in this report and also in the Supplementary GWM report. The impact of the proposed development on water table elevations which could lead to changes in water quality have been assessed through preparation of a numerical MODFLOW groundwater model. Drawing 12035_SUPP_GWM_006 provides an overview of the changes in groundwater table elevation likely to be caused by the development.

Anticipated groundwater level changes due to the development are minimal, predominantly occurring within the footprint of the extraction lake with no or low changes outside of the lot boundaries. The changes in groundwater elevation predicted by the model are brought about by the changes in topography caused by extraction of sand. Essentially, reducing the land elevation and removing the substrate that contains the groundwater results in an associated lowering of the immediate groundwater table as it equilibrates with the surface water level of the extraction lake.

The magnitude of drawdown that is predicted to be experienced outside of the lot boundaries is a lowering of the groundwater table by up to 0.5m. Lowering of the groundwater table can cause groundwater quality impacts in areas where acid sulfate soils occur such as the TSP site. However, in this instance, long term groundwater level monitoring at the site indicates that the predicted change in groundwater levels is within the natural climatic variation experienced in this locale and as such is unlikely to result in changes in groundwater quality associated with acid sulfate soil environments.

Further assessment of water quality specifically addressing lake salinity post closure and soluble iron concentrations are provided in the following sections.

3 Lake salinity post closure

The DPIE and NRAR submission requested in item 3.1b) that '*the proponent should analyse and report on lake salinity risks post closure*'. Concerns were raised regarding '*high salinity*' within water samples collected from deep groundwater monitoring wells, whilst water samples collected from the shallow groundwater monitoring wells exhibited lower salinity. G&S was requested to provide additional information regarding the potential for groundwater mixing through the continued extraction of materials to a depth of 20 m.

In addressing DPIE Water and NRAR's concerns, it is important to clarify that there is one aquifer present on the site. Well construction bore logs and Tweed Region geological maps indicate the site is comprised of Quaternary river gravels, alluvium and sand, allowing the formation of a single unconfined, continuous aquifer. A conceptual model of this aquifer's characteristics is provided in the G&S report entitled 'Revised Water Balance Modelling, Tweed Sand Plant Expansion, Cudgen, New South Wales October 2021', (Drawing 12035 12035 – SUPP_GWM_002).

The groundwater monitoring bore network at TSP consists of shallow bores (~6 m) and deeper bores (up to 20 m). The varied depths are designed to monitor the natural salinity gradient present within this unconfined aquifer, they do not represent monitoring in separate aquifers.

Given the presence of a single aquifer (located in the Tweed-Brunswick Coastal Sands Groundwater Source), the issue to be considered is the salinity gradient within the groundwater, its impact on long-term lake salinity and any changes that may occur as a result of the creation of the extraction lake.

In simple terms, groundwater closer to the land surface exhibits lower salinity because it is more readily recharged by rainfall. At depth, the groundwater in the same locale exhibits greater salinity concentrations as it is less influenced by rainfall and more influenced by its proximity to the regional estuarine conditions in the Tweed River and ultimately the Pacific Ocean. The relationship is also driven by density, with higher density saline waters naturally accumulating at lower depths in the landform. This relationship has been demonstrated by long-term groundwater monitoring undertaken at the site and discussed in the TSP Annual Reviews submitted in September each year.

Surface water sampling from within the lake has been regularly conducted as part of the site environmental monitoring requirements for the past 20 years. In order to explore the stability of lake salinity over time, the GSI Environmental Mann-Kendall toolkit software was utilised to conduct Mann-Kendall trends analyses on four discrete time periods selected from the 20-year database.[4] The Mann-Kendall analysis allows for the determination of trends within a data set and characterises those trends as one of the following:

- Increasing
- Probably increasing
- Stable
- No trend
- Probably decreasing
- Decreasing

Electrical conductivity (EC) (a measure of salinity) was recorded in situ at two surface water locations within the existing extraction lake (SW1 and SW2) on a quarterly frequency between October 2001 and April 2006.

[4] GSI Man-Kendall software has a dataset limit of 20 data points.

An additional surface water location (SW3) was added to the monitoring schedule at the May 2007 sampling event and continued from that time onwards. Monitoring locations are shown on Drawing 12035_003.

3.1 Mann-Kendall trends analysis

In order to assess the presence of trends within the electrical conductivity data recorded for the site, a Mann-Kendall analysis was performed on the EC data recorded in the lake from December 2001 up to the most recent monitoring event in June 2021.

Results for monitoring location SW1 indicated a 'stable' trend in the data set with an 86.6% confidence factor, results for monitoring location SW2 indicated a 'probably decreasing' trend in the data set with a 90.6% confidence factor, and results for monitoring location SW3 indicated a 'decreasing' trend in the data set with a 98.6% confidence factor, (see Appendix 2 for a tabular and graphical representation of the Mann-Kendall analyses).

Combined these results show that lake salinity is stable and tending toward a decreasing trend over the ~ 20 years of monitoring data available for the site.

3.2 Analysis – Lake salinity v increasing lake size

An examination of the relationship between lake size and EC concentrations was conducted by comparing lake size as it increases over time with corresponding EC concentrations recorded in the lake. The purpose of the analysis was to determine whether increasing lake size and the associated assimilation of higher salinity deep groundwater as the lake expands, has an impact on the EC concentrations within the lake. This analysis aimed to determine whether a relationship exists between lake size and EC and if so, does lake size result in increasing stable or decreasing EC.

To complete the assessment aerial imagery was sourced from Nearmap for a selection of years and used to determine the area of the lake. The average EC of all three surface water monitoring locations was determined from sampling events performed closest to the aerial photography dates. The results are described in Table 3.2.1.

Table 3.2.1 Lake area and average EC from May 2010 to June 2021

Image Date	~Area (m^2)	Average EC (us/cm)	Water sample date
6/5/10	210,524	3510	Mar-2010
5/8/12	230,312	2461	Sep-2012
9/9/13	246,149	1962	Sep-2013
1/6/15	263,758	2220	Sep-2015
24/4/17	284,582	1658	Apr-2017
8/8/18	290,590	2453	Sep-2018
6/11/19	300,107	3079	Dec-2019
1/6/20	307,673	2703	Jun-2020
6/6/21	318,022	1772	Jun-2021

The data indicates that as lake size increases salinity levels return a 'stable' trend. This suggests that based on current data increasing lake size does not correspond with increasing salinity. The Mann Kendall trends analysis is provided in Appendix 2.

3.3 Lake EC v rainfall prior to sampling

An analysis was undertaken to investigate the relationship between rainfall volumes and lake EC concentrations measured over the same time span as described in Table 3.2.1. Rainfall data was collated for the 30, 60 and 90 days preceding the monitoring events undertaken closest to the dates of the aerial imagery (however rainfall data was not available for the 2010 date) and the average EC of all three surface water monitoring locations was determined from sampling events performed closest to the aerial photography dates.

A simple regression analysis including an x-axis intercept was undertaken of the three rainfall periods prior to sampling. The analysis showed there was no correlation between any of the rainfall periods assessed with 30, 60 and 90 days yield adjusted R^2 of 0.024, 0.003 and 0.034 respectively. Appendix 3 shows the statistical summaries for these analyses.

This result is anticipated given the large volume of water held in the lake making the contributions by rainfall comparatively small.

3.4 Lake salinity post closure

The EC data set available for the existing TSP site is comprehensive, spanning the past 20 years of the site's operational life. Based on this data set, EC concentrations within the extraction lake and long- term trends within this water body are well defined. The statistical analyses described in this section indicate that the EC levels within the extraction lake are stable with one of the three monitoring locations indicating a decreasing EC trend.

The source of elevated salinity in the deep (~20 m) groundwaters at the site is well established and associated with regional estuarine conditions in the Tweed River and ultimately the Pacific Ocean. As the TSP lake expands it will continue to assimilate shallow and deep groundwaters into the waterbody through the extraction of sand and seepage into and out of the water body driven by precipitation and evaporation in much the same way as has occurred since commencement of extraction at the site. The stable EC trends observed over the long history of monitoring at the site are anticipated to continue throughout the expansion of the site with monitoring and ongoing assessment of EC results proposed to continue at all surface and groundwater monitoring locations throughout the site and expansion area.

3.5 Climate change considerations

It is noted that the TSC Climate Change Policy[5] predicts sea level rise of 0.4 m by 2050 and 0.9 m by 2100 (above 1990 mean sea levels), as well as an increase in the frequency and depth of tidal inundation of low lying lands and poor drainage in low lying areas such as the TSP site. Sea-level rise will also impact on drainage and groundwater in low-lying coastal floodplains leading to a potential increase in the duration of floods, water-logging of soils and soil salination. These impacts may also be exacerbated by the infiltration of saline water into coastal aquifers, reducing the quality and viability of groundwater for irrigation.[6]

The groundwater impacts associated with sea-level rise have been modelled for the site and are described in the Supplementary GWM report. It is important to note that the subject lands may experience changes in salinity as a result of sea-level rise independent of this development proposal.

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[5] Tweed Shire Council (undated). *Climate Change Policy – Net Zero by 2030* Version 1.0.

[6] Climate Change in the Northern Rivers Catchment, prepared for the New South Wales Government by the CSIRO (2007).

4 Water quality, soluble iron and GDE impacts – a statistical analysis

The DPIE and NRAR submission requested in item 3.1c) that '*the proponent should quantify the risk of water quality changes and their impact on GDEs, including the increase in soluble iron*.' Specifically, the submission requested that:

> '*elevated and erratic fluctuations in iron concentration measured in the shallow groundwater observation bores peaking recently at just under 100 mg/L at one site. Several deeper observation bores are also showing erratic fluctuations in iron concentration in recent years.'*

and noted

> *'The iron fluctuations could be caused by evaporative processes, introduced from the oxidation of acid sulfate soil material, a combination of the two or another process. An analysis of ion ratios such as chloride to iron and chloride to sulfate may identify the process causing high iron concentrations. DPIE Water seeks further geochemical work to understand these processes and assess if project expansion will exacerbate the release of iron G&S have been requested to undertaken additional geochemical analysis to assess whether the project expansion will exacerbate the release of iron.'*

Iron is the fourth most abundant element in the earth's crust and may be present in natural waters in varying quantities depending upon the geology of the area and other influences on the waterbody.

Underground rock formations naturally contain approximately 5% iron. Iron is commonly present within groundwater, being a direct result of precipitation infiltrating and weathering these formations. This dissolved iron gradually moves downward into the underlying aquifer(s). Initially present in the reduced, ferrous (Fe^{2+}) state, this dissolved iron will remain stable in an anaerobic groundwater environment. However, in the presence of oxygen it will oxidise to become ferric (Fe^{3+}), which will quickly hydrolyse and form insoluble ferric hydroxide. These oxidation and hydrolysis processes are strongly dependant on pH, as reaction rates increase with increased pH concentrations. [7][8]Suspended flocs of ferric hydroxide can cause increased turbidity, decreased light penetration and smothering of benthic organisms.

To address the DPIE/NRAR submission, an investigation was conducted to identify onsite shallow and deep groundwater monitoring wells where monitoring results (current or historic) returned iron concentrations in excess of 20 mg/L. A concentration of 20 mg/L was adopted as this corresponds with the water quality objectives approved for the existing TSP site.

A review of the iron, pH, sulphate, chloride, standing water level and sulfate to chloride ratio data collected from the shallow monitoring bore network and the extraction lake between April 2005 and June 2021 was undertaken to investigate the relationships between the chemical and physical parameters and the observed fluctuations in dissolved iron in the shallow bore network.

The locations of the monitoring bores are depicted in drawing 12035-003. The time span of the assessment reflects the period immediately before Hanson acquired and operated the site (2006) to the most recent monitoring event in June 2021.

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[7] Tuenissen, K. Abrahamse, A. Leijssen, H. *et al.* 'Removal of both dissolved and particulate iron from groundwater'. Drink. Water Eng. Sci. Discuss., 1, 87–115, 2008.

[8] Rusydi, A.F., Onodera, SI., Saito, M. *et al.* 'Vulnerability of groundwater to iron and manganese contamination in the coastal alluvial plain of a developing Indonesian city.' *SN Appl. Sci.* 3, 399 (2021).

The following statistical analyses were performed:

- The relationships or correlations between groundwater quality and lake water quality were assessed using the Kendal's tau correlation. The Kendal's tau was used because the data sets were not normally distributed and the tau has, as part of the assessment, a correction for this data distribution.
- The decision criteria for assessing the statistical significance for a correlation between the data sets was a probability <0.05 (alpha value).
- The assessment of the statistical differences between the data sets was undertaken by a Kruskal Wallis test with the critical differences between the pairs assessed by a Dunn's test with an alpha correction for contrast using a Dunn/Sidak correction.
- Trends analyses were undertaken using a Mann-Kendal trends assessment.

4.1 Statistical assessment of surface and groundwater data sets

A summary of the data used for the Kendal's tau correlation analysis is shown in Table 4.1.1. The full data sets are attached in Appendix 4.

Table 4.1.1 Range median and number of dissolved iron (Fe), pH, sulfate (SO_4), chloride (Cl) and SO_4 to Cl ratio for the lake and shallow monitoring bores from April 2005 to June 2012 at the tweed sands site

Statistical measure	Monitoring location Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
Dissolved iron											
Minimum	0.001	0.01	0.07	0.05	0.05	0.04	0.53	0.007	0.039	0.08	0.026
Maximum	0.547	13.4	13.2	98.3	37.3	58	34.4	13.1	9.5	11.3	35.6
Median	0.05	4.6	1.435	28.75	20.35	6.235	4.31	3.05	4.35	4.01	19.4
Count	40	39	32	36	28	38	32	31	32	29	31
pH											
Minimum	7.04	3.66	5.35	5.63	6.08	5.23	5.22	6.04	6.22	5.84	6.12
Maximum	8.91	9.12	8.55	8.64	8.62	9.33	9.51	8.63	8.95	8.82	9.26
Median	8.39	6.84	6.52	6.72	6.98	6.84	6.16	7.02	7.18	7.02	6.97
Count	40	39	33	36	28	38	31	38	37	33	36
SO_4											
Minimum	130	13	2	16	29	72	1	24	40	41	128
Maximum	407	250	510	537	332	719	650	2140	151	340	1600
Median	216	76	8.7	137	165	233	12.5	110	83	95.9	362
Count	39	39	32	36	28	38	32	31	31	29	31
Cl											
Minimum	343	15	11	15	27	58	13	60	110	96	140
Maximum	900	410	990	160	210	810	216	10600	310	229	10100
Median	613	38	26	47	57	230	26	240	160	150	280
Count	39	39	32	36	28	38	32	31	31	29	31
SO_4:Cl ratio											
Minimum	0.22	0.16	0.11	0.23	0.69	0.33	0.05	0.13	0.16	0.33	0.16
Maximum	0.70	6.25	0.90	10.67	6.24	2.75	30.95	0.65	1.10	1.75	1.79
Median	0.38	1.94	0.24	3.84	2.30	0.91	0.41	0.38	0.47	0.78	1.21
Count	39	39	32	36	28	38	32	31	31	29	31

The Kandall's tau analysis results are depicted as tables arranged in a pairwise manner with the tau as the top right hand side of the table and the calculated probability as the left bottom side of the table. Statistically significant correlations are in bold and the probability values less then 0.05 in red. A positive tau (correlation) means that as one of the pair increases so does the other and conversely as one decreases so does the other. A negative tau (correlation) means that as one of the pair increases the other decreases and conversely as one decreases the other increases. Appendix 4 provides a full summary of the correlation assessments.

4.1.1 Correlation assessment for pH (Kendall's tau)

Table 4.1.1.1 shows the correlations between the bores and lake for pH. With the exception of MB7 there is no statistically relevant correlations (although negative in nature) between the lake and the groundwater bore monitoring network. The lake does have a negative correlation (pr 0.0163) with MB 7 which means as the bore becomes more acidic the lake becomes more alkaline. MB7 is located about 130m east of the lake and within the boundary of the neighbouring Cudgen Lakes Sand Extraction Project. MB7 is significantly more distant from the lake than MB 1, 2, 3, 4 and 5 which are located within approximately 20m of the lake edge. Except for the pair of MB7 and MB9 (tau 02258, pr 0.0918) the monitoring bore network were all positively correlated suggesting that they all increase and decrease in pH together. MB9 is located some 200m west of the lake edge on the boundary of the TSP existing site and is separated from MB7 by the extraction lake.

Table 4.1.1.1 Summary of the correlations using Kendall's tau and calculated probabilities of significance for the associations between the lake and shallow monitoring bore **pH** levels for the monitoring period from April 2005 to June 2021 (bold indicates a statistically significant correlation pr<0.05)

Tau												
Median	8.39	6.84	6.52	6.72	6.975	6.835	6.16	7.015	7.18	7.02	6.97	
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
Lake		-0.164	-0.0721	-0.0016	-0.1173	-0.0271	**-0.3039**	-0.1182	-0.0377	-0.0476	-0.016	Lake
MB1b	0.1416		**0.3708**	**0.3497**	**0.4459**	**0.469**	**0.3268**	**0.4608**	**0.4428**	**0.3244**	**0.6288**	MB1b
MB2b	0.5553	0.0029		**0.4186**	**0.3199**	**0.541**	**0.3704**	**0.2603**	**0.2584**	**0.639**	**0.3445**	MB2b
MB3	0.9891	0.0031	0.0008		**0.6619**	**0.4556**	**0.4245**	**0.5135**	**0.2612**	**0.4864**	**0.4102**	MB3
MB4	0.3809	0.0009	0.0219	0.		**0.5216**	**0.3154**	**0.6542**	**0.5062**	**0.4836**	**0.5202**	MB4
MB5b	0.8104	0.	0.	0.00015	0.0001		**0.3626**	**0.4083**	**0.5693**	**0.5462**	**0.6049**	MB5b
MB7	0.0163	0.0098	0.0048	0.00099	0.0271	0.0049		**0.2935**	0.2258	**0.3783**	**0.3582**	MB7
MB8a	0.296	0.0001	0.0363	0.00001	0.	0.0005	0.0254		**0.4976**	**0.4453**	**0.3821**	MB8a
MB9a	0.7428	0.0001	0.045	0.03261	0.0003	0.	0.0918	0.		**0.4422**	**0.4818**	MB9a
MB10a	0.6971	0.008	0.	0.00021	0.0005	0.	0.0067	0.0003	0.0004		**0.4143**	MB10a
MB11a	0.891	0.	0.0087	0.00097	0.0002	0.	0.0088	0.0012	0.	0.0011		MB11a
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
p-value												

4.1.2 Statistical difference assessment for pH (Kruskall Wallace and Dunn's test)

Table 4.1.2.1 (next page) outlines the statistical differences between the extraction lake and monitoring bores. The lake pH is statistically different to all bores. The shallow monitoring bores show a mixed response amongst each other with:

- MB1 different to MB9;
- MB2 different to MB 4,5,8,9,10 and 11;
- MB3 different to MB8,9 and 10;
- MB4 and 5 different to MB2 and MB7;
- MB7 different to MB8 and 11; and
- MB11 different to 9.

The results do not indicate a consistent pattern in groundwater pH and spatial distribution within the landscape.

Both the correlation analysis (Kendall's tau) and the results of the Kruskal Wallis and Dunn's test suggest the extraction lake and shallow groundwater environment behave independently in terms of pH.

Table 4.1.2.1 Summary probabilities of the contrasts between the lake and shallow groundwater monitoring bores' **pH** based on a Kruskal Wallis and Dunn's tests with statistically significant differences between pairs of the monitoring locations as bold (decision criteria pr<0.05)

		Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
	Median	8.39	6.84	6.52	6.72	6.975	6.835	6.16	7.015	7.18	7.02	6.97
Lake	8.39		**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0002**	**0.0000**	**0.0000**
MB1b	6.84	**0.0000**		0.2883	0.6342	0.1254	0.3247	0.0886	0.0861	**0.0013**	0.0663	0.2533
MB2b	6.52	**0.0000**	0.2883		0.558	**0.0141**	**0.0456**	0.526	**0.0069**	**0.**	**0.0054**	**0.0325**
MB3	6.72	**0.0000**	0.6342	0.558		0.052	0.1504	0.2212	**0.0312**	**0.0003**	**0.0239**	0.1125
MB4	6.975	**0.0000**	0.1254	**0.0141**	0.052		0.5333	**0.0025**	0.9628	0.1504	0.8313	0.6465
MB5b	6.835	**0.0000**	0.3247	**0.0456**	0.1504	0.5333		**0.0088**	0.4673	0.0257	0.3778	0.8649
MB7	6.16	**0.0000**	0.0886	0.526	0.2212	**0.0025**	**0.0088**		**0.0009**	**0.**	**0.0007**	**0.006**
MB8a	7.015	**0.0000**	0.0861	**0.0069**	**0.0312**	0.9628	0.4673	**0.0009**		0.1312	0.8562	0.5845
MB9a	7.18	**0.0002**	**0.0013**	**0.**	**0.0003**	0.1504	0.0257	**0.**	0.1312		0.202	**0.0421**
MB10a	7.02	**0.0000**	0.0663	**0.0054**	**0.0239**	0.8313	0.3778	**0.0007**	0.8562	0.202		0.480
MB11a	6.97	**0.0000**	0.2533	**0.0325**	0.1125	0.6465	0.8649	**0.006**	0.5845	**0.0421**	0.480	

4.1.3 Correlation assessment for Dissolved iron (Kendall's tau)

Table 4.1.3.1 shows the correlations between the bores and extraction lake for dissolved Fe. Except for MB10 (where a negative correlation exists), there are no statistically relevant correlations between the lake and the shallow groundwater bores. The negative correlation between the lake and MB10 (pr 0.0076) indicates that as the dissolved Fe concentration in groundwater increases (at this location), lake Fe levels decrease. MB10 is located about 380 m north-west of the lake and on the existing TSP site boundary. Between the extraction lake and MB10, bores MB1 and MB2 are located and neither shows a correlation. Dissolved Fe concentrations appear to change in a consistent manner (both up and down) across most of the monitoring network with the notable exception of MB2, and to a lesser extent MB7. Bore MB2 shows a positive correlation with MB5, 7 and 10a.

Table 4.1.3.1 Summary of correlations using Kendall's tau and calculated probabilities of significance for the associations between the lake and shallow monitoring bores **Dissolved iron (Fe)** concentration for the April 2005 to June 2021 monitoring period (bold indicates a statistically significant correlation pr<0.05).

Tau												
Median (mg/L)	0.05	4.6	1.435	28.75	20.35	6.235	4.31	3.05	4.35	4.01	19.4	
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
Lake		-0.0806	-0.2178	-0.1423	0.0428	-0.0154	-0.1891	-0.1073	-0.044	**-0.3504**	-0.1118	Lake
MB1b	0.47		0.2211	**0.3159**	**0.3936**	**0.4307**	0.2071	**0.3894**	**0.3668**	**0.5123**	**0.5230**	MB1b
MB2b	0.0798	0.0753		0.1922	0.1612	**0.2916**	**0.479**	0.1091	-0.0619	**0.4436**	0.1786	MB2b
MB3	0.2222	0.0076	0.1287		**0.4635**	**0.4419**	0.2411	0.2523	**0.4628**	**0.5309**	**0.4499**	MB3
MB4	0.7494	0.0033	0.2481	0.0007		**0.4521**	**0.3183**	**0.4134**	**0.5546**	**0.4991**	**0.4234**	MB4
MB5b	0.892	0.0002	0.0212	0.0002	0.0009		**0.4392**	**0.3822**	**0.4585**	**0.4974**	**0.5943**	MB5b
MB7	0.1283	0.1016	0.0003	0.0567	0.0258	0.0005		0.1743	0.16	**0.4113**	0.198	MB7
MB8a	0.3963	0.0025	0.4552	0.0595	0.0038	0.0036	0.2443		**0.4946**	**0.4053**	**0.6166**	MB8a
MB9a	0.7237	0.0037	0.6716	0.0005	0.0001	0.0004	0.2734	0.0001		**0.3486**	**0.6054**	MB9a
MB10a	0.0076	0.0001	0.003	0.0002	0.0006	0.0002	0.0074	0.0025	0.0079		**0.4828**	MB10a
MB11a	0.3769	0.	0.2328	0.001	0.0038	0.	0.1858	0.	0.	0.0003		MB11a
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
p-value												

4.1.4 Statistical difference assessment for dissolved iron (Kruskall Wallace and Dunn's test)

Table 4.1.4.1 outlines the statistical differences between the extraction lake and monitoring bores. The lake dissolved iron levels are statistically different to all shallow groundwater bores. The shallow monitoring bores show a mixed response amongst each other with:

- MB1 different to bores MB2 and 7;
- MB different to MB2 and 5;
- MB 3 different to all except MB2 and 4;
- MB4 being different to MB1, 2, 8, 9 and 10;
- MB5 different to MB2;
- MB7 different to MB3;
- MB8 different to MB3, 4 and 11;
- MB9 different to MB3, 4 and 11 and
- MB10 different to MB3 and 4.

The results do not indicate a consistent pattern in groundwater dissolved iron levels and their spatial distribution within the landscape.

Table 4.1.4.1 Summary probabilities of the contrasts between the lake and shallow groundwater monitoring bores' **dissolved iron (Fe)** based on a Kruskal Wallis and Dunn's tests with statistically significant differences between pairs of the monitoring locations as bold (decision criteria pr<0.05)

			MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
	Median (mg/L)	0.05	4.6	1.435	28.75	20.35	6.235	4.31	3.05	4.35	4.01	19.4
Lake	0.05		**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**	**0.0000**
MB1b	4.6	**0.0000**		0.4744	**0.0001**	**0.0287**	0.1851	0.1895	0.7337	0.7564	0.8926	0.0713
MB2b	1.435	**0.0000**	0.4744		0.	**0.0059**	**0.0488**	0.0531	0.7246	0.699	0.5917	**0.0164**
MB3	28.75	**0.0000**	**0.0001**	0.		0.1237	**0.007**	**0.0111**	**0.**	**0.**	**0.0001**	**0.043**
MB4	20.35	**0.0000**	**0.0287**	**0.0059**	0.1237		0.3354	0.3761	**0.0167**	**0.0173**	**0.03**	0.6787
MB5b	6.235	**0.0000**	0.1851	**0.0488**	**0.007**	0.3354		0.9638	0.1127	0.1171	0.1741	0.5856
MB7	4.31	**0.0000**	0.1895	0.0531	**0.0111**	0.3761	0.9638		0.1172	0.1217	0.1771	0.631
MB8a	3.05	**0.0000**	0.7337	0.7246	**0.**	**0.0167**	0.1127	0.1172		0.9751	0.8504	**0.0423**
MB9a	4.35	**0.0000**	0.7564	0.699	**0.**	**0.0173**	0.1171	0.1217	0.9751		0.8734	**0.0438**
MB10a	4.01	**0.0000**	0.8926	0.5917	**0.0001**	**0.03**	0.1741	0.1771	0.8504	0.8734		0.071
MB11a	19.4	**0.0000**	0.0713	**0.0164**	**0.043**	0.6787	0.5856	0.631	**0.0423**	**0.0438**	0.071	

4.1.5 Correlation assessment between pH and dissolved iron (Kendall's tau)

The examination of dissolved iron and pH relationships was undertaken using the Kendall's tau analysis as summarised in Table 4.1.5.1 (following page). It was expected that a significant negative correlation would be observed between dissolved iron and pH because the solubility of iron or the form Fe^{2+} is related to the production of acid conditions or low pH. With the exception of monitoring bore MB2 there was no correlation between the measured pH and the dissolved iron concentrations.

The concentration of MB2 with a maximum of 13.2mg/L and most acid pH of 5.35 seems to be relatively low compared to bores MB3, 4, 5,7 and 11 with maximum dissolved iron concentrations of 98.3, 37.3, 58, 34.4, and 35.6mg/L respectively. These high dissolved iron bores had no correlation between dissolved iron and pH (Table 4.1.5.1).

Table 4.1.5.1 Summary of correlations using Kendall's tau between dissolved iron (Fe) and pH concentrations for the lake and shallow monitoring bores (bold indicates a statistically significant correlation pr<0.05).

VAR vs. VAR	N	Tau	Inversions	Z	p-value
Lake D Fe vs. lake Ph	40	0.0513	74	0.4665	0.6409
MB1b D Fe vs. MB1b Ph	39	-0.0665	-98	0.596	0.5512
MB2b D Fe vs. MB2b Ph	32	**-0.4332**	-428	3.4844	0.0005
MB3 D Fe vs. MB3 Ph	36	-0.1578	-198	1.3538	0.1758
MB4 D Fe vs. MB4 Ph	28	-0.0588	-44	0.4393	0.6604
MB5b D Fe vs. MB5b Ph	38	-0.2157	-302	1.9065	0.0566
MB7 D Fe vs. MB7 Ph	31	-0.2239	-208	1.7695	0.0768
MB8a D Fe vs. MB8a Ph	31	-0.1683	-156	1.33	0.1835
MB9a D Fe vs. MB9a Ph	31	0.0347	32	0.274	0.7841
MB10a D Fe vs. MB10a Ph	29	-0.2129	-172	1.6212	0.1050
MB11a D Fe vs. MB11a Ph	31	0.0043	4	0.0343	0.9727

Although the resolution in the data set is coarse at a six monthly interval, the large number of sample events (between 29 and 40 for each location) strengthens the analysis and lends weight to the findings. The correlation-based analysis and the results of the Kruskal Wallis and Dunn's test suggests the lake (that contains the Hanson operations) and the bores behave independently in terms of the dissolved iron (Fe) and the landform groundwater pH. The assessment shows no clear pattern in the distribution of the dissolved iron in the landform that may be related to the presence of the lake or activities in it.

4.1.6 Correlation assessment for chloride (Kendall's tau)

Table 4.1.6.1 shows the correlations between the bores and lake for Chloride (Cl). With the exception of MB10 there are no statistically relevant correlations between the lake and the groundwater bore monitoring network. The lake does have a positive correlation (pr <0.0001) with MB10 which means as the bore chloride concentration increases the lake chloride concentrations also increase. MB10 is located about 380m north-west of the lake and on the existing site boundary. Between the lake and MB10 are bores MB1 and MB2 both of which show no correlation. The monitoring bore network shows no consistent pattern in the fluctuation of chloride concentrations with few correlations between the bores.

Table 4.1.6.1 Summary of the correlations using Kendall's tau and calculated probabilities of significance for the associations between the lake and shallow monitoring bores **Chloride** concentration for the monitoring period from April 2005 to June 2021 on Tweed Sands Site (bold indicates a statistically significant correlation pr<0.05).

						Tau						
Median	613	38	26	47	57	230	26	240	160	150	280	
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
Lake		-0.0143	-0.2113	0.149	-0.0027	-0.1717	0.1198	0.0324	0.2167	**0.5636**	-0.0477	Lake
MB1b	0.8995		**0.2441**	**0.3229**	0.0347	0.1013	0.1093	**0.3503**	-0.0745	0.1777	**0.3399**	MB1b
MB2b	0.0949	0.0496		**0.276**	**0.4194**	-0.0827	-0.1538	-0.0956	**0.3253**	0.1495	0.0485	MB2b
MB3	0.2079	0.0064	0.0291		0.1643	-0.0628	0.0785	**0.3178**	0.0661	**0.3458**	0.1647	MB3
MB4	0.9841	0.7955	0.0027	0.2294		-0.1576	-0.1559	**-0.2886**	**0.5865**	0.1985	-0.1685	MB4
MB5b	0.1348	0.3776	0.5134	0.6013	0.2488		0.0501	0.1485	-0.2192	-0.1828	0.1968	MB5b
MB7	0.3436	0.3877	0.2413	0.5349	0.2746	0.6921		**0.3206**	-0.2093	**0.349**	0.1008	MB7
MB8a	0.7979	0.0065	0.5128	0.0176	0.0432	0.258	0.0322		**-0.4107**	0.0804	**0.4715**	MB8a
MB9a	0.0868	0.5631	0.0297	0.6287	0.0001	0.0951	0.162	0.0014		**0.2746**	**-0.2887**	MB9a
MB10a	0.0000	0.1759	0.3178	0.0154	0.1741	0.1722	0.023	0.5481	0.0403		-0.0567	MB10a
MB11a	0.7064	0.0083	0.746	0.228	0.2487	0.134	0.5006	0.0003	0.0251	0.6721		MB11a
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
						p-value						

4.1.7 Correlation assessment for sulfate (Kendall's tau)

Table 4.1.7.1 shows the correlation between the sulfate concentrations of the shallow groundwater bores and the extraction lake. The lake shows a positive correlation with MB3, 9 and 10 and a negative correlation with MB11. Bore MB 3 is located on the lakes edge while bores MB9, 10 and 11 are placed at a distance on the boundary of the existing site. Bores MB1 and MB2 are located on the lakes edge between the lake and Bores MB9 and 10 and show no correlation with concentrations of sulfate in the extraction lake. The shallow groundwater bores show no consistent pattern in the fluctuations of sulfate concentration with few correlations found between the bores.

Table 4.1.7.1 Summary of the correlations using Kendall's tau and calculated probabilities of significance for the associations between the lake and shallow monitoring bores **Sulfate** concentration for the monitoring period from April 2005 to June 2021 on Tweed Sands Site (bold indicates a statistically significant correlation pr<0.05).

	Tau											
Median (mg/L)	216	76	8.7	137	165	233	12.5	110	83	95.9	362	
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
Lake		0.09721	0.1884	**0.337**	0.191	-0.1668	0.0912	-0.184	**0.3064**	**0.5136**	**-0.3634**	Lake
MB1b	0.3902		0.0971	0.1968	0.0588	0.1118	0.1882	**0.4592**	-0.0928	0.1194	0.1458	MB1b
MB2b	0.1364	0.4347		0.244	0.1541	-0.0131	0.0609	-0.219	**-0.3347**	-0.247	-0.2021	MB2b
MB3	0.0044	0.0964	0.0538		0.6332	-0.0645	0.0414	**-0.3155**	-0.2034	0.1946	-0.2575	MB3
MB4	0.1538	0.6604	0.2696	0.		-0.0572	-0.223	-0.2416	-0.2514	0.1606	-0.1455	MB4
MB5b	0.1463	0.3302	0.9173	0.5919	0.6754		0.1022	0.0075	-0.2129	-0.0505	-0.0567	MB5b
MB7	0.471	0.1369	0.6427	0.7433	0.1182	0.4194		0.0401	0.2004	0.2851	-0.1634	MB7
MB8a	0.1459	0.0004	0.1339	0.0185	0.0905	0.9547	0.7888		0.0394	-0.0747	**0.382**	MB8a
MB9a	0.0155	0.4714	0.0253	0.1366	0.0853	0.105	0.1806	0.7595		**0.3191**	-0.0738	MB9a
MB10a	0.0001	0.3632	0.0989	0.1727	0.2716	0.7063	0.0633	0.5771	0.0172		**-0.382**	MB10a
MB11a	0.0041	0.2577	0.177	0.0595	0.3194	0.6658	0.2751	0.003	0.5667	0.0043		MB11a
	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a	
	p-value											

4.1.8 Correlation assessment between sulfate and chloride (Kendall's tau)

The concentrations of sulfate and chloride in the extraction lake and shallow groundwater are relatively low compared to the saline deeper groundwater and the estuarine conditions of the Tweed River, and as such the reliability of the sulfate to Chloride ratio as an indicator of the acidifying events or potential for an acidifying event is diminished (Sullivan et al 2018 page 19).[9] Nevertheless, Table 4.1.8.1 suggests that the lake has a low potential for acidification as does MB2, MB8 and MB9. Similarly, the pH range and median values indicate that such events may be limited for all the bores in the monitoring network.

Table 4.1.8.1 Summary showing range, median and number of samples for the calculated SO_4 to Cl ratio and pH for sample dates from April 2005 to June 2021 at the Tweed Sands site.

	Monitoring location										
Statistical measure	lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
Minimum	0.22	0.16	0.11	0.23	0.69	0.33	0.05	0.13	0.16	0.33	0.16
Maximum	0.70	6.25	0.90	10.67	6.24	2.75	30.95	0.65	1.10	1.75	1.79
Median	0.38	1.94	0.24	3.84	2.30	0.91	0.41	0.38	0.47	0.78	1.21
Count	39	39	32	36	28	38	32	31	31	29	31

9 Sullivan, L, Ward, N, Toppler, N and Lancaster, G 2018, National Acid Sulfate Soils guidance: National acid sulfate soils sampling and identification methods manual, Department of Agriculture and Water Resources, Canberra ACT. CC BY 4.0.

pH											
Minimum	7.04	3.66	5.35	5.63	6.08	5.23	5.22	6.04	6.22	5.84	6.12
Maximum	8.91	9.12	8.55	8.64	8.62	9.33	9.51	8.63	8.95	8.82	9.26
Median	8.39	6.84	6.52	6.72	6.98	6.84	6.16	7.02	7.18	7.02	6.97
Count	40	39	33	36	28	38	31	38	37	33	36

The correlations for each sample site for the sulfate and chloride concentrations are summarised in Table 4.1.8.2 below. The lake and MB4, 5, 7, 8 and 10 indicate a unform increase in both sulfate and chloride which suggests the changes are more due to saline water intrusion to the bores and lake rather than some imbalance in the ratios of the ions.

Table 4.1.8.2 Summary of correlations using Kendall's tau between Sulfate and Chloride concentrations for the lake and shallow monitoring bores (bold indicates a statistically significant correlation pr<0.05).

VAR vs. VAR	N	Tau	Inversions	Z	p-value
Lake SO4 vs. Lake Cl	39	**0.2917**	432.	2.6147	0.0089
MB1b SO4 vs. MB1b Cl	39	0.2139	314.	1.9173	0.0552
MB2b SO4 vs. MB2b Cl	32	0.2075	200.	1.6688	0.0952
MB3 SO4 vs. MB3 Cl	36	0.0929	116.	0.7976	0.4251
MB4 SO4 vs. MB4 Cl	28	**0.3040**	228.	2.2703	0.0232
MB5b SO4 vs. MB5b Cl	38	**0.4625**	648.	4.0878	0.
MB7 SO4 vs. MB7 Cl	32	**0.4964**	482.	3.9927	0.0001
MB8a SO4 vs. MB8a Cl	31	**0.7470**	688.	5.9039	0.
MB9a SO4 vs. MB9a Cl	31	0.0651	60.	0.5149	0.6066
MB10a SO4 vs. MB10a Cl	29	**0.3970**	318.	3.0236	0.0025
MB11a SO4 vs. MB11a Cl	31	0.5693	526.	4.4992	0.

4.1.9 Correlation assessment between dissolved iron and sulfate concentrations (Kendall's tau)

The assessment of the correlations between dissolved iron and the sulfate concentrations are shown in Table 4.1.9.1 below. The response is mixed with bores MB3,4 and 9 showing a negative correlation meaning as dissolved iron decreases sulfate decreases whilst MB 5, 7 and 11 show the opposite. The remainder of the sample locations show no correlation at all.

Table 4.1.9.1 Summary of correlations using Kendall's tau between dissolved iron (Fe) and sulfate concentrations for the lake and shallow monitoring bores on Tweed Sands Site (bold indicates a statistically significant correlation pr<0.05).

VAR vs. VAR	N	Tau	Inversions	Z	p-value
Lake SO4 vs. lake D Fe	39	0.1392	192	1.2476	0.2122
MB1b SO4 vs. MB1b D Fe	39	0.0014	2	0.0122	0.9903
MB2b SO4 vs. MB2b D Fe	32	**-0.2819**	-274	2.2676	0.0234
MB3 SO4 vs. MB3 D Fe	36	**-0.2761**	-346	2.3696	0.0178
MB4 SO4 vs. MB4 D Fe	28	-0.0133	-10	0.0994	0.9208
MB5b SO4 vs. MB5b D Fe	38	**0.4060**	570	3.5881	0.0003
MB7 SO4 vs. MB7 D Fe	32	**0.3177**	312	2.5557	0.0106
MB8a SO4 vs. MB8a D Fe	31	0.2148	198	1.6973	0.0896
MB9a SO4 vs. MB9a D Fe	31	**-0.2768**	-256	2.1873	0.0287
MB10a SO4 vs. MB10a D Fe	29	-0.2370	-192	1.8052	0.0710
MB11a SO4 vs. MB11a D Fe	31	**0.3384**	314	2.6742	0.0075

4.1.10 Correlation assessment between dissolved iron and groundwater level (Kendall's tau)

The assessment of the impact of a falling water table was estimated by examining the correlation between the measured standing water level (as a near surface level (NSL)) and dissolved iron. The logic of this assessment was based on the assumption that if the water table falls there will be an oxidising event causing some pH changes resulting in an increase in dissolved iron. Only Bores MB2 and MB3 showed an increasing dissolved iron concentration with a lowering of the water table. There were no other sites that showed any significant correlation. Both MB2 and MB3 are positioned on the edge of the lake and it is likely the water level in these bores changes with the lake level. However, bores MB1, 5 and 4 are also in a similar location and showed no such response.

Table 4.1.10.1 Summary of correlations using Kendall's tau between dissolved iron (Fe) and bore standing water level (NSL) concentrations for the lake and shallow monitoring bores (bold indicates a statistically significant correlation pr<0.05).

VAR vs. VAR	N	Tau	Inversions	Z	p-value
MB1b D Fe vs. MB1B SWL	37	0.1771	234	1.543	0.1228
MB2b D Fe vs. MB2B SWL	31	**0.2736**	252	2.1625	0.0306
MB3 D Fe vs. MB3 SWL	35	**0.2975**	352	2.5142	0.0119
MB4 D Fe vs. MB7 SWL	27	-0.1239	-86	0.9068	0.3645
MB5b D Fe vs. MB5B SWL	37	0.0697	92	0.6071	0.5438
MB7 D Fe vs. MB7 SWL	31	0.2119	196	1.6747	0.0940
MB8a D Fe vs. MB8a SWL	30	-0.0670	-58	0.5198	0.6032
MB9a D Fe vs. MB9a SWL	31	0.0260	24	0.2055	0.8372
MB10a D Fe vs. MB10a SWL	29	-0.1290	-104	0.9827	0.3258
MB11a D Fe vs. MB11a SWL	31	0.0806	74	0.6371	0.5241

4.1.11 Trends analysis for dissolved iron (Mann-Kendall)

The Mann-Kendall trends assessment was used to assess the changes over time of the dissolved iron concentrations in the shallow monitoring bores and the extraction lake.

The April 2005 to June 2021 trends (see Table 4.1.11.1) indicate decreasing dissolved iron concentrations within the extraction lake whilst each of the bores show an increasing trend in dissolved iron concentrations.

Table 4.1.11.1 Summary of Mann-Kendall trend assessment of dissolved iron (Fe) for the monitoring bores (1 to 11) and the lake from April 2005 to June 2021

Parameter	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
Coefficient of variation	1.43	0.88	1.15	0.85	0.79	1.17	1.14	1.00	0.80	.093	0.89
Mann-K statistic	-147	176	217	267	89	264	130	113	113	192	213
Confidence factor (%)	95.6	98.4	>99.9	>99.9	95.9	>99.9	98.2	97.2	96.6	>99.9	>99.9
Trend (I = increasing; D = decreasing; S = stable)	D	I	I	I	I	I	I	I	I	I	I

If the analysis is pruned to the Environmental Protection Licence requirement of retaining the previous 4 years of data only, the trends assessment as outlined in Table 4.1.11.2 (following page) is very different showing the trends in the shallow groundwater to be either decreasing, stable or no trend.

Table 4.1.11.2 Summary of Mann-Kendall trend assessment of dissolved iron (Fe) for the monitoring bores (1 to 11) and the lake from March 2015 to June 2021

Parameter	Lake	MB1b	MB2b	MB3	MB4	MB5b	MB7	MB8a	MB9a	MB10a	MB11a
Coefficient of variation	1.47	0.64	0.67	0.52	0.54	0.79	0.95	0.63	0.57	0.46	0.54
Mann-K statistic	-24	-17	7	-5	-26	-9	9	-27	-21	-5	-22
Confidence factor (%)	96.4	89.1	67.6	61.9	97.5	72.9	72.9	98.0	94.0	61.9	97.1
Trend (I = increasing; D = decreasing; S = stable)	D	S	No trend	S	D	S	No trend	D	Probably D	S	D

Although this appears to be a developing improvement such fluctuations are not unusual for the larger data set collected from 2005 to 2021.

Figure 1 below shows the timeseries plot of dissolved iron for the full data set and demonstrates a similar decline in iron concentrations from April 2013 to September 2016, and again from September 2010 to September 2012.

The full data set and summary table for both Mann-Kendall trends assessment described above are attached in Appendix 4.

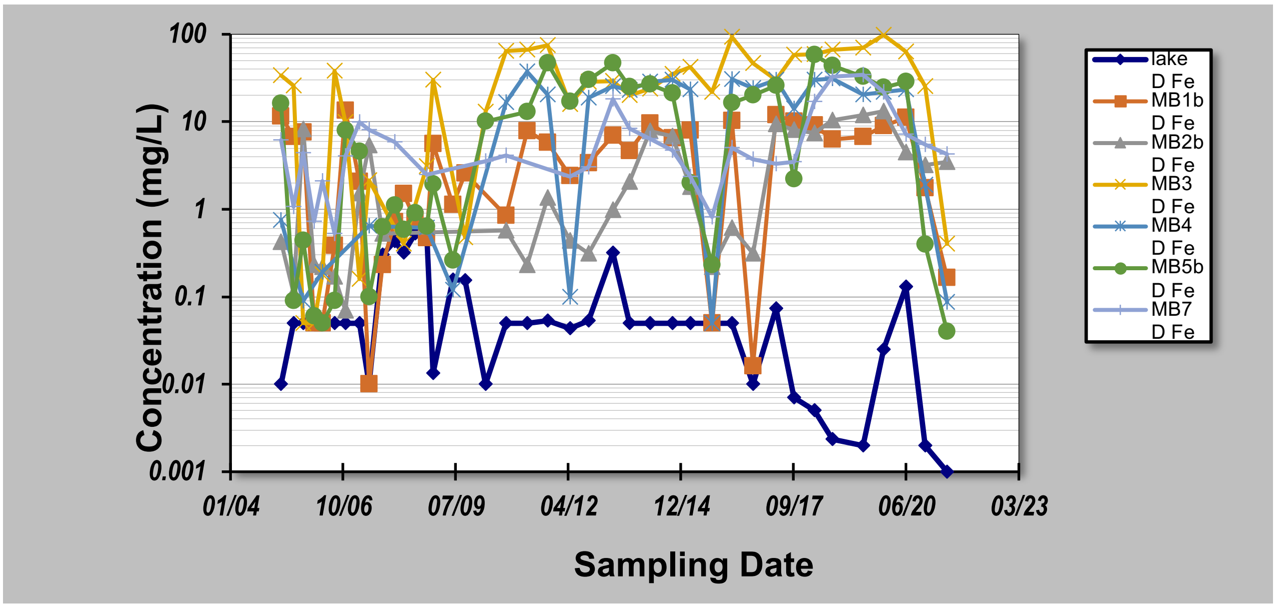

Figure 1 Plot of dissolved iron concentrations in the extraction lake and shallow monitoring bores from April 2005 to June 2021

4.2 Findings of the statistical analysis

The data analysis detailed in the previous sections indicates there are no consistent patterns or correlations between the presence of dissolved iron in the groundwater and the conditions encountered within the TSP extraction lake. Nor can any temporal changes in iron concentrations be linked in a meaningful way to the ongoing dredging and sand removal from the lake under present and historical conditions.

There appears to be no link between the chemical characteristics of the lake and the surrounding shallow groundwater in the monitoring bores. The iron detected in the monitoring network is likely to be related to some other processes separate to those associated with the sand extraction at the Tweed sands site, for instance:

- the existing and still operating agricultural drainage system,
- maintenance works on the agricultural drainage system which have been observed periodically,
- neighbouring sand extractions,
- dewatering from other construction projects including the neighbouring TSC Sewage Treatment Works and neighbouring sand extraction project,
- seasonal fluctuations in rainfall and associated fluctuations of the groundwater table,
- relic events that move through the groundwater from time to time in response to climate (drought, rain, floods or tides).

The expansion of the lake will, in all likelihood, intercept the dissolved iron within the groundwater as the works proceed. The historical surface and groundwater data indicates that the site has experienced pervious time periods where dissolved iron was present in the groundwater with no associated change in the iron concentrations of the lake. The performance of the lake chemistry thus far indicates that the lake is of sufficient size to buffer/mitigate any changes in dissolved iron in the landform without significantly altering the water chemistry of the extraction lake. As the proposed expansion will continue to extract and process sand in much the same way as the existing TSP operation, the past environmental performance of the area provides a robust indication of the ongoing behaviour of the surface and groundwater environments into the future.

4.2.1 Environmental impacts and GDEs

Dissolved iron in groundwater is included in the site's monitoring suite due to its known toxicity for aquatic ecosystems and its usefulness as an indicator for the success or otherwise of acid sulfate soil management. With respect to aquatic ecosystems, increased concentrations of ferrous iron (Fe^{2+}) can fix to alkaline gill surfaces of aquatic animals causing epithelial damage and interference of respiration. While iron bacteria present in water with high iron concentrations can colonise fish gills, or cause tissue damage when ingested. (10)(11)

High iron availability can also lead to toxicity in plants, where excessive iron uptake causes damage to cell structures, or through iron precipitate on root structures.[12] The presence of iron staining in the form of iron bacteria would additionally indicate elevated iron concentrations.

Recent aquatic macroinvertebrate studies (including electrofishing) within the TSP extraction lake[13] indicated a large variety of fish species with a total of 970 fish from 16 species recorded in the extraction lake. The study concluded that:

> *'the aquatic macroinvertebrate and fish assemblages in the Tweed Sands lake were relatively diverse and abundant and represented a healthy aquatic ecological community'.*

Intermittent iron staining has been observed within the agricultural drainage line located on the southern side of Altona Road. However, the timing of these observations coincided with drainage and dewatering works conducted at the neighbouring Cudgen Sand Extraction Project site from 2017 (discussed in more detail below). Otherwise, the above indicators of environmental impacts related to elevated iron concentrations

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[10] A. Slaninova, J. Machova, Z. Svobodova 'Fish kill caused by aluminium and iron contamination in a natural pond used for fish rearing: a case report' Veterinarni Medicina 59, 2014 (11): 573-581.

[11] Ding, X. Song, L. Han, Y. et al. 'Effects of Fe3+ on Acute Toxicity and Regeneration of Planarian (Dugesia japonica) at Different Temperatures'. BioMed Research International Vol. 2019, Article ID8591631, 9 pages, 2019.

[12] Saaltink, Rémon & Dekker, Stefan & Eppinga, Maarten & Griffioen, Jasper & Wassen, Martin. (2017). 'Plant-specific effects of iron-toxicity in wetlands'. Plant and Soil. 416. 10.1007/s11104-017-3190-4.

[13] Freshwater Ecology (July 2020). Tweed Sands Fish and Aquatic Macroinvertebrate Assessment.

within the site groundwater have not been observed by site personnel, or environmental scientists conducting regular environmental monitoring activities throughout the site.

With respect to potential impacts on GDE's, G&S drawings numbered 12035-101 to 12035-104 contained in Appendix 1 show the site in its regional context and its proximity to mapped GDEs. This mapping exercise indicated the presence of a 'High Potential Terrestrial GDE' on the northern perimeter of the expansion area and a 'Low Potential terrestrial GDE' adjacent to the southern boundary of the expansion footprint west of Lot 1 on DP1250570.

The high potential GDE is located partly within the development footprint and as such a portion of this vegetation community is proposed to be removed. The remaining vegetation would be incorporated into the lake's riparian area which would be rehabilitated as part of the site's overall rehabilitation and landscaping plans. The low potential GDE located adjacent to the southern boundary of the expansion footprint will also be incorporated into the lakes riparian buffer which has been expanded in this vicinity to reduce modelled groundwater drawdown impacts in this locale.[14]

Whilst supplementary groundwater modelling does indicate between 0.1m and 0.5m of drawdown could occur within the mapped low-potential GDE, the magnitude of impacts is within the range of natural seasonal variation and is thus unlikely to cause significant changes to groundwater chemistry in the locale. In addition, the site's comprehensive water quality data set and the statistical analyses presented in this report indicate that the size of the lake is such that it acts a stabilising feature to the local surface and groundwater environments and buffers/mitigates against significant changes in water chemistry.

4.2.2 Groundwater drawdown events

The Cudgen Lakes Sand Extraction Project is located to the east of the Hanson Tweed Sand Plant and commenced operations on 13 September 2016. It commenced dewatering works and sand extraction in 2017. The 2017-2018 Annual Review for that operation described groundwater drawdown within the site and immediate surrounds which occurred as a consequence of the dewatering activities, indicating that the drawdown extended 500 m to the west of the Cudgen Lakes property and into the Hanson Tweed Sand Plant site boundary, as well as 300 m to the north and east of the Cudgen Lakes site.[15]

The shallow groundwater monitoring well MB7 is located to the east of the Hanson Tweed Sand Plant (see drawings in Appendix 1) within the Cudgen Lakes property and the affected drawdown area. Analysis was performed comparing groundwater levels and associated iron concentrations from data collected at this groundwater monitoring well from July 2009 through to June 2021, with results indicating a correlation between the reduced groundwater levels recorded through 2017, and increased iron concentrations (see plots in Appendix 4).

Analysis was also performed comparing pH concentrations and associated iron concentrations from data collected at MB7 during the same time period. A correlation between pH and iron concentrations has been previously outlined. However this analysis outlined relatively stable pH concentrations, coinciding with a significant increase in iron concentrations (Appendix 4).

The correlation between the reduced groundwater levels and increased iron concentrations more strongly supports the causation of iron fluctuations. Furthermore, increased iron concentrations were also observed through surface and groundwater monitoring undertaken at the Cudgen Lakes site as reported within the 2017 – 2018 Annual Review for that site.

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[14] Gilbert & Sutherland (2021). Supplementary Groundwater Model Report, Tweed Sand Plant Expansion, Cudgen, New South Wales.

[15] *Gales-Kingscliff, Annual Review for the Cudgen Lakes Sand Quarry, 1 July 2017 to 30 June 2018* prepared by R.W. Corkery & Co. Pty Ltd.

5 Conclusions

This supplementary report was prepared to respond to items 3.1 a), b) and c) as contained in the NRAR/DPIE Water submission. This report provides further information and assessment to directly assess the relevant minimal impact considerations, and respond to the queries relating to iron and salinity within the site's waters.

The Aquifer Interference Policy 2012 was reviewed with respect to the proposed TSP Expansion. The Policy requires the Proponent to ensure that '*no more than minimal harm will be done to any water source, or its dependent ecosystems, as a consequence of its being interfered with in the course of the activities to which the approval relates'*.

The impacts of the Project with respect to water table elevation, water pressure and water quality have been directly assessed in this report. This assessment indicates that no more than 'minimal harm' is predicted to occur as a result of the Project in accordance with the relevant criterion.

Various statistical analyses of salinity in the extraction lake and groundwater environment were undertaken to assess the potential salinity risks of the project. The analyses indicated that:

- EC concentrations within the extraction lake and long-term trends within this water body are well defined.
- EC levels within the extraction lake are stable with one of the three monitoring locations indicating a decreasing EC trend.
- It is well established that the elevated salinity in the site's deep (~20 m) groundwaters is associated with regional estuarine conditions in the Tweed River and ultimately the Pacific Ocean.
- As the TSP lake expands it will continue to assimilate shallow and deep groundwaters into the waterbody.
- The stable EC trends observed over the long history of monitoring at the site are anticipated to continue throughout the expansion of the site. Monitoring and ongoing assessment of EC is proposed to continue at all surface and groundwater monitoring locations throughout the site and expansion area.

With respect to dissolved iron concentrations in the groundwater and associated risks, the data analysis presented herein indicated:

- No consistent patterns or correlations between the presence of dissolved iron in the groundwater and the conditions encountered within the TSP extraction lake. Any temporal changes in iron concentrations cannot be definitively attributed to the ongoing dredging and sand processing activities at the site under present and/or historical conditions.
- There appears to be no link between the chemical characteristics of the lake and the surrounding shallow groundwater in the monitoring bores.
- These findings are supported by the G&S report entitled 'Revised Water Balance Modelling, Tweed Sand Plant Expansion, Cudgen, New South Wales October 2021', which indicates that the extraction lake typically operates as a groundwater recharge window whereby waters seep from the lake to the groundwater environment rather than groundwaters seeping into the lake.
- The expansion of the lake will intercept the dissolved iron within the groundwater as the works proceed. The historical surface and groundwater data indicates that the site has experienced pervious time periods where dissolved iron was present in the groundwater with no associated change in the iron concentrations of the lake. The performance of the lake chemistry thus far indicates that the lake is of sufficient size to buffer/mitigate any changes in dissolved iron in the landform without significantly altering the water chemistry of the extraction lake.
- As the proposed expansion will continue to extract and process sand in much the same way as the existing TSP operation, the past environmental performance of the area provides a robust indication of the ongoing behaviour of the surface and groundwater environments into the future.

- With respect to potential impacts on GDE's the magnitude of drawdown likely to occur within the small area of mapped low-potential terrestrial GDE on the site's south-western boundary is within the range of natural seasonal variation and is thus unlikely to cause significant changes to groundwater chemistry in the locale.
- In addition, the site's comprehensive water quality data set and the statistical analyses herein indicate that the size of the current lake, and by extrapolation the proposed expanded lake, is such that it acts as a stabilising feature to the local surface and groundwater environments and buffers/mitigates against significant changes in water chemistry.

Long term site observations and other environmental assessments at the site indicate that:

- Iron staining or associated evidence of iron toxicity (such as fish kills) have not been observed at the TSP site.
- Recent aquatic macroinvertebrate studies (including electrofishing) within the TSP extraction lake indicated that the aquatic macroinvertebrate and fish assemblages in the TSP extraction lake were relatively diverse and abundant and represented a healthy aquatic ecological community.

TSP proposes a comprehensive environmental monitoring regime for the expansion project, including surface and groundwater monitoring and inspections of the success of site rehabilitation plantings. Should the expansion works result in increased iron concentrations, these monitoring programs would readily identify such change in water quality, and any secondary indicators such as fish kills or vegetation stress.

6 Limitations of reporting

Gilbert & Sutherland Pty Ltd has made every effort to ensure that the information provided in this report is accurate. The interpretation of scientific data, however, involves professional judgment and as such is open to error.

In recognising the potential for errors in scientific interpretation, Gilbert & Sutherland Pty Ltd does not guarantee that the information is totally accurate or complete and clients are advised not to rely solely on this information when making commercial decisions. Any representation, statement, opinion or advice, expressed or implied is made in good faith and on the basis that the authors, Gilbert & Sutherland Pty Ltd, their agents or employees are not liable (whether by reason of lack of care or otherwise) to any person for any damage or loss whatsoever which has occurred or may occur in relation to that person taking or not taking (as the case may be) action in respect of any representation, statement or advice referred to above.

Furthermore, this information should not be relied upon by any persons other than the client, for whom it has been compiled. This information reflects the specific brief and the budget of the client concerned, who enjoys an individual tolerance of risk.

7 Appendix 1 – Drawings

PROJECT TITLE

HANSON TWEED SAND PLANT EXPANSION PHASE 5 TO PHASE 11

ENVIRONMENTAL IMPACT STATEMENT

DRAWING TITLE

FIGURE 19: EXTRACTION PHASES

REV	DESCRIPTION	DATE	DRAWN	DESIGN	CHECK	APPROVED
A	PHASING ARRANGEMENT CHANGES - REQ. PLANNER	25/01/2021	ZP	LN	LN	LN
B	PHASING ARRANGEMENT CHANGES - REQ. PLANNER	15/10/2021	MS	LN	LN	LN

ISSUE: PRELIMINARY

CLIENT: HANSON CONSTRUCTION MATERIALS PTY LTD

BASE PROVIDED BY: SIXMAPS DCDB

MANAGER: LANCE NEWLEY

ZONE PLANNING GROUP

GOLD COAST
1638 Tweed Street, Burleigh Heads QLD 4220
PO Box 3805, Burleigh Town QLD 4220

GLADSTONE
2/172 Goondoon St, Gladstone, QLD 4680
PO Box 5332, Gladstone QLD 4680

zonelandscape.com.au | 07 55622303

JOB / DRAWING NO: Z19163- F119

SHEET NO. SHEET 17 OF 21

PROJECT TITLE

HANSON TWEED SAND PLANT EXPANSION PHASE 5 TO PHASE 11

ENVIRONMENTAL IMPACT STATEMENT

DRAWING TITLE

FIGURE 20: SITE LAYOUT

REV	DESCRIPTION	DATE	DRAWN	DESIGN	CHECK	APPROVED
A	PRELIMINARY ISSUE	17/03/21	ZP	LN	LN	LN
B	PRELIMINARY ISSUE	15/10/21	MS	LN	LN	LN

ISSUE: PRELIMINARY

CLIENT: HANSON CONSTRUCTION MATERIALS PTY LTD

BASE PROVIDED BY: SIXMAPS DCDB

MANAGER: LANCE NEWLEY

ZONE PLANNING GROUP

GOLD COAST
1638 Tweed Street, Burleigh Heads QLD 4220
PO Box 3805, Burleigh Town QLD 4220

GLADSTONE
2/172 Goondoon St, Gladstone, QLD 4680
PO Box 5332, Gladstone QLD 4680

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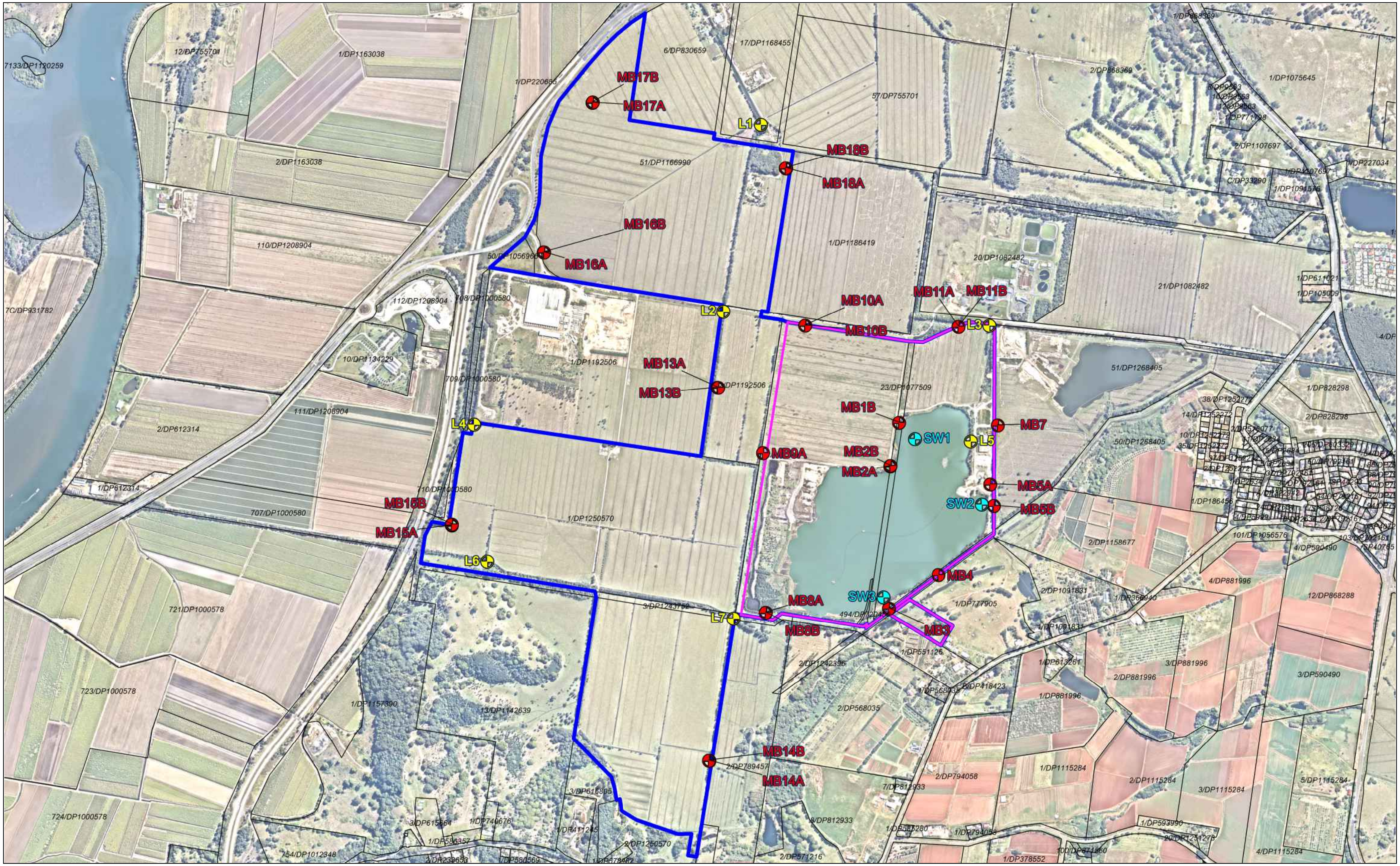
JOB / DRAWING NO: Z19163- F120



ORIENTATION

SCALE

125 250 375 500 625
metres

ROBINA
PO Box 4115 Robina QLD4230 07 5578 9944
Email robina@access.gs **www.access.gs**

LEGEND

- Cadastral boundaries
- Site Boundary - Existing
- Site boundary - Expansion Area
- Groundwater monitoring bores
- Surface water monitoring locations
- Surface water loggers

SOURCES

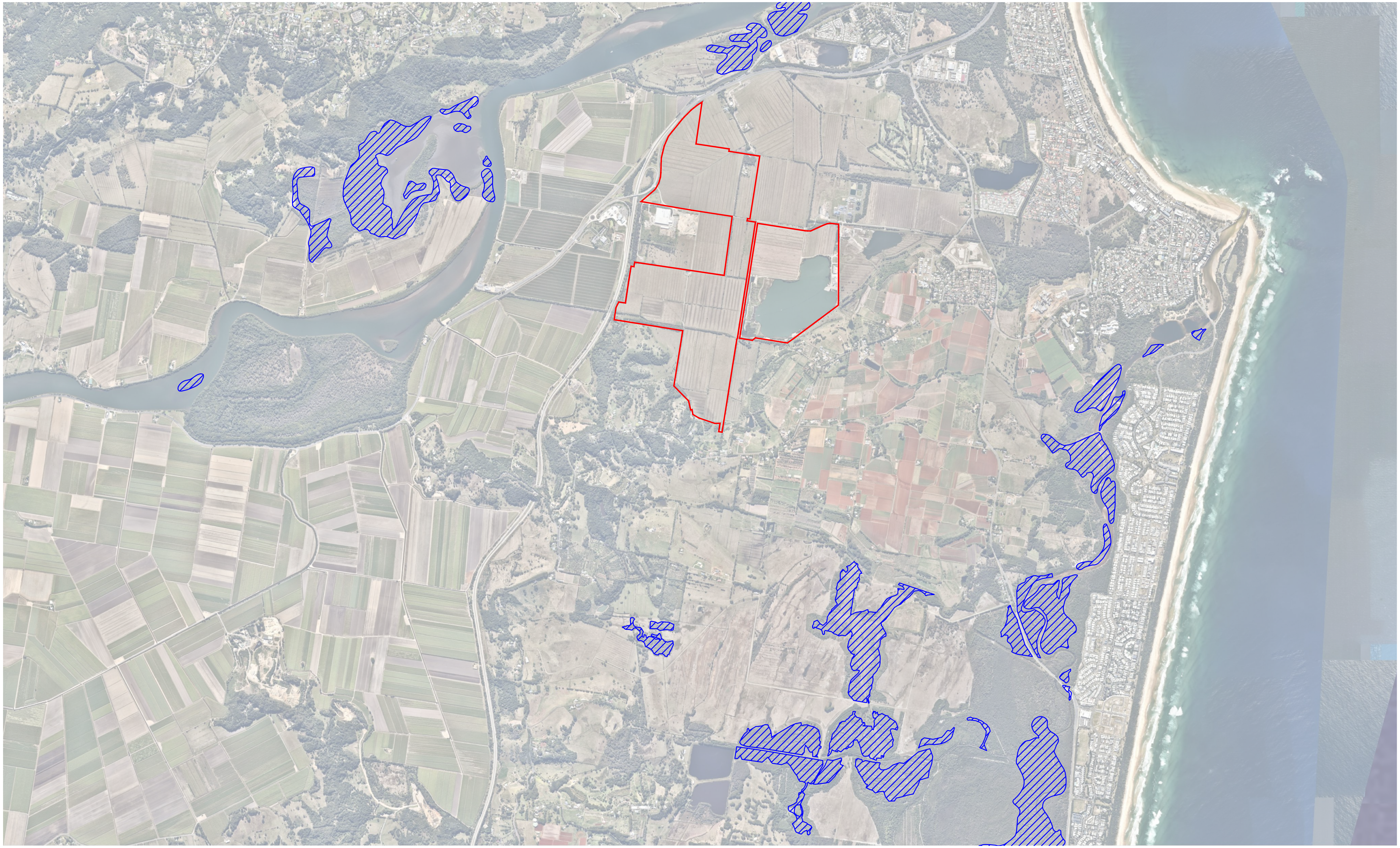
Image: Nearmap image dated 14 September 2020.

Cadastral: NSW Six Maps, sourced 23/11/2020.

PROJECT	CLIENT	DRAWING
TWEED SAND PLANT EXPANSION	HANSON CONSTRUCTION MATERIALS	MONITORING LOCATIONS

SCALE	DATE	DRAWN	CHECKED	PROJECT	DRAWING	REVISION
1:12 500@A3	19/01/2021	AJF	CMA	12035	003	-

GILBERT SUTHERLAND



ORIENTATION

SCALE 1:32000

400 800 1200 1600 metres

ROBINA

PO Box 4115 Robina QLD4230 07 5578 9944
Email robina@access.gs www.access.gs

LEGEND

Site Boundary

'High Priority' Groundwater Dependent Ecosystems

SOURCES

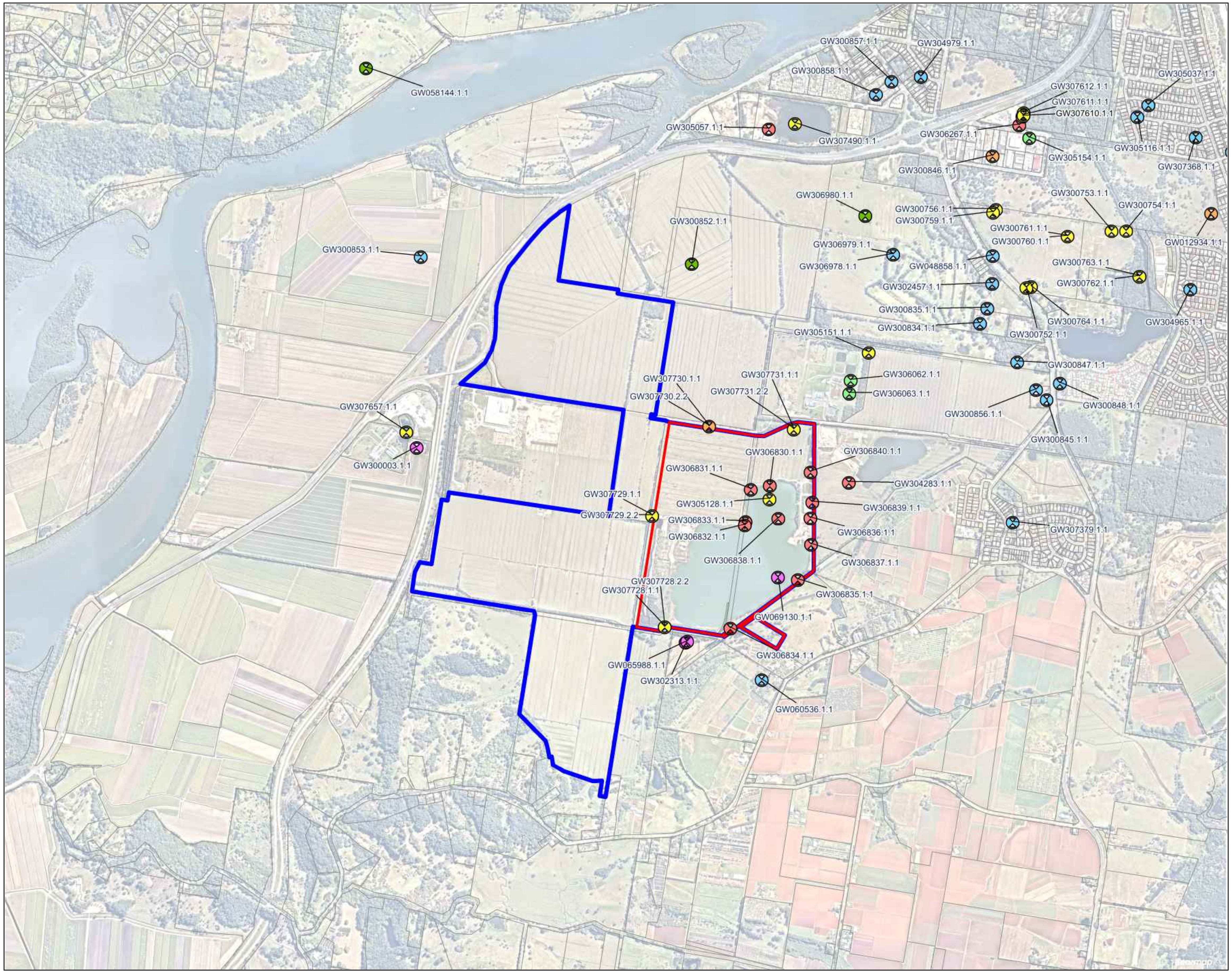
Image: Nearmap 2020. Image date: 5/08/2021

GDE's: Water Sharing Plan for the North Coast Coastal Sands Groundwater Sources 2016

PROJECT	CLIENT	DRAWING
TWEED SAND PLANT EXPANSION	HANSON CONSTRUCTION MATERIALS	'HIGH PRIORITY' GROUNDWATER DEPENDENT ECOSYSTEMS

SCALE	DATE	DRAWN	CHECKED	PROJECT	DRAWING	REVISION
1:32 000@A3	22/09/2021	SWP	ELH	12035	104	-

GILBERT SUTHERLAND



REGISTERED BORES
BOREHOLE CLASSIFICATION

- Water Supply
- Monitoring
- Commercial and Industrial
- Stock and Domestic
- Dewatering
- Exploration
- Irrigation
- Unknown
- Other

ORIENTATION

SCALE

200 400 600 800 1000
metres

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PO Box 4115 Robina QLD4230 07 5578 9944
Email robina@access.gs www.access.gs

LEGEND

- Cadastral boundaries
- Site Boundary - Existing
- Site boundary - Expansion Area

SOURCES

Image: Nearmap image dated 14 September 2020.

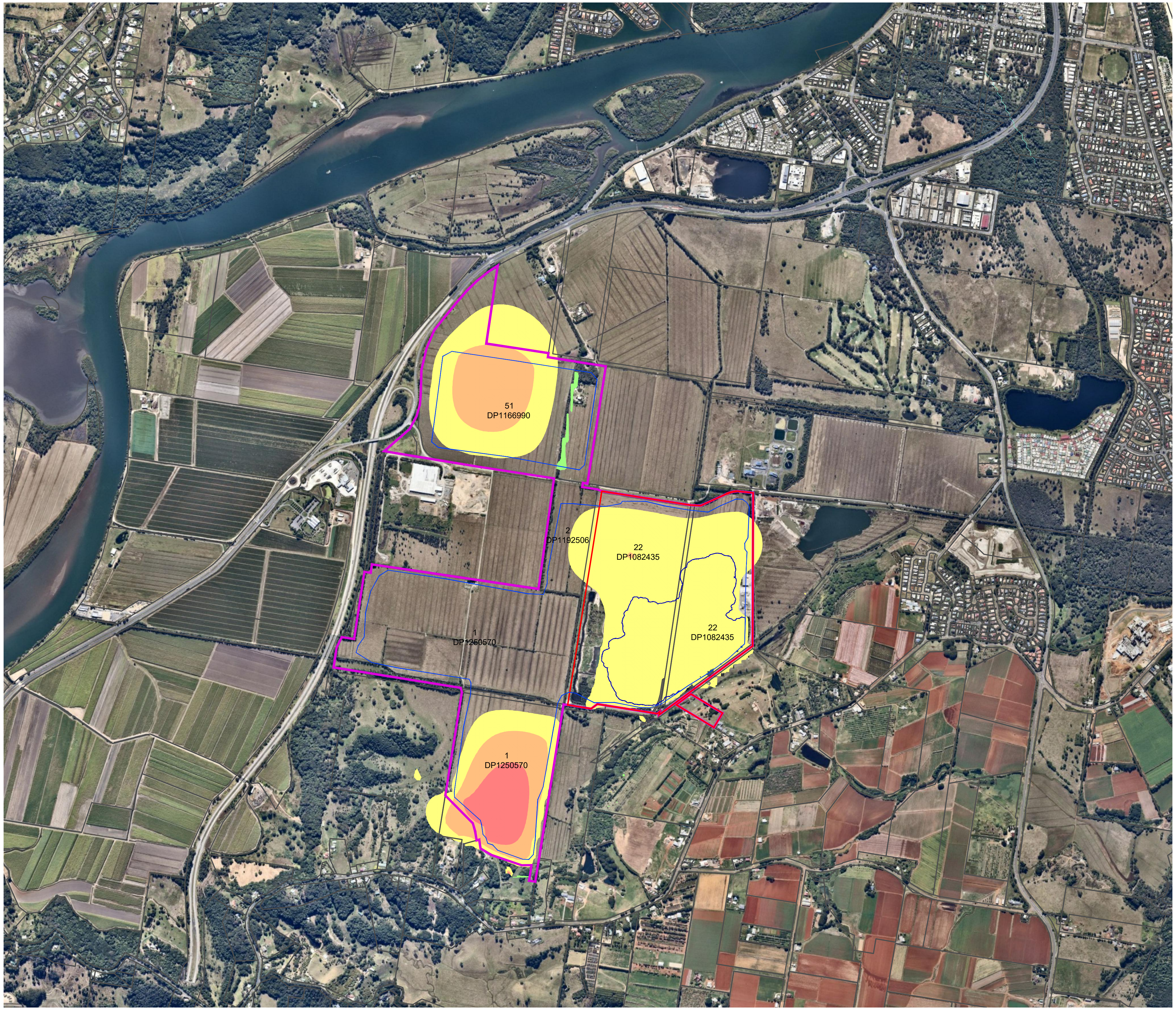
Cadastral: NSW Six Maps, sourced 23 November 2020.

Boreholes: Bureau of Meteorology, Australian Groundwater Explorer (http://www.bom.gov.au/water/groundwater/explorer/map.shtml),. GIS data for Tweed River region sourced 18 January 2021.

PROJECT	CLIENT	DRAWING
TWEED SAND PLANT EXPANSION	HANSON CONSTRUCTION MATERIALS	REGISTERED BOREHOLES IN CLOSE PROXIMITY TO SITE

SCALE	DATE	DRAWN	CHECKED	PROJECT	DRAWING	REVISION
1:20 000@A3	19/01/2021	AJF	ELH	12035	501	-

GILBERT SUTHERLAND



Change in groundwater elevation

Minimum change (m)	Maximum change (m)	Color
-0.500	-1.000	
-0.300	-0.500	
-0.100	-0.300	
0.100	0.500	
0.500	1.000	

ORIENTATION

SCALE

200 400 600 800 1000
metres

ROBINA

PO Box 4115 Robina QLD4230 07 5578 9944
Email robina@access.gs **www.access.gs**

LEGEND

- Cadastral boundaries
- Site boundary - Existing
- Site boundary - Expansion area
- Lake boundary - Existing
- Lake boundary - Ultimate expansion area

SOURCES

Image: Nearmap image dated 5 August 2021.

Cadastral: NSW Six Maps, sourced 23 November 2020.

PROJECT
TWEED SAND PLANT EXPANSION

CLIENT
HANSON CONSTRUCTION MATERIALS

DRAWING
CHANGE IN MODELLED GROUNDWATER CONDITIONS ELEVATION (EXISTING TO DEVELOPED SITE) TWEED SAND PLANT ONLY

SCALE	DATE	DRAWN	CHECKED	PROJECT	DRAWING	REVISION
1:20 000@A3	30/09/2021	AJF/SWP	ELH	12035	SUPP_GWM_006	-

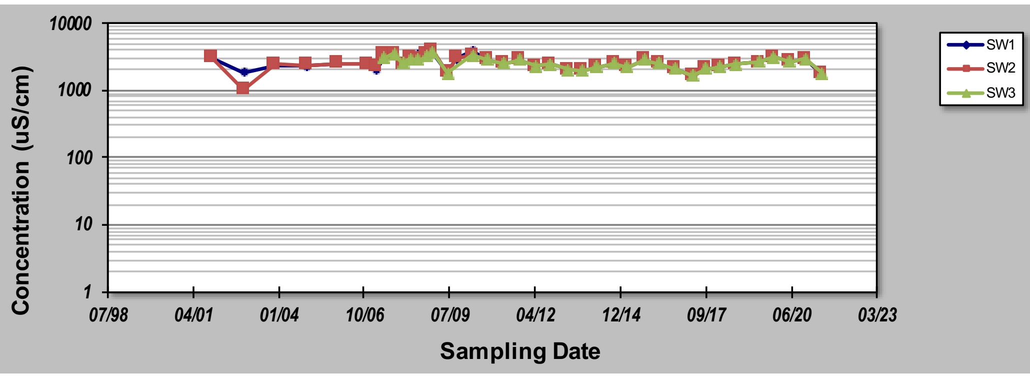
GILBERT SUTHERLAND

8 Appendix 2 – Statistical analysis results for lake salinity

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	25-Aug-21	Job ID:	12035
Facility Name:	Gilbert & Sutherland	Constituent:	2001 to 2021 Electrical conductivity
Conducted By:	Matt Greer	Concentration Units:	uS/cm

	Sampling Point ID:	SW1	SW2	SW3				
Sampling Event	Sampling Date	2001 TO 2021 ELECTRICAL CONDUCTIVITY CONCENTRATION (uS/cm)						
1	Dec-2001	2990	3033					
2	Dec-2002	1875	1019					
3	Dec-2003	2346	2425					
4	Dec-2004	2279	2338					
5	Dec-2005	2546	2551					
6	Dec-2006	2482	2427					
7	Mar-2007	1,970	2,230					
8	May-2007	3,090	3,570	3,060				
9	Sep-2007	3,550	3,560	3,570				
10	Jan-2008	2,442	2,453	2,510				
11	Apr-2008	3,100	3,100	2,900				
12	Jul-2008	3,420	2,840	2,830				
13	Oct-2008	3,380	3,440	3,180				
14	Dec-2008	3,550	3,920	3,690				
15	Jun-2009	1,812	1,847	1,782				
16	Sep-2009	2,903	2,982					
17	Mar-2010	3,830	3,340	3,360				
18	Sep-2010	2,840	2,840	2,850				
19	Mar-2011	2,542	2,538	2,546				
20	Sep-2011	2,822	2,805	2,808				
21	Apr-2012	2,390	2,287	2,291				
22	Sep-2012	2,513	2,433	2,436				
23	Apr-2013	2,017	2,015	2,034				
24	Sep-2013	1,966	1,955	1,972				
25	Mar-2014	2,220	2,227	2,222				
26	Oct-2014	2,480	2,490	2,480				
27	Mar-2015	2,230	2,210	2,220				
28	Sep-2015	2,822	2,828	2,824				
29	Mar-2016	2,533	2,529	2,526				
30	Sep-2016	2,070	2,100	2,100				
31	Apr-2017	1,667	1,652	1,655				
32	Sep-2017	2,082	2,090	2,083				
33	Mar-2018	2,186	2,196	2,190				
34	Sep-2018	2,450	2,460	2450				
35	Jun-2019	2,611	2,614	2,644				
36	Dec-2019	3,086	3,083	3,069				
37	Jun-2020	2,697	2,703	2,708				
38	Dec-2020	2,913	2,904	2,907				
39	Jun-2021	1,764	1,777	1,776				
40								
Coefficient of Variation:		0.21	0.23	0.20				
Mann-Kendall Statistic (S):		-93	-110	-129				
Confidence Factor:		86.6%	90.6%	98.6%				
Concentration Trend:		Stable	Prob. Decreasing	Decreasing				



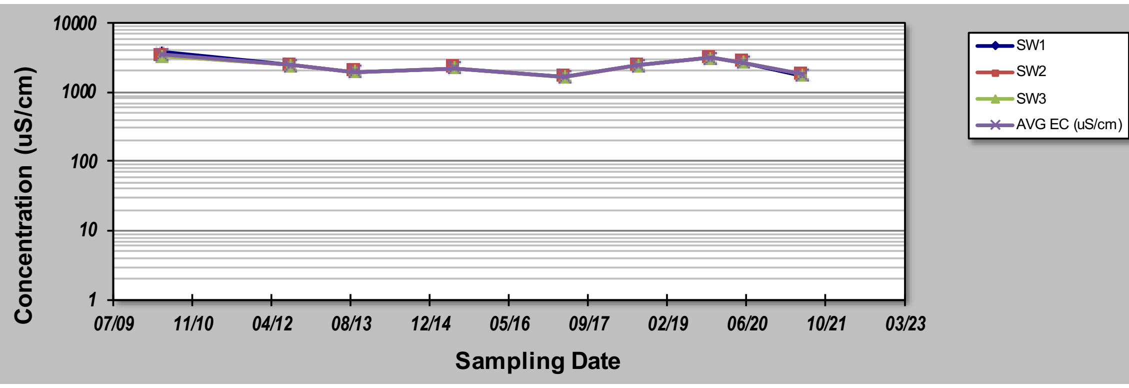
Notes:

1. At least four independent sampling events per well are required for calculating the trend. *Methodology is valid for 4 to 40 samples.*
2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
3. Methodology based on "MAROS: A Decision Support System for Optimizing Monitoring Plans", J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, *Ground Water*, 41(3):355-367, 2003.

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	23-Aug-21	Job ID:	12035
Facility Name:	Gilbert & Sutherland	Constituent:	Lake Surface Area and Electrical Conductivity
Conducted By:	Matt Greer	Concentration Units:	uS/cm

Sampling Event	Sampling Date	SW1	SW2	SW3	AVG EC (uS/cm)			
		LAKE SURFACE AREA AND ELECTRICAL CONDUCTIVITY CONCENTRATION (uS/cm)						
1	6/5/10	3830	3340	3360	3510			
2	5/8/12	2513	2433	2436	2461			
3	9/9/13	1964	1966	1955	1962			
4	1/6/15	2230	2210	2220	2220			
5	24/4/17	1667	1652	1655	1658			
6	8/8/18	2450	2460	2450	2453			
7	6/11/19	3086	3083	3069	3079			
8	1/6/20	2697	2703	2708	2703			
9	6/6/21	1764	1777	1776	1772			
10								
11								
12								
13								
14								
15								
16								
17								
18								
19								
20								
Coefficient of Variation:		0.28	0.24	0.24	0.25			
Mann-Kendall Statistic (S):		-6	-4	-4	-6			
Confidence Factor:		69.4%	61.9%	61.9%	69.4%			
Concentration Trend:		Stable	Stable	Stable	Stable			



Notes:

1. At least four independent sampling events per well are required for calculating the trend. *Methodology is valid for 4 to 40 samples.*
2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
3. Methodology based on "MAROS: A Decision Support System for Optimizing Monitoring Plans", J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, *Ground Water*, 41(3):355-367, 2003.

9 Appendix 3 – Regression analysis – lake salinity

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.184464405
R Square	0.034027117
Adjusted R Square	-0.126968364
Standard Error	547.8352279
Observations	8

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	63432.4338	63432.4338	0.21135448	0.66189514
Residual	6	1800740.62	300123.437		
Total	7	1864173.06			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2484.948584	325.964355	7.62337521	0.00026563	1687.34254	3282.55463	1687.34254	3282.55463
90 day rain	-0.283757239	0.61722175	-0.4597331	0.66189514	-1.7940444	1.22652996	-1.7940444	1.22652996

RESIDUAL OUTPUT

Observation	*Predicted AVG EC (uS/*	*Residuals*
1	2442.101241	18.5654259
2	2390.451748	-426.11841
3	2179.563368	645.103299
4	2332.514195	-674.51419
5	2438.92316	14.4101736
6	2462.352995	616.980338
7	2382.795978	319.870689
8	2286.630649	-514.29732

PROBABILITY OUTPUT

Percentile	*AVG EC (uS/cm)*
6.25	1658
18.75	1772.33333
31.25	1964.33333
43.75	2453.33333
56.25	2460.66667
68.75	2702.66667
81.25	2824.66667
93.75	3079.33333

10 Appendix 4 – Statistical analysis of dissolved iron and associated indicators

Kruskal Wallis test summary

Dissolved iron concentration

	lake D Fe	MB1b D Fe	MB2b D Fe	MB3 D Fe	MB4 D Fe	MB5b D Fe
median	0.05	4.60	1.44	28.75	20.35	6.24
rank sum	1534.5	6976.5	5143.5	10000.5	6623	8018.5
count	40	39	32	36	28	38
r^2/n	58867	1247989	826737	2778056	1566576	1692009
	MB7 D Fe	MB8a D Fe	MB9a D Fe	MB10a D Fe		
median	4.31	3.05	4.35	4.01		
rank sum	6789.5	5275.5	5472.5	5085.5		
count	32	31	32	29		
r^2/n	1440541	897771	935883	891804		

count	368
r^2/n	13906282.4
H-stat	121.90
H-ties	121.92
df	10
p-value	2.0654E-21
alpha	0.05
sig	yes

DUNN's TEST alpha 0.05 0.00090909

group	R-sum	size	R-mean	z-crit
lake D Fe	1534.5	40	38.36	
MB1b D Fe	6976.5	39	178.88	
MB2b D Fe	5143.5	32	160.73	
MB3 D Fe	10000.5	36	277.79	
MB4 D Fe	6623	28	236.54	
MB5b D Fe	8018.5	38	211.01	
MB7 D Fe	6789.5	32	212.17	
MB8a D Fe	5275.5	31	170.18	
MB9a D Fe	5472.5	32	171.02	
MB10a D Fe	5085.5	29	175.36	
MB11a D Fe	6976.5	31	225.05	
		368		1.9600

D TEST

group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
lake D Fe	MB1b D Fe	140.52	23.94	5.87	46.92	0.000
lake D Fe	MB2b D Fe	122.37	25.23	4.85	49.45	0.000
lake D Fe	MB3 D Fe	239.43	24.44	9.80	47.90	0.000
lake D Fe	MB4 D Fe	198.17	26.21	7.56	51.37	0.000
lake D Fe	MB5b D Fe	172.65	24.10	7.17	47.23	0.000
lake D Fe	MB7 D Fe	173.81	25.23	6.89	49.45	0.000
lake D Fe	MB8a D Fe	131.81	25.45	5.18	49.89	0.000
lake D Fe	MB9a D Fe	132.65	25.23	5.26	49.45	0.000
lake D Fe	MB10a D Fe	137.00	25.94	5.28	50.85	0.000
lake D Fe	MB11a D Fe	186.69	25.45	7.33	49.89	0.000
MB1b D Fe	MB2b D Fe	18.15	25.37	0.72	49.73	0.474
MB1b D Fe	MB3 D Fe	98.91	24.59	4.02	48.19	0.000
MB1b D Fe	MB4 D Fe	57.65	26.35	2.19	51.64	0.029
MB1b D Fe	MB5b D Fe	32.13	24.25	1.33	47.52	0.185
MB1b D Fe	MB7 D Fe	33.29	25.37	1.31	49.73	0.190
MB1b D Fe	MB8a D Fe	8.71	25.60	0.34	50.17	0.734
MB1b D Fe	MB9a D Fe	7.87	25.37	0.31	49.73	0.756
MB1b D Fe	MB10a D Fe	3.52	26.08	0.14	51.12	0.893
MB1b D Fe	MB11a D Fe	46.16	25.60	1.80	50.17	0.071
MB2b D Fe	MB3 D Fe	117.06	25.84	4.53	50.65	0.000
MB2b D Fe	MB4 D Fe	75.80	27.53	2.75	53.95	0.006
MB2b D Fe	MB5b D Fe	50.28	25.52	1.97	50.02	0.049
MB2b D Fe	MB7 D Fe	51.44	26.59	1.93	52.12	0.053
MB2b D Fe	MB8a D Fe	9.44	26.81	0.35	52.54	0.725
MB2b D Fe	MB9a D Fe	10.28	26.59	0.39	52.12	0.699
MB2b D Fe	MB10a D Fe	14.63	27.27	0.54	53.45	0.592
MB2b D Fe	MB11a D Fe	64.31	26.81	2.40	52.54	0.016
MB3 D Fe	MB4 D Fe	41.26	26.80	1.54	52.53	0.124
MB3 D Fe	MB5b D Fe	66.78	24.74	2.70	48.49	0.007
MB3 D Fe	MB7 D Fe	65.62	25.84	2.54	50.65	0.011
MB3 D Fe	MB8a D Fe	107.61	26.06	4.13	51.08	0.000
MB3 D Fe	MB9a D Fe	106.78	25.84	4.13	50.65	0.000
MB3 D Fe	MB10a D Fe	102.43	26.54	3.86	52.02	0.000
MB3 D Fe	MB11a D Fe	52.74	26.06	2.02	51.08	0.043
MB4 D Fe	MB5b D Fe	25.52	26.49	0.96	51.92	0.335
MB4 D Fe	MB7 D Fe	24.36	27.53	0.89	53.95	0.376
MB4 D Fe	MB8a D Fe	66.36	27.73	2.39	54.35	0.017
MB4 D Fe	MB9a D Fe	65.52	27.53	2.38	53.95	0.017
MB4 D Fe	MB10a D Fe	61.17	28.18	2.17	55.24	0.030

MB4 D Fe	MB11a D Fe	11.49	27.73	0.41	54.35	0.679
MB5b D Fe	MB7 D Fe	1.16	25.52	0.05	50.02	0.964
MB5b D Fe	MB8a D Fe	40.84	25.74	1.59	50.46	0.113
MB5b D Fe	MB9a D Fe	40.00	25.52	1.57	50.02	0.117
MB5b D Fe	MB10a D Fe	35.65	26.23	1.36	51.41	0.174
MB5b D Fe	MB11a D Fe	14.04	25.74	0.55	50.46	0.586
MB7 D Fe	MB8a D Fe	41.99	26.81	1.57	52.54	0.117
MB7 D Fe	MB9a D Fe	41.16	26.59	1.55	52.12	0.122
MB7 D Fe	MB10a D Fe	36.81	27.27	1.35	53.45	0.177
MB7 D Fe	MB11a D Fe	12.88	26.81	0.48	52.54	0.631
MB8a D Fe	MB9a D Fe	0.84	26.81	0.03	52.54	0.975
MB8a D Fe	MB10a D Fe	5.18	27.48	0.19	53.86	0.850
MB8a D Fe	MB11a D Fe	54.87	27.02	2.03	52.95	0.042
MB9a D Fe	MB10a D Fe	4.35	27.27	0.16	53.45	0.873
MB9a D Fe	MB11a D Fe	54.03	26.81	2.02	52.54	0.044
MB10a D Fe	MB11a D Fe	49.69	27.48	1.81	53.86	0.071

pH

	lake Ph	MB1b Ph	MB2b Ph	MB3 Ph	MB4 Ph	MB5b Ph
median	8.39	6.84	6.52	6.72	6.98	6.84
rank sum	13549.5	6205	4318.5	5282.5	5650	7005
count	40	39	33	36	28	38
r^2/n	4589723.76	987231.41	565134.614	775133.507	1140089.29	1291316.45
	MB7 Ph	MB8a Ph	MB9a Ph	MB10a Ph		
median	6.16	7.02	7.18	7.02		
rank sum	3504	7717.5	8964.5	6862		
count	31	38	37	33		
r^2/n	396065.032	1567363.32	2171952.98	1426880.12		

count	389
r^2/n	16194013
H-stat	110.918571
H-ties	110.924609
df	10
p-value	3.4729E-19
alpha	0.05
sig	yes

DUNN's TEST		alpha		0.05	0.00090909
group	*R-sum*	*size*	*R-mean*	*z-crit*	
lake Ph	13549.5	40	338.74		
MB1b Ph	6205	39	159.10		
MB2b Ph	4318.5	33	130.86		
MB3 Ph	5282.5	36	146.74		
MB4 Ph	5650	28	201.79		
MB5b Ph	7005	38	184.34		
MB7 Ph	3504	31	113.03		
MB8a Ph	7717.5	38	203.09		
MB9a Ph	8964.5	37	242.28		
MB10a Ph	6862	33	207.94		
MB11a Ph	6796.5	36	188.79		
		389		1.95996398	

D TEST

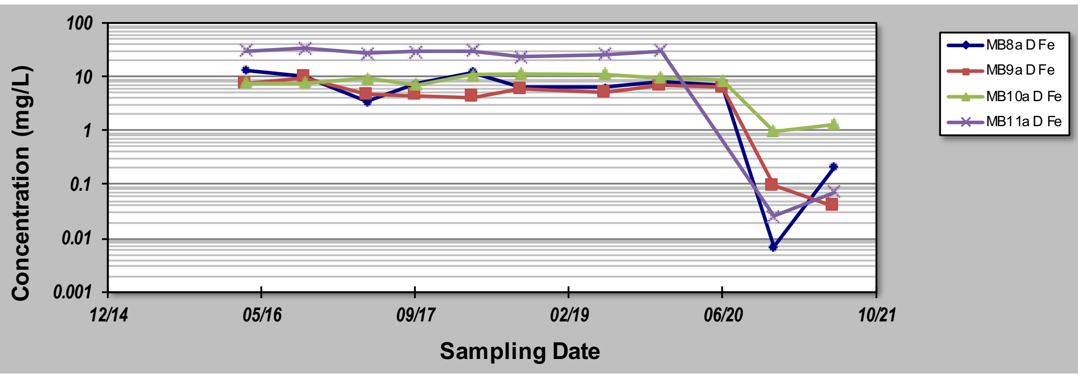
group 1	*group 2*	*R-mean*	*std err*	*z-stat*	*R-crit*	*p-value*
lake Ph	MB1b Ph	179.63	25.30	7.10	49.59	0.000
lake Ph	MB2b Ph	207.87	26.44	7.86	51.82	0.000
lake Ph	MB3 Ph	192.00	25.83	7.43	50.63	0.000
lake Ph	MB4 Ph	136.95	27.70	4.94	54.30	0.000
lake Ph	MB5b Ph	154.40	25.47	6.06	49.92	0.000
lake Ph	MB7 Ph	225.71	26.90	8.39	52.73	0.000
lake Ph	MB8a Ph	135.65	25.47	5.33	49.92	0.000
lake Ph	MB9a Ph	96.45	25.65	3.76	50.27	0.000
lake Ph	MB10a Ph	130.80	26.44	4.95	51.82	0.000
lake Ph	MB11a Ph	149.95	25.83	5.81	50.63	0.000
MB1b Ph	MB2b Ph	28.24	26.59	1.06	52.12	0.288
MB1b Ph	MB3 Ph	12.37	25.99	0.48	50.93	0.634
MB1b Ph	MB4 Ph	42.68	27.85	1.53	54.59	0.125
MB1b Ph	MB5b Ph	25.24	25.63	0.98	50.23	0.325
MB1b Ph	MB7 Ph	46.07	27.05	1.70	53.03	0.089
MB1b Ph	MB8a Ph	43.99	25.63	1.72	50.23	0.086
MB1b Ph	MB9a Ph	83.18	25.80	3.22	50.57	0.001
MB1b Ph	MB10a Ph	48.84	26.59	1.84	52.12	0.066
MB1b Ph	MB11a Ph	29.69	25.99	1.14	50.93	0.253
MB2b Ph	MB3 Ph	15.87	27.10	0.59	53.11	0.558
MB2b Ph	MB4 Ph	70.92	28.89	2.45	56.62	0.014
MB2b Ph	MB5b Ph	53.48	26.75	2.00	52.44	0.046
MB2b Ph	MB7 Ph	17.83	28.12	0.63	55.12	0.526

MB2b Ph	MB8a Ph	72.23	26.75	2.70	52.44	0.007
MB2b Ph	MB9a Ph	111.42	26.92	4.14	52.76	0.000
MB2b Ph	MB10a Ph	77.08	27.68	2.78	54.25	0.005
MB2b Ph	MB11a Ph	57.93	27.10	2.14	53.11	0.033
MB3 Ph	MB4 Ph	55.05	28.33	1.94	55.53	0.052
MB3 Ph	MB5b Ph	37.61	26.15	1.44	51.25	0.150
MB3 Ph	MB7 Ph	33.70	27.55	1.22	54.00	0.221
MB3 Ph	MB8a Ph	56.36	26.15	2.16	51.25	0.031
MB3 Ph	MB9a Ph	95.55	26.32	3.63	51.59	0.000
MB3 Ph	MB10a Ph	61.20	27.10	2.26	53.11	0.024
MB3 Ph	MB11a Ph	42.06	26.50	1.59	51.94	0.113
MB4 Ph	MB5b Ph	17.44	28.00	0.62	54.89	0.533
MB4 Ph	MB7 Ph	88.75	29.31	3.03	57.45	0.002
MB4 Ph	MB8a Ph	1.31	28.00	0.05	54.89	0.963
MB4 Ph	MB9a Ph	40.50	28.16	1.44	55.20	0.150
MB4 Ph	MB10a Ph	6.15	28.89	0.21	56.62	0.831
MB4 Ph	MB11a Ph	12.99	28.33	0.46	55.53	0.646
MB5b Ph	MB7 Ph	71.31	27.21	2.62	53.33	0.009
MB5b Ph	MB8a Ph	18.75	25.79	0.73	50.56	0.467
MB5b Ph	MB9a Ph	57.94	25.97	2.23	50.90	0.026
MB5b Ph	MB10a Ph	23.60	26.75	0.88	52.44	0.378
MB5b Ph	MB11a Ph	4.45	26.15	0.17	51.25	0.865
MB7 Ph	MB8a Ph	90.06	27.21	3.31	53.33	0.001
MB7 Ph	MB9a Ph	129.25	27.38	4.72	53.66	0.000
MB7 Ph	MB10a Ph	94.91	28.12	3.37	55.12	0.001
MB7 Ph	MB11a Ph	75.76	27.55	2.75	54.00	0.006
MB8a Ph	MB9a Ph	39.19	25.97	1.51	50.90	0.131
MB8a Ph	MB10a Ph	4.85	26.75	0.18	52.44	0.856
MB8a Ph	MB11a Ph	14.30	26.15	0.55	51.25	0.584
MB9a Ph	MB10a Ph	34.34	26.92	1.28	52.76	0.202
MB9a Ph	MB11a Ph	53.49	26.32	2.03	51.59	0.042
MB10a Ph	MB11a Ph	19.15	27.10	0.71	53.11	0.480

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	13-Sep-21	Job ID:	12035
Facility Name:	Tweed sands	Constituent:	Dissolved iron
Conducted By:	PM	Concentration Units:	mg/L

Sampling Event	Sampling Date	MB8a D Fe	MB9a D Fe	MB10a D Fe	MB11a D Fe			
		DISSOLVED IRON CONCENTRATION (mg/L)						
1	Mar-2016	13.10	7.26	7.61	30.80			
2	Sep-2016	10.00	9.50	7.70	34.00			
3	Apr-2017	3.40	4.70	9.40	27.00			
4	Sep-2017	7.50	4.50	7.20	29.00			
5	Mar-2018	12.00	4.20	11.00	30.00			
6	Sep-2018	6.33	5.83	11.30	23.00			
7	Jun-2019	6.25	5.11	11.10	25.90			
8	Dec-2019	8.06	6.79	9.50	30.80			
9	Jun-2020	7.05	6.30	8.72				
10	**Dec-2020**	0.007	0.096	0.963	0.026			
11	**Jun-2021**	0.209	0.039	1.34	0.072			
12								
13								
14								
15								
16								
17								
18								
19								
20								
Coefficient of Variation:		0.63	0.57	0.46	0.54			
Mann-Kendall Statistic (S):		-27	-21	-5	-22			
Confidence Factor:		98.0%	94.0%	61.9%	97.1%			
Concentration Trend:		Decreasing	Prob. Decreasing	Stable	Decreasing			



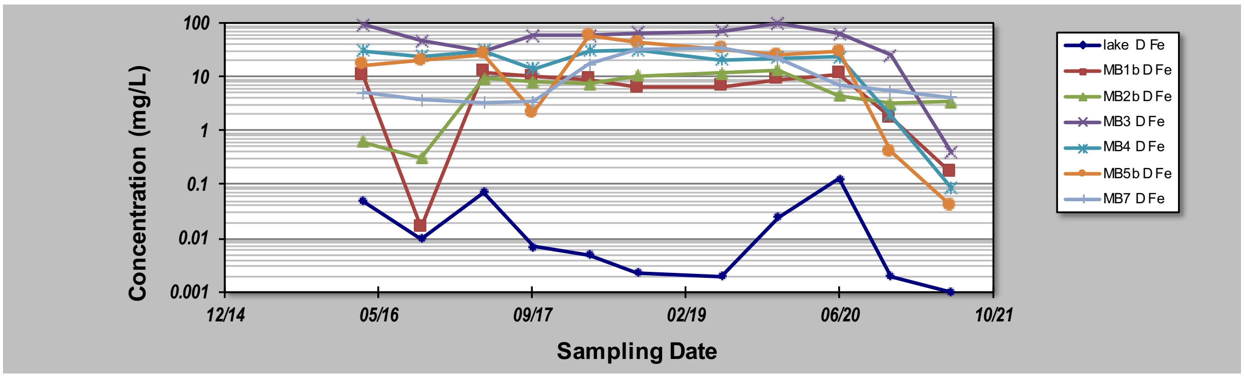
Notes:

1. At least four independent sampling events per well are required for calculating the trend. *Methodology is valid for 4 to 40 samples.*
2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
3. Methodology based on "MAROS: A Decision Support System for Optimizing Monitoring Plans", J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, *Ground Water*, 41(3):355-367, 2003.

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date: 13-Sep-21
Facility Name: Tweed sands
Conducted By: PM
Job ID: 12035
Constituent: Dissolved iron
Concentration Units: mg/L

Sampling Point ID:		lake D Fe	MB1b D Fe	MB2b D Fe	MB3 D Fe	MB4 D Fe	MB5b D Fe	MB7 D Fe
Sampling Event	Sampling Date	DISSOLVED IRON CONCENTRATION (mg/L)						
1	Mar-2016	0.05	10.30	0.61	93.00	**30.80**	16.50	5.07
2	Sep-2016	0.01	0.02	0.31	47.00	24.00	20.00	3.70
3	Apr-2017	0.07	12.00	9.40	30.00	30.00	26.00	3.30
4	Sep-2017	0.01	10.00	8.10	58.00	14.00	2.20	3.50
5	Mar-2018	0.01	9.10	7.40	59.00	30.00	58.00	17.00
6	Sep-2018	0.00	6.24	10.40	66.00	31.40	43.50	32.80
7	Jun-2019	0.00	6.69	11.90	69.60	20.40	33.00	34.40
8	Dec-2019	0.03	8.90	13.20	98.30	22.00	24.80	22.00
9	Jun-2020	0.13	11.20	4.52	63.70	23.40	28.80	7.17
10	**Dec-2020**	0.00	1.74	3.21	25.4	1.9	0.397	5.52
11	**Jun-2021**	0.00	0.166	3.47	0.4	0.087	0.04	4.23
12								
13								
14								
15								
16								
17								
18								
19								
20								
Coefficient of Variation:		1.47	0.64	0.67	0.52	0.54	0.79	0.95
Mann-Kendall Statistic (S):		-24	-17	7	-5	-26	-9	9
Confidence Factor:		96.4%	89.1%	67.6%	61.9%	97.5%	72.9%	72.9%
Concentration Trend:		Decreasing	Stable	No Trend	Stable	Decreasing	Stable	No Trend



Notes:

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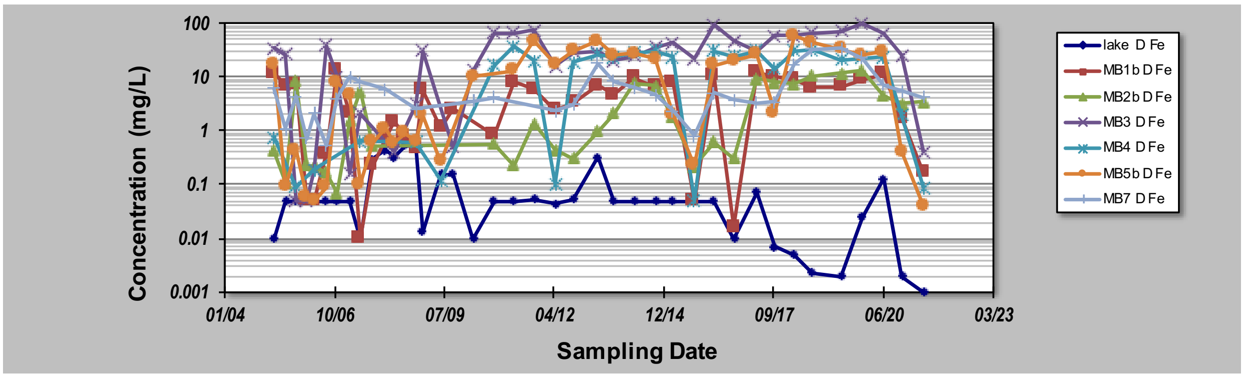
2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
3. Methodology based on "MAROS: A Decision Support System for Optimizing Monitoring Plans", J.J. Aziz, M. Ling, H.S. Rifai, C.J. Newell, and J.R. Gonzales, *Ground Water*, 41(3):355-367, 2003.

GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	13-Sep-21	**Job ID:**	12035
Facility Name:	Tweed sands	**Constituent:**	Dissolved iron
Conducted By:	PM	**Concentration Units:**	mg/L

Sampling Event	Sampling Date	lake D Fe	MB1b D Fe	MB2b D Fe	MB3 D Fe	MB4 D Fe	MB5b D Fe	MB7 D Fe
		DISSOLVED IRON CONCENTRATION (mg/L)						
1	Apr-2005	0.01	11.50	0.42	34.10	0.75	16.20	6.14
2	Jul-2005	0.05	6.77	0.11	25.80		0.09	1.07
3	Oct-2005	0.05	7.51	8.19	0.05	0.09	0.44	4.39
4	Jan-2006	0.05	0.05	0.23	0.05		0.06	0.72
5	Apr-2006	0.05	0.05	0.22	0.18	0.19	0.05	2.10
6	Jul-2006	0.05	0.38	0.17	37.90		0.09	0.53
7	Nov-2006	0.05	13.40	0.07	9.84		7.92	4.03
8	Mar-2007	0.05	2.07	1.52	0.16		4.55	9.85
9	May-2007	0.01	0.01	5.39	2.12	0.64	0.10	8.12
10	Sep-2007	0.30	0.23	0.53			0.62	
11	Jan-2008	0.43	0.71				1.10	5.90
12	Apr-2008	0.32	1.50		0.40		0.58	
13	Jul-2008	0.53	0.76				0.91	
14	Oct-2008	0.55	0.47		3.10	0.61	0.63	2.50
15	Dec-2008	0.01	5.55		30.00		1.93	
16	Jun-2009	0.16	1.12			0.12	0.26	
17	Sep-2009	0.15	2.56		0.48			
18	Mar-2010	0.01			13.00		10.00	3.56
19	Sep-2010	0.05	0.84	0.57	64.20	16.60		4.13
20	Mar-2011	0.05	7.82	0.23	66.50	37.30	12.90	
21	Sep-2011	0.05	5.76	1.35	74.40	20.30	46.50	
22	Apr-2012	0.04	2.41	0.44	16.00	0.10	17.00	2.35
23	Sep-2012	0.05	3.35	0.31	28.40	18.80	30.20	3.05
24	Apr-2013	0.32	6.91	0.98	29.10	25.60	46.80	18.10
25	Sep-2013	0.05	4.60	2.08	20.10	23.10	25.00	8.35
26	Mar-2014	0.05	9.62	7.81	23.90	28.40	26.80	6.36
27	Oct-2014	0.05	6.46	6.82	35.00	30.00	21.30	4.68
28	Mar-2015	0.05	7.91	1.80	42.40	23.30	1.99	2.37
29	Sep-2015	0.05	0.05	0.22	21.70	0.05	0.23	0.81
30	Mar-2016	0.05	10.30	0.61	93.00	**30.80**	16.50	5.07
31	Sep-2016	0.01	0.02	0.31	47.00	24.00	20.00	3.70
32	Apr-2017	0.07	12.00	9.40	30.00	30.00	26.00	3.30
33	Sep-2017	0.01	10.00	8.10	58.00	14.00	2.20	3.50
34	Mar-2018	0.01	9.10	7.40	59.00	30.00	58.00	17.00
35	Sep-2018	0.00	6.24	10.40	66.00	31.40	43.50	32.80
36	Jun-2019	0.00	6.69	11.90	69.60	20.40	33.00	34.40
37	Dec-2019	0.03	8.90	13.20	98.30	22.00	24.80	22.00
38	Jun-2020	0.13	11.20	4.52	63.70	23.40	28.80	7.17
39	**Dec-2020**	0.00	1.74	3.21	25.4	1.9	0.397	5.52
40	**Jun-2021**	0.00	0.166	3.47	0.4	0.087	0.04	4.23
Coefficient of Variation:		1.43	0.88	1.15	0.85	0.79	1.17	1.14
Mann-Kendall Statistic (S):		-147	176	217	267	89	264	130
Confidence Factor:		95.6%	98.4%	>99.9%	>99.9%	95.9%	>99.9%	98.2%
Concentration Trend:		Decreasing	Increasing	Increasing	Increasing	Increasing	Increasing	Increasing



Notes:

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2. Confidence in Trend = Confidence (in percent) that constituent concentration is increasing (S>0) or decreasing (S<0): >95% = Increasing or Decreasing; ≥ 90% = Probably Increasing or Probably Decreasing; < 90% and S>0 = No Trend; < 90%, S≤0, and COV ≥ 1 = No Trend; < 90% and COV < 1 = Stable.
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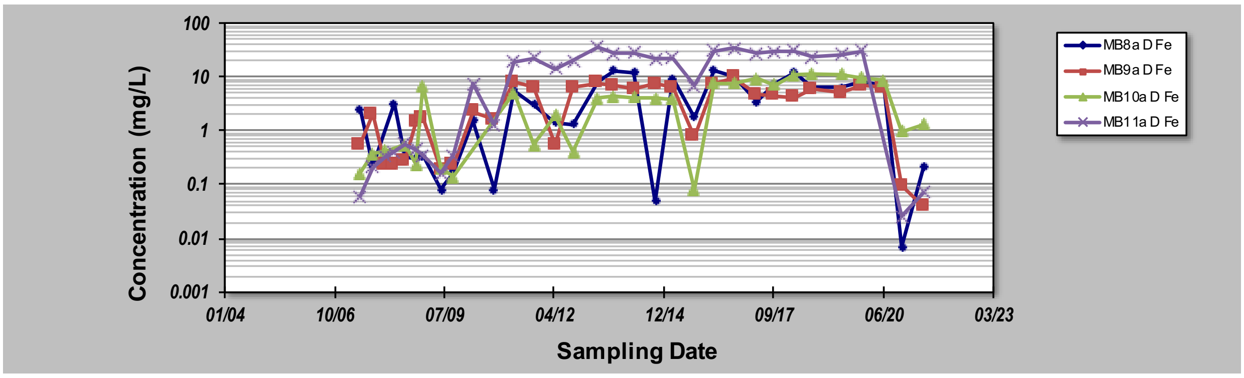
GSI MANN-KENDALL TOOLKIT
for Constituent Trend Analysis

Evaluation Date:	13-Sep-21	**Job ID:**	12035
Facility Name:	Tweed sands	**Constituent:**	Dissolved iron
Conducted By:	PM	**Concentration Units:**	mg/L

Sampling Point ID:		MB8a D Fe	MB9a D Fe	MB10a D Fe	MB11a D Fe
Sampling Event	**Sampling Date**	**DISSOLVED IRON CONCENTRATION (mg/L)**			
1	Apr-2005				
2	Jul-2005				
3	Oct-2005				
4	Jan-2006				
5	Apr-2006				
6	Jul-2006				
7	Nov-2006				
8	Mar-2007				
9	May-2007	2.51	0.54	0.16	0.06
10	Sep-2007	0.23	2.00	0.38	0.21
11	Jan-2008		0.23	0.42	0.33
12	Apr-2008	3.20	0.24		0.40
13	Jul-2008	0.33	0.28	0.55	0.57
14	Oct-2008	0.31	1.40	0.24	0.46
15	Dec-2008	0.35	1.71	6.96	0.34
16	Jun-2009	0.08	0.19	0.20	0.16
17	Sep-2009	0.17	0.23	0.14	0.34
18	Mar-2010	1.53	2.25		7.29
19	Sep-2010	0.08	1.62		1.25
20	Mar-2011	5.64	8.10	5.01	19.40
21	Sep-2011	3.05	6.22	0.54	22.40
22	Apr-2012	1.40	0.54	1.91	14.00
23	Sep-2012	1.34	6.27	0.40	20.10
24	Apr-2013	7.99	7.58	4.01	35.60
25	Sep-2013	13.00	6.88	4.30	27.20
26	Mar-2014	12.00	5.91	4.15	28.40
27	Oct-2014	0.05	7.26	4.06	21.80
28	Mar-2015	9.45	6.28	3.84	22.30
29	Sep-2015	1.76	0.77	0.08	6.74
30	Mar-2016	13.10	7.26	7.61	30.80
31	Sep-2016	10.00	9.50	7.70	34.00
32	Apr-2017	3.40	4.70	9.40	27.00
33	Sep-2017	7.50	4.50	7.20	29.00
34	Mar-2018	12.00	4.20	11.00	30.00
35	Sep-2018	6.33	5.83	11.30	23.00
36	Jun-2019	6.25	5.11	11.10	25.90
37	Dec-2019	8.06	6.79	9.50	30.80
38	Jun-2020	7.05	6.30	8.72	
39	**Dec-2020**	0.007	0.096	0.963	0.026
40	**Jun-2021**	0.209	0.039	1.34	0.072
Coefficient of Variation:		1.00	0.80	0.93	0.89
Mann-Kendall Statistic (S):		113	113	192	213
Confidence Factor:		97.2%	96.6%	>99.9%	>99.9%
Concentration Trend:		Increasing	Increasing	Increasing	Increasing



Notes:
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