

Ok Birim Tailings Storage Facility Project

Environmental and Social Impact Assessment

Appendix C

Surface water quality report



TECHNICAL MEMORANDUM

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PROJECT: Ok Birim Tailings Storage Facility

SUBJECT: Hydrogeochemical Assessment and Implications for River Water Quality

This technical memorandum outlines the findings of a hydrogeochemical assessment for the Ok Birim Tailings Storage Facility (the project) being undertaken by Ok Tedi Mining Limited (OTML). The assessment is being carried out by Environmental Geochemistry International Pty Ltd (EGi) as part of the environmental and social impact assessment (ESIA) for the project. The project is located approximately 1 km west of the confluence of the Ok Birim and Ok Tedi, and drainage from the site will report to the Ok Tedi. The proposed TSF development area will encompass a TSF impoundment footprint, hydro-cyclone house, laydown area and associated ancillary infrastructure.

OTML currently discharge process tailings from their Tailings Pyrite Plant (TPP) directly into the Ok Kumiup near the mine which subsequently flows into the Ok Tedi and downstream to Bige where sand is dredged and placed in engineered stockpiles on the riverbanks. When commissioned, the Ok Birim TSF will replace most riverine discharge of tailings. Instead, tailings slurry discharge from the TPP will be piped directly to the TSF which will be developed as a ring-dyke structure comprising internal storage cells developed progressively, with embankments constructed using a coarse-grained fraction separated from tailings. An on-site cyclone house will separate piped tailings into fines and coarse sands prior to TSF disposal, with coarse sands used for embankment construction, and fines deposited in the TSF cells. The current design also includes drainage of tailings decant water from the TSF with transfer to sediment ponds and discharge of supernatant to the Ok Tedi.

The release of excess water from the TSF to the Ok Tedi may have implications for water quality, both in the Ok Tedi and downstream in the Fly River. Changes to the practice of tailings disposal will reduce sediment loads in the river. The cessation of riverine discharge of ex-mill tailings (apart from that required during pipeline maintenance) may also have implications for the geochemical characteristics of riverine deposited sediments, which currently include a mix of ex-mill tailings, waste rock eroding from the failing waste rock dumps and natural (non-mine derived) sediments.

The objective of the hydrogeochemical assessment was to provide a basis for impact assessment of the TSF to support the ESIA for the Project, and in particular the potential for the TSF to impact water quality along the Ok Tedi and Fly River. The assessment included review of available data sets for riverine sediments and water quality along the Ok Tedi and Fly River, and the development of a hydrogeochemical model, *OkChem-TSF*, to predict the chemistry of water discharge from the TSF as well as potential changes the discharge may have on river water quality.

1. EXISTING RIVER WATER QUALITY

There is an extensive record of water quality monitoring of the Ok Tedi and Fly River. Data provided to EGi include quarterly catchment water quality data extending from mid-July 2004. This dataset includes assay data for a range of key parameters (pH, alkalinity, EC, DOC, Temp), major solutes (SO_4 , Ca, K, Na, Mg) and trace elements (Ag, Al, As, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, Pb, Sb, Se and Zn) for nine monitoring locations (LOB, Ningerum, Atkamba, Nukumba, Obo, Ogwa, Oxbow4, Oxbow5 and Lewada (Figure 1)). An initial review of this data has been carried out to provide source terms for modelling. At this stage, the discussion of monitoring data is confined to sulphate and copper as they were particularly relevant to the development of the *OkChem-TSF* model used to assess potential impacts of the proposed TSF on river water quality.

Figure 2 and Figure 3 show statistical summaries for sulphate and copper concentrations at various locations in the Ok Tedi and Fly River during the past five years (i.e., from March 2020 to January 2025). The data indicate significant variability at each site for both sulphate and copper, presumably to some extent associated with differing flow conditions at the time of sampling. However, there are overall trends that are of interest.

For example, in the Ok Tedi there is a significant overall decrease in sulphate concentrations between LOB (median 94 mg/L) and Ningerum (median 37 mg/L), and a further overall decrease between Ningerum and Atkamba (median 16 mg/L). This is consistent with mine-impacted water in the upper Ok Tedi being diluted by inflows from unimpacted lowland rivers and streams such as Ok Birim. Sulphate concentration is lower again at Nukumba (12 mg/L), downstream of the Ok Tedi-Fly confluence, but thereafter median sulphate concentrations remain relatively steady in the Fly River as it flows downstream. This would seem to suggest any release of sulphate from mine derived sediments deposited in the Fly River is not adversely impacting water quality relative to what it is at Nukumba. However, flow in the Fly River typically increases 2 to 3-fold between Nukumba and Lewada hence the sulphate load in terms of tonnes/day also increases 2 to 3-fold. The data suggest a sulphate concentration of around 10 mg/L is effectively "background" for the lower Fly River.

There is also considerable variation in copper concentration between sampling events but overall, the data suggest a different pattern for the river system compared to sulphate. For copper, unlike sulphate, there would appear to be no decrease in concentration in the Ok Tedi between LOB and Atkamba. Instead, median concentrations progressively increase (i.e., LOB 5.5 $\mu\text{g/L}$, Ningerum 6.3 $\mu\text{g/L}$ and Atkamba 8.5 $\mu\text{g/L}$). The apparent increases may not be statistically significant given variation in the data, but the absence of any decrease is noteworthy given there is significant dilution occurring in the lower Ok Tedi, as evident by sulphate concentration decreasing by more than 80% between LOB and Atkamba. It is only in the lower Fly River, below the confluence with the Strickland River, that copper concentration appears to be significantly lower (i.e. medians around 2 $\mu\text{g/L}$ at Ogwa and Lewada).

It is understood dissolved copper concentrations in natural waters not impacted by OTML operations (such as Ok Birim) are typically no greater than 1 $\mu\text{g/L}$, and more likely around 0.5 $\mu\text{g/L}$, which means the concentrations recorded in the Ok Tedi and lower Fly River are typically two-orders of magnitude greater than background. Therefore, the relative consistency of copper concentration in the Ok Tedi and in the Fly River down to Obo, despite ever increasing flow associated with background water inflows, indicates there is additional influx of copper (from one or more sources) to the lower Ok Tedi and Fly River. The discharge from BIGE is a potential source of additional copper to the Ok Tedi, however this is a point-source discharge, the effect of which would only be apparent between Ningerum and Atkamba. Examination of water quality data collected monthly between January 2020 and December 2024 indicates that there was no statistical difference in dissolved copper concentrations in water collected upstream and downstream of Bige, and across this period, while there was some variation in copper concentrations, at each sampling time upstream and downstream concentrations were very similar. The consistency of copper concentrations reported upstream and downstream of this segment of the Ok Tedi suggest there is also a more diffuse source of copper release to the river system. Mine derived sediments deposited within the river system (i.e., sand bars and levees) are known to have high copper contents and therefore represent potential sources, albeit subject to weathering and other hydrogeochemical processes that effect solubility. Additionally, there is solid phase copper being transported down the river associated with suspended solids. These potential sources are discussed in further detail in following sections.

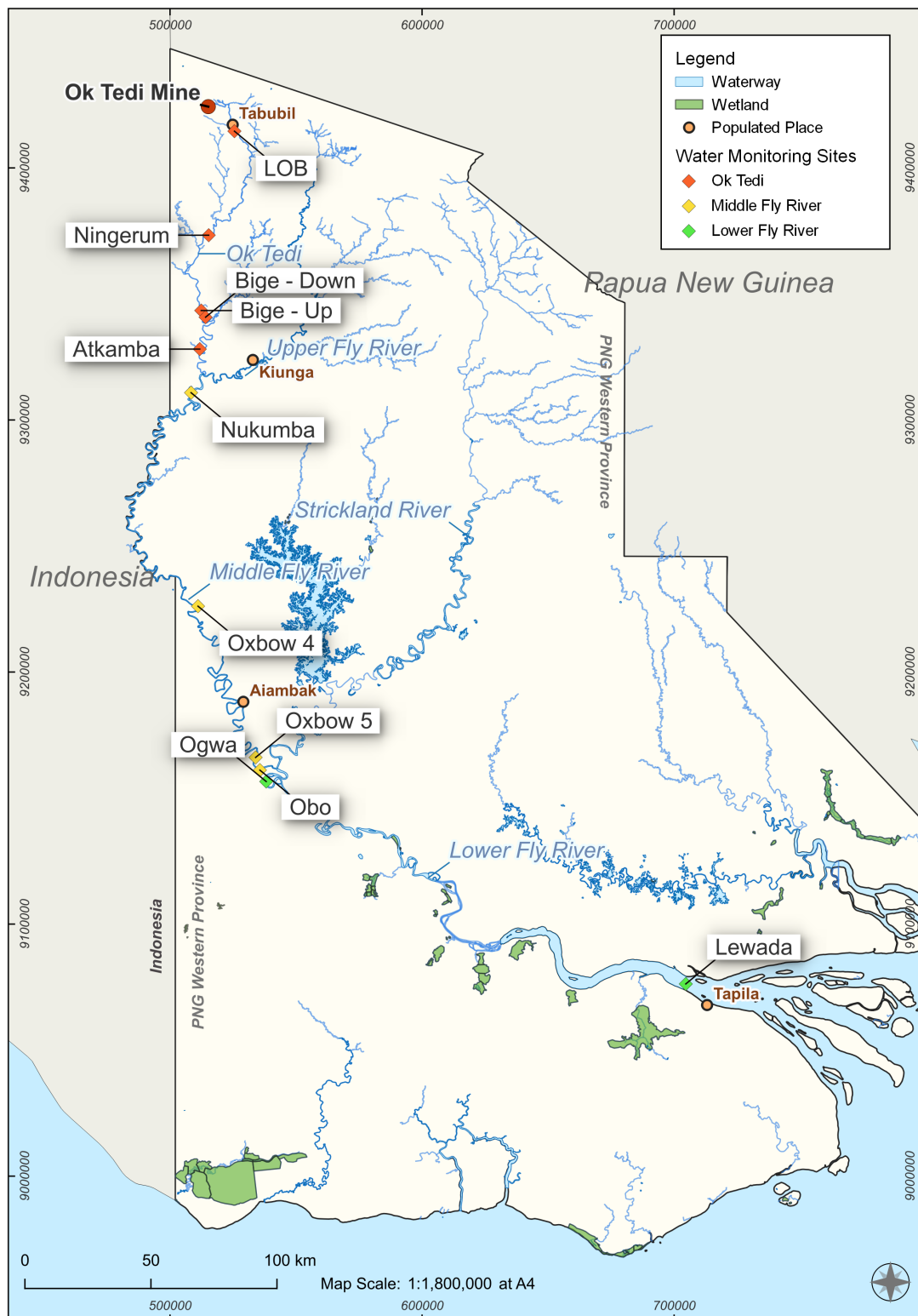


Figure 1: Sampling locations on Ok Tedi and Fly River.

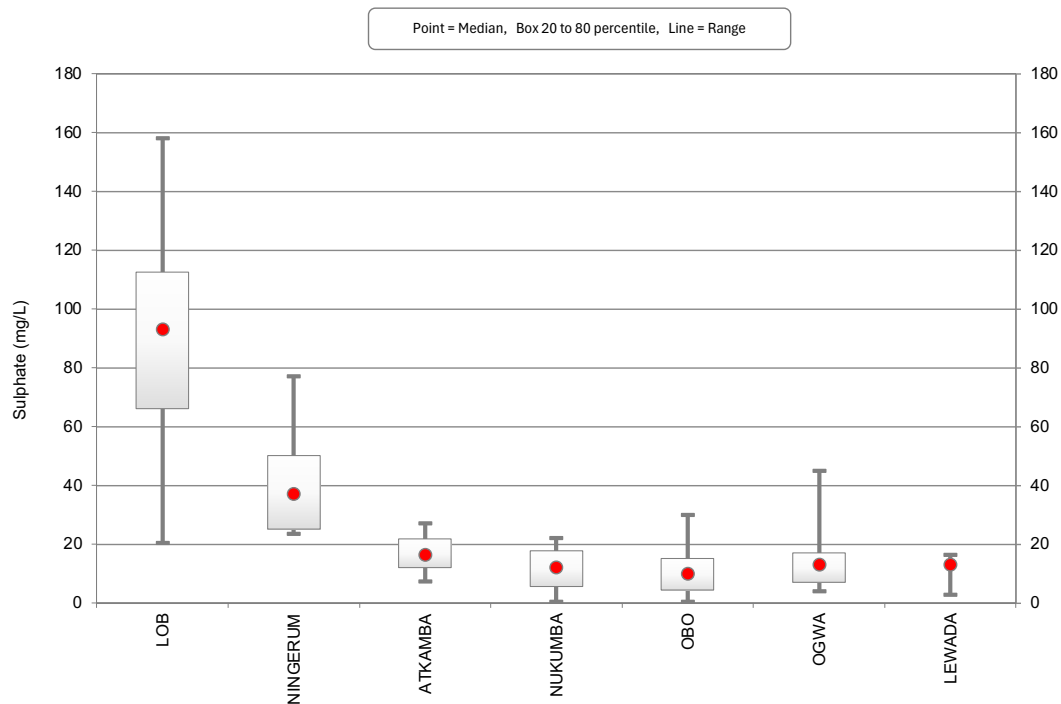


Figure 2: Statistical summary of sulphate concentrations in the Ok Tedi and Fly River between 2020-25

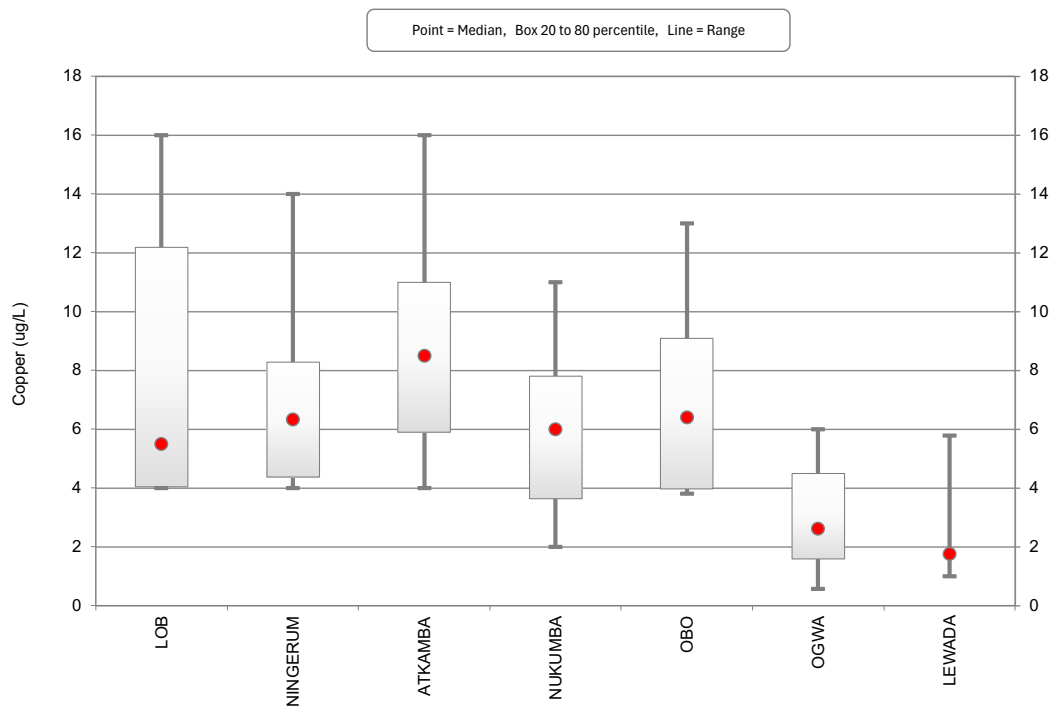


Figure 3: Statistical summary of copper concentrations in the Ok Tedi and Fly River between 2020-25

2. PREVIOUS OKBALARD AND OKCHEM MODELLING

The hydrogeochemical model developed for the Ok Birim TSF and the downstream environs is fundamentally based on modelling carried out by EGi and Dr Geoff Pickup, Consulting Geomorphologist, in 2011-2012 (EGi, 2012). The 2011-12 study was commissioned by OTML to assist with an evaluation of the likely impact of Mine Life Extension (MLE) on:

- The geochemistry of mine derived sediments depositing within the Ok Tedi and Fly River catchments; and
- The potential impact on river water chemistry during operations and post-closure due to acid and elements released from the sediments and contained in drainage from the mine pit.

Three linked models formed the basis of the approach adopted for the MLE study. They included a sediment mass balance model, an acid-base balance and acid generation rate model (*OkBalARD*) and a geochemical mixing and equilibrium model (*OkChem*).

The mass balance model was developed by Pickup et al (2010, 2010a) to estimate the mass, sulphur content and acid neutralising capacity (ANC) of sediments depositing in Mine Area Creeks, the Bige dredge slot and various river reaches from the mine to the Lower Fly River. The model was spreadsheet-based, and the overall approach was semi-empirical and based on observed and planned inputs of tailings and waste rock, together with observed and predicted deposition rates in Mine Area Creeks and river reaches to generate properties of depositing sediments using quarterly time steps.

The results of the mass balance model were subsequently used as input to *OkBalARD*, an Acid Base Balance and Acid Generation Rate model developed by EGi to predict the acid base characteristics of mine derived sediments deposited in the mine area creeks and down through the Ok Tedi and Fly River system on a quarterly basis through to the end of mine life. The output from *OkBalARD*, which was also spreadsheet based, included predicted loadings of dissolved sulphate and acid that potentially could be released because of sulphide oxidation from sediments depositing in each of 12 locations within the river system.

The predicted acid loads from *OkBalARD* were, in turn, used as inputs to *OkChem*, which computed river water chemistry utilising the geochemical phase equilibrium model *Phreeqc* within the Ok Tedi, at the Ok Tedi Bridge, Ningerum, logi and Atkamba and within the Fly River at Nukumba, Manda and Obo under 4 climatic regimes reflecting El Nino, Low, Medium and High flow conditions in the rivers.

OkChem and an earlier version of *OkBalARD* (called *OkARD*) were first developed around 2005 to estimate future water quality in the river system under various mine plan options being considered by OTML at that time, including the need for the Tailings Pyrite Plant (TPP) that was subsequently commissioned in 2008. Both models were modified and updated for the 2011-12 MLE study.

3. OKCHEM-TSF

An expanded version of *OkChem* has been developed for assessment of the Ok Birim TSF, which is referred to as *OkChem-TSF* to differentiate the latest model from earlier versions of *OkChem*. A working version of *OkChem-TSF* is now available and has been used to make preliminary predictions on potential impacts of the proposed Ok Birim TSF on river water quality as reported in this memorandum. *OkChem-TSF* differs from *OkChem* in several ways including:

- It uses existing water quality at Ningerum, adjusted for lower total suspended solids (TSS), as the starting source term for river water chemistry (i.e. it does not specifically model individual inputs upstream of Ningerum)
- Includes a module to predict the water quality of the discharge from the proposed TSF into the Ok Tedi downstream of Ningerum.
- Includes a module to calculate inputs to the river from areas of exposed riverine deposited sediment (i.e. sand bars and levee banks). These inputs were previously determined using the companion *OkBalARD* model.
- Allows for adsorption/desorption reactions between copper and other metals with suspended sediment in *Phreeqc* calculations.

The modules that calculate inputs from the TSF beach area and exposed riverine deposited sediments incorporate the Constant Intrinsic Oxidation Reaction (CIOR) methodology, which was also used in *OkBalARD* and is described below.

Like *OkChem*, the *OkChem-TSF* model is specific for the Ok Tedi-Fly River system and runs on a computing platform linking *Microsoft Excel* with the *Phreeqc* chemical speciation program. The *Excel* component of *OkChem-TSF* contains all input data such as source term chemistries for various water inputs (i.e. background river water qualities, discharge from BIGE). It also includes spreadsheet-based modules for calculation of sulphate and metals loadings from the TSF and from river deposited sediments using CIOR methodology. Embedded within the *OkChem-TSF* file are macros that manipulate the input data and produce an output file that can be read as input to the *Phreeqc* chemical speciation program, which calculates the pH and chemistry of waters at various locations in the Ok Tedi and Fly River downstream of the TSF discharge point for a range of flow conditions.

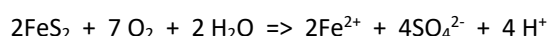
3.1 Constant Intrinsic Oxidation Reaction (CIOR) Module

Inputs to the river system from tailings and mine derived sediments are determined using the CIOR methodology developed by ANSTO (Ritchie 1994, Gibson, et al 1994), which predicts the behaviour of pyritic mine waste materials such as tailings or waste rock placed within a storage facility where the dominant mode of oxygen transfer is diffusion (i.e., where convective air movement is negligible).

The CIOR method assumes the rate at which sulphides oxidise is independent of both the sulphide content of the material and the concentration of oxygen within the surrounding pore space if both have concentrations greater than zero. The rate of oxidation is therefore assumed to be an *intrinsic* property of the pyritic material (and hence referred to as intrinsic oxidation rate or IOR) within the context of the chemical and microbial conditions that prevail in the waste storage facility being modelled.

With the CIOR method it is assumed that sulphide oxidation occurs at a uniform rate throughout a reaction zone, the depth of which is dependent on the rate of sulphide oxidation. Oxidation continues within the reaction zone until such time that all sulphur within the zone is consumed. At that point, the zone becomes 'inert' as it is devoid of sulphide, and hence oxygen diffuses through it without loss, and a new reaction zone is formed within the underlying unreacted waste material. Therefore, with the CIOR method, the oxidation process is modelled as a series of steps down through a waste impoundment, rather than as a continuously moving reaction front.

The IOR for a material is commonly expressed in terms of the amount of oxygen consumed per unit volume (or weight) of material per unit time (i.e., kg O₂/m³/s). In such circumstances, it is generally assumed that sulphide oxidation occurs according to the following reaction:



Based on this reaction the stoichiometric ratio of oxygen to sulphur is 1.75, which means that 1.75 moles of oxygen are needed to oxidise 1 mole of sulphur as pyrite. Alternatively, approximately 1.7 kg of sulphate is produced per kg of oxygen consumed. The overall reaction of a material is commonly expressed in terms of the acid sulphate generation rate (ASGR) with units of tonnes of sulphate generated per hectare per year (i.e., tonne SO₄/ha/y). The reference to *acid sulphate* denotes that the sulphate is released from sulphide oxidation. It does not include any additional sulphate that might be released through dissolution of sulphate-bearing minerals such as gypsum which may also occur within the waste rock.

As noted above, the IOR is a characteristic of the material when placed under the conditions being modelled. In principle, the IOR will depend on a range of factors and a different IOR value may be appropriate for another situation where external parameters such as temperature, pH, and redox potential are markedly different. The IOR values for mine waste materials vary widely, from less than 5x10⁻⁸ kg O₂/m³/s for materials that have relatively low reactivities up to more than 5x10⁻⁶ kg O₂/m³/s for materials that have very high reactivities.

3.2 Geochemical Characteristics of Tailings and Sediment

A key, over-riding assumption for the Ok Birim TSF assessment is that tailings deposited in the TSF beach, and river deposited sediment, will be non-acid forming (NAF) and have ANC/MPA ratios that are of such magnitude that there is zero risk of acid generation. Hence it is assumed that runoff/leachates from these materials will be alkaline. This is a major shift from past modelling when it was assumed a portion of tailings/sediment was PAF and acidified when exposed to atmospheric conditions within the river system. Since commissioning of the TPP, this is no longer the case. However, the NAF tailings that will be placed in the Ok Birim TSF, as well as riverine sediments, will still have a significant sulphide content, most likely in the range 0.5 to 1 %S. This sulphide will be susceptible to oxidation in situations where the tailings/sediment are exposed to atmospheric conditions and there is capacity for ingress of oxygen into the pore space of the tailings/sediment.

The TSF embankments constructed with the coarse-grained cyclone underflow will be particularly susceptible to oxidation processes, as they will be free-draining and dewater readily, thereby allowing for ingress of oxygen. The tailings deposited within cells will comprise both uncycloned final tailings and cyclone overflow (fine grained fraction), which will be spigotted from embankment crests to develop an upstream beach which drains to the TSF pond. The moisture content of tailings deposition will likely remain high, thereby limiting the potential for oxygen ingress, however, some drying of near surface material may be a possibility where active deposition is not occurring. Similarly, there will be potential for oxidation to occur in exposed areas of riverine sand bars and embankments, as was previously assumed with *OkBalARD* modelling for the 2011-12 MLE study.

The IOR value assigned to Ok Tedi tailings and riverine deposited sediments was based on the results of selected site-based laboratory leach tests involving materials considered representative of tailings from the TPP and sediments deposited within the river system since the TPP was commissioned (i.e. NAF with around 1 %S and ANC/MPA ratio exceeding 1.5). The sulphate release data from nine column leach tests were used to estimate an appropriate IOR for modelling. The column designations were ExMill1, Dredge5, Site4Bulk, Site 6 Bulk, LOT Floodplain 1, LOT Floodplain3, Fly Floodplain1, TPP Comp1 and TPP Comp2. The compositions of column leachates during the first 12 months of testing were also used to derive a chemistry representing leachate from oxidising tailings/sediment, consistent with the IOR and assuming the material in the field is exposed and free draining.

The CIOR component of *OkChem-TSF* provides a basis for estimation of the depth of sulphide oxidation within exposed tailings or sediment under a given set of conditions (e.g., IOR, moisture content, depth to water table). In turn, the mass of material undergoing oxidation, and the corresponding load of sulphate that potentially could be released to the river, can be determined. Using sulphate as a base-factor, the loadings of other elements that could potentially be released to the river can also be quantified based on their respective concentrations in the defined tailings/sediment leachate, relative to sulphate concentrations.

Further considerations with the CIOR method are as follows:

- Within *OkChem-TSF*, input values assigned to key parameters in the CIOR module (e.g., IORs) can differ between tailings/sediment sources however for preliminary modelling all sources were assigned the same characteristics pending more data becoming available.
- The defined leachate composition used in *OkChem-TSF* for exposed tailings/sediment is based on actual data from column leach testing and hence is a function of the leach rate used for the lab-based column tests. For the OTML column tests this rate of leaching is typically around 1.5 m³ water/tonne tailings/year. Relating this to a field situation is difficult, as the mass of material being “leached” in the field and reporting as runoff will depend on a range of factors, some of which may be difficult to quantify.
- In the current version of *OkChem-TSF*, the depth of material being “leached” is assumed to be the same as the depth oxidation, as estimated using the CIOR module. The elemental loadings that potentially could report to the river are initially calculated based on the corresponding tonnes of material in the oxidation zone, the defined leachate composition, and the leach rate upon which the defined leachate chemistry was derived.
- The actual leach rate in the field will depend the depth of oxidation, which in turn will depend on conditions (i.e. moisture content). Differences between field and laboratory leach rates are accounted for in *OkChem-TSF* by either diluting the leachate generated by the tailings/sediment with rainfall at a rate consistent with the difference

in field/lab leach rates, or in situations where the field rate is less than the lab leach rate, using the *Phreeqc* component of *OkChem-TSF* to effectively evaporate water.

- For preliminary CIOR modelling of the TSF beach and exposed riverine sediment, a total sulphur content of 1.0 %S and an IOR of $5 \times 10^{-8} \text{ kg(O}_2\text{)/m}^3\text{/s}$ were assumed.

3.3 Physical Characteristics of Exposed Riverine Sediment

Table 1 gives the areas, moisture content, and depth to water table of exposed riverine sediment for various segments of the Ok Tedi-Fly River system that were assumed for preliminary modelling. The data included in Table 1 are the same as used in *OkBaIARD* modelling for the 2011-12 MLE study.

Table 1: Input data pertaining to Exposed Riverine Sediments used in *OkChem-TSF*

Parameter	Flow Condition	Unit	River Segment			
			Lower Middle Ok Tedi (Ningerum - Bige)	Lower Ok Tedi (Bige - D'Albertis)	Upper Middle Fly (D'Albertis - Manda)	Lower Middle Fly (Manda - Obo)
Area	El Nino	(ha)	1350	650	2350	600
	Low	(ha)	1150	490	940	120
	Median	(ha)	855	300	505	70
	High	(ha)	560	110	70	20
Depth to Water table	El Nino	(m)	5	4	2	2
	Low	(m)	3	3	1	1
	Median	(m)	2.5	2.5	0.5	0.5
	High	(m)	1.5	0.2	0.2	0.2
Gravimetric Moisture Content		(%)	15	15	15	15

4. PHYSICO-CHEMICAL PROCESSES AFFECTING RIVER WATER CHEMISTRY

The dissolved concentrations of major ions and trace elements such as copper within the river system will depend not only on loadings from various inputs such as the TSF, BIGE and other mine related sources, but also any solubility constraints that may come into effect within river water. As noted above, the inclusion of *Phreeqc* in the *OkChem-TSF* model provides a basis for quantifying such constraints. The *Phreeqc* program was developed and released for public use by the US Geological Survey (USGS) and is generally regarded as one of the leading hydrogeochemical programs currently available for simulating chemical reactions and transport processes in natural or contaminated water. *Phreeqc* has the capability to model the pH and chemical speciation reactions including solubility, redox, ion-exchange, and surface complexation for a single solution or mixes of two or more solutions. Consequently, the output from *Phreeqc* provides an indication of the distribution of elements between dissolved and solid phases.

4.1 pH

The pHs of source waters are specified as inputs to *OkChem-TSF* but the *Phreeqc* component of the hydrogeochemical model computes the pH of the combined river water mix. This capability is essential as the solubilities of many elements (and especially metals) are pH dependent. The use of *Phreeqc* means the model can compute concentrations of dissolved and solid phases. In the latter case, solid phases of elements will occur when the total concentration in the mix exceeds the solubility product of one or more of the compounds included in the thermodynamic database.

4.2 Precipitation of Solid Phases

The output from *Phreeqc* provides an indication of the distribution of elements between dissolved and solid phases, which in the latter case may be a precipitate that is predicted to form as the various water sources interact, or when an element is predicted to be adsorbed onto a colloidal surface such as ferrihydrite (an iron oxide). The *Phreeqc* program includes a selection of thermodynamic databases that define the various reactions that can occur. The thermodynamic database known as *Minteq.v4* was utilised. This database includes thermodynamic data for many solid mineral phases as well as reaction constants for metals sorption.

Some of the mineral phases included in the database are unlikely to form in the river systems because the dissolved concentrations of relevant elements are well below the saturation indices of such mineral phases. There are also some pure mineral phases in the database that only exist under specific conditions and are unlikely to form under natural river conditions, irrespective of elemental concentrations, and hence they are unlikely to be solubility limiting phases. For example, the crystalline iron oxides such as goethite and hematite are highly stable and have very low solubility, but they require specific conditions to form. Instead, the solubility of iron in the Ok Tedi-Fly River system is more likely controlled by amorphous iron hydroxide.

Table 2 lists the solid phases that were allowed to precipitate if appropriate conditions are met within the river system as modelled. Precipitation will only occur if the concentrations of the respective elements exceed the solubility product for that mineral phase. The exclusion of other solids phases represents a conservative approach in that the model could over-estimate the dissolved concentrations of some elements.

The output file generated by *Phreeqc* includes saturation indices for all solid phases included in the thermodynamic database, which can be used to check if the concentrations of any solutes in river water are supersaturated with respect to solubility indices in the database, and assess whether a solubility constraint should be applied and the model re-run.

Table 2: Solid phases considered in *Phreeqc* modelling of river water.

Element	Solid Phase	Chemical Formula
Calcium	Lime	CaO
	Calcite	CaCO ₃
	Portlandite	Ca(OH) ₂
	Anhydrite	CaSO ₄
	Gypsum	CaSO ₄ .2H ₂ O
Magnesium	Magnesite	MgCO ₃
	Epsomite	MgSO ₄ .7H ₂ O
Iron	Ferrihydrite	Fe(OH) ₃ (amorphous)
	Siderite	FeCO ₃
Aluminium	Aluminium hydroxide	Al(OH) ₃ (amorphous)
	Alunite	KAl ₃ (SO ₄) ₂ (OH) ₆
Copper	Copper hydroxide	Cu(OH) ₂
	Brochantite	Cu ₄ SO ₄ (OH) ₆
	Malachite	Cu ₂ CO ₃ (OH) ₂
Cadmium	Cadmium hydroxide	Cd(OH) ₂
	Otavite	CdCO ₃
Chromium	Chromium hydroxide	Cr(OH) ₃
Cobalt	Cobalt hydroxide	Co(OH) ₂ or Co(OH) ₃
	Cobalt carbonate	CoCO ₃
Lead	Lead hydroxide	Pb(OH) ₂
	Anglesite	PbSO ₄
Nickel	Nickel hydroxide	Ni(OH) ₂
Manganese	Rhodochrosite	MnCO ₃
Zinc	Zinc hydroxide	Zn(OH) ₂

4.3 Metal-Sediment Interaction

A key inclusion to *OkChem-TSF* that was not considered in the original *OkChem*, is metal-sediment interaction. For some metals and metalloids, the factor controlling solubility within a natural system is not precipitation but rather complexation or adsorption reactions involving colloidal matter such as clay minerals or precipitate phases such as ferrihydrite, which is a weakly crystalline iron hydroxide. Copper is likely to be associated with iron hydroxyoxides that occur within some OTML ore types, and hence also occur in tailings. Iron hydroxyoxides also commonly precipitate when iron rich drainage such as acidic rock drainage (ARD) is neutralised with an alkali, which is potentially occurring in Mine Area Creeks where ARD is mixed with alkaline runoff.

Such precipitate can have strong sorption capacities for metals such as copper, cadmium, and zinc. In some situations, sorption reactions may reduce the dissolved concentrations of some elements below that which would be expected based on solubility products of commonly occurring pure mineral phases. It is also the case that copper and other metals could desorb from mine derived, fine colloidal material, thereby adding to dissolved metal loadings in river water.

In recognition of this possibility, one of the source inputs to *OkChem-TSF* is solid-phase ferrihydrite with associated solid-phase copper, and *Phreeqc* is programmed to allow for metal sorption/desorption to occur based on the diffuse layer model developed by Dzombak and Morel (1990)⁵. The diffuse layer model assumes the presence of two types of sorption sites on the ferrihydrite surface, one type with a "strong" binding capacity (designated as Hfo-s) and the other type only a "weak" binding capacity (Hfo-w). The default equilibrium constants for metal complexation reactions involving ferrihydrite included in the *Minteq.v4* thermodynamic database were used. Default properties of Hfo complexation sites were also adopted.

At this stage EGi has no empirical data relating to the occurrence of metal enriched iron hydroxyoxides within the fines fraction of suspended solids being carried by the Ok Tedi or Fly River. Therefore, for preliminary modelling, source term inputs were adjusted so that *OkChem-TSF* predictions for copper concentrations in the Ok Tedi at Ningerum were consistent with median water quality monitoring data for the river system since 2020, as shown in Figure 3.

The input parameters required to model metal-sediment interaction in *Phreeqc* include the amount of solid-phase ferrihydrite present in the water (as moles/L) which determines the amounts of binding capacity (i.e., Hfo-s and Hfo-w), and also the amount of copper (as moles/L) that is initially bound to the ferrihydrite (i.e. Hfo-wCu+). In both cases, the amounts specified for the Ok Tedi at Ningerum were used for model calibration against existing water quality for copper. The amounts downstream were then adjusted assuming direct correlations between the amount of Hfo-wCu+ and the suspended solids load, which at present decreases with distance downstream.

4.4 Suspended Sediment Load

As noted in Section 4.3, metal-sediment interaction may be a significant control factor on dissolved concentrations of copper and some other metals in the river system. This interaction is quantified by the inclusion of metal adsorption reactions involving ferrihydrite in *OkChem-TSF*. In turn, ferrihydrite will likely occur as surface coatings on sediment suspended within the river, in particular the finer fractions such as clay and silt which have much higher specific surface areas compared to sand. It is therefore likely the occurrence of ferrihydrite and associated metal binding sites (Hfo-s, Hfo-w, and Hfo-wCu+) within the river system will be closely related to the TSS load being carried by the river at any location. At present, the main contributor to TSS in the river system is the tailings discharge. There is also erosion from waste rock dumps which may be partially mineralised, as well as non-mineralised TSS that enters via tributaries that are not mine impacted. We currently have no empirical data to proportion the reactive copper between tailings, waste rock, and natural sediments for the current operations, hence for modelling it was assumed reactive copper occurs uniformly across the TSS load transported by the Ok Tedi and Fly River.

Data presented by Geoff Pickup (2025) suggests that TSS upstream of Ningerum will reduce after riverine tailings deposition ceases from a current median of around 2500 mg/L down to median around 1000 - 1500 mg/L, albeit varying over a wide range (i.e. from around 500 - 2000 mg/L) depending on flow conditions, as shown in Figure 4.

Assuming a constant fraction of the reactive copper fraction in the suspended solids, the added reactive copper component in *OkChem-TSF* and *PHREEQC* calculations were proportioned according to the relative reductions in TSS.

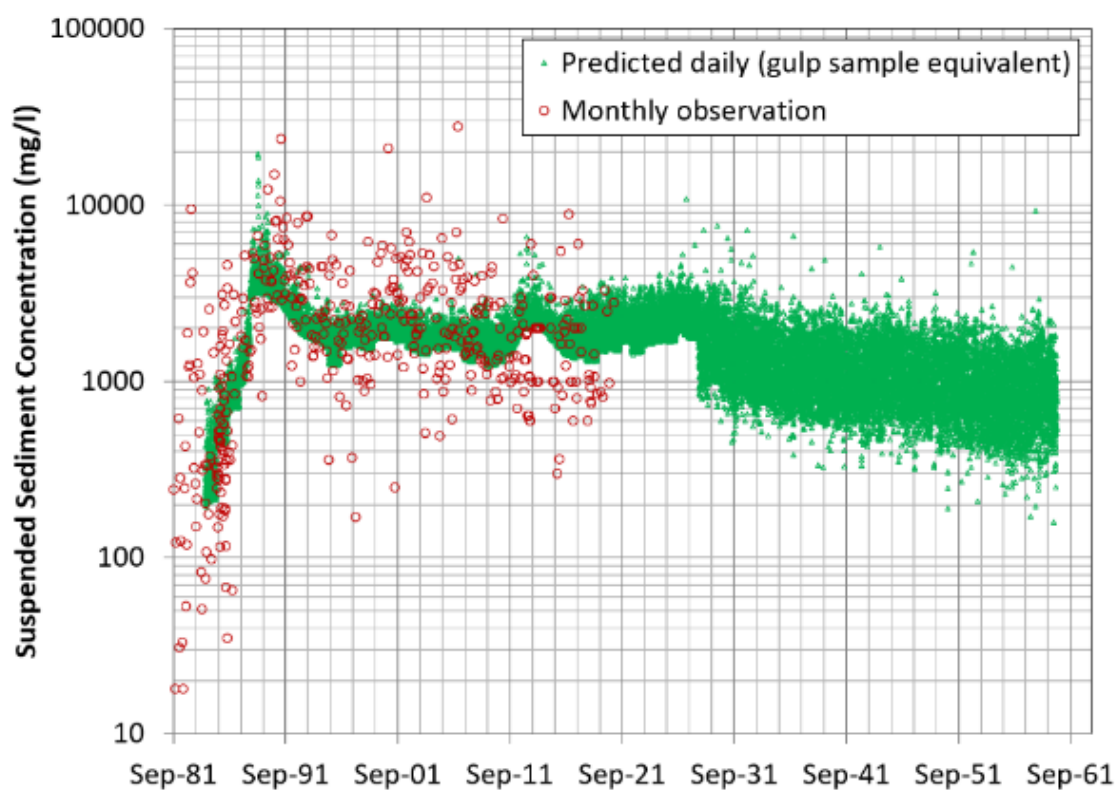


Figure 4: Observed and predicted TSS concentrations for Ningerum (source Pickup 2025)

4.5 Dissolved Organics

The *Phreeqc* component of *OkChem-TSF* also allows for complexation of copper and other metals by organics, which can significantly affect the solubility of metals particularly under circum-neutral and alkaline conditions as exist in the Ok Tedi and Fly River. The *Minteq.v4* thermodynamic database included with *Phreeqc* includes reaction constants for humic acid and fulvic acid which are commonly used as analogues of natural organics within a river system. Humic substances (which generally refers to both humic and fulvic acids) are highly chemically reactive, and have high affinity binding sites for metals, in particular copper. The high stability of dissolved copper-humic complexes can result in higher dissolved copper concentration than what otherwise may be predicted based on other solubility constraints, although it is also the case that organic-complexed copper is generally considered to be much less toxic to aquatic life than ionic (or labile) copper forms.

Analytical methods have been developed for analysis of waters specifically for humic substances, but EGI are not aware of any data specifically for the Ok Tedi-Fly River system. Instead, dissolved organic carbon (DOC) or total organic carbon (TOC) measurements are commonly carried out for routine monitoring. Humic concentrations used in *OkChem-TSF* model were based on measurements of DOC made by OTML as part of the water quality monitoring program. Measured DOCs typically range from 0.5 to 1 mg/L for mountain streams through to 2 to 3 mg/L for the major lowland rivers (i.e. Fly). It is expected that some drainage within the floodplain may have even higher DOC.

For preliminary modelling, the major river inputs (i.e. Fly River above Ok Tedi, and the Strickland River above the Fly River) were assigned mid-range DOCs of 1 mg/L. For smaller, unnamed rivers and streams entering the middle and lower Fly River a DOC of 2 mg/L was assumed.

As humic substances comprise a range of different organic molecules there is no definitive method for conversion of DOC to humic concentration. However, it is generally accepted that humic substances account for 40 to 60% of the DOC in natural rivers (but may be as much as 90% for wetlands) and typically humic substances comprise approximately 55 %C. Therefore, for preliminary modelling the humic concentrations assigned to inputs in *OkChem-TSF* were calculated as follows:

$$\text{Humic (mg/L)} = \text{DOC (mg/L)} * a / b$$

where,

a = portion of humic substance within the measured DOC (40-60%), and

b= the carbon content of humic substance (~55%)

As 'a' and 'b' are very similar the concentrations of humic and DOC are essentially the same. Humic concentrations included as input to *OkChem-TSF* are expressed in units of mg/L but are converted to molar concentrations of organic complexation capacity within the *Phreeqc* program assuming a molecular weight of 2000. This conversion means that a DOC of 1.0 mg/L corresponds to 5×10^{-7} M humic. Assuming 1:1 molar humic – copper complexation, it would correspond to a copper complexing capacity (CuCC) of approximately 32 µg/L. A complexing capacity of this magnitude is consistent with measurements of CuCC made by CSIRO (2005) and Apte (2008) as part of OTML's water quality monitoring program. This indicated CuCC values for the river system ranging from 9 to 38 µg/L.

4.6 Oxygen and Carbon Dioxide Constraints

Phreeqc has the capability of modelling water chemistries that are in equilibrium with atmospheric conditions or other defined partial pressures of gaseous phases. Of relevance to this study are oxygen, which influences the chemical behaviour of redox elements such as iron, which can occur as Fe^{2+} or Fe^{3+} , and carbon dioxide which is typically produced when acidic and alkaline drainages mix. For modelling of Ok Tedi-Fly River system, the following were assumed:

- The concentration of dissolved oxygen in river waters is in equilibrium with the concentration of oxygen in the atmosphere, which is typically defined as 21% O_2 , or a partial pressure of 0.21 atmospheres. This can also be expressed as $p\text{O}_2$ of -0.67.
- The concentration of dissolved carbon dioxide is in equilibrium with a $p\text{CO}_2$ of -3.3. This is slightly higher than if the water was fully equilibrated with atmospheric CO_2 , which is typically defined as 0.0003 atmospheres, or a $p\text{CO}_2$ of -3.5. Tropical rivers such as the Fly typically have a $p\text{CO}_2$ that exceeds atmospheric (i.e., they exhibit CO_2 supersaturation) and consequently are often a net source of CO_2 to the atmosphere, with high $p\text{CO}_2$ driven by high rates of organic matter decomposition within the catchment and resultant elevated concentrations of TOC and DOC in river water. The main consequence of imposing a $p\text{CO}_2$ that is higher than atmospheric is that the predicted river water pH may be slightly lower than what would otherwise be the case if the water was fully in equilibrium with the atmosphere. This represents a conservative approach in that solubilities of some metals may be slightly higher than if it was assumed the water was fully equilibrated with the atmosphere.

5. TSF CONCEPT DESIGN

At this stage, the TSF module of *OkChem-TSF* is based on a rudimentary concept design as outlined in the Project Conventions document provided by Tetra Tech (2025) but also draws on design elements included in Ok Birim TSF Pre-Feasibility Study Design Update (KCB 2024) and technical memoranda prepared by (KCB (2025a, 2025b) pertaining to TSF Concept Design C5. Key elements of the rudimentary concept design are as follows:

- TSF constructed as a ring-dyke structure with two conceptually defined storage cells to be constructed and closed consecutively.

- A total TSF footprint of approximately 1,410 ha, comprising 900 ha for Cell 1 and 510 ha for Cell 2.
- Outer and centreline-raised embankments constructed using cyclone underflow sand.
- No permanent water cover for tailings in the TSF impoundment areas.
- Tailings expected to be NAF based on current geochemical characterisation results.
- TSF positioned above the high banks of the Ok Birim and Ok Tedi and located entirely within the Ok Tedi catchment to minimise introducing new impacts to the Ok Birim, which will remain unaffected by current mining activities.
- During operations, the TSF will operate as a flow-through system with excess decant water reporting to the Ok Tedi in a controlled manner via a siphon system. Each TSF cell will incorporate a siphon discharge system, associated pipelines and outlet, and emergency spillway to enable planned and emergency release of excess TSF decant water.
- Planned discharge of surplus TSF decant water will flow to the Ok Tedi after reduction of suspended solids to meet applicable water quality criteria.
- Surface water diversions will be established to divert existing streams and clean surface water flows away from the TSF during all phases of the project. Sedimentation ponds will be constructed strategically to limit fugitive sediment.

The TSF module in *OkChem-TSF* currently partitions the TSF footprint into two cells (Cell 1 and Cell 2), each of which is further partitioned into four surface types, namely:

- Tailings beach;
- Embankment;
- Natural surface; and
- Decant pond.

The areas assigned to each area can be varied to simulate progressive development of the TSF through time.

As a detailed water balance for TSF Concept Design C5 has still to be developed by KCB, the current version of *OkChem-TSF* incorporates only a rudimentary water balance that is loosely based on the KCB water balance developed for the PFS. For preliminary modelling it was assumed that the water discharged from the TSF into the Ok Tedi will be a mixture of the following water types:

- Bleed water from discharged tailings;
- Runoff/seepage from the exposed tailings beach area associated with rainfall;
- Runoff/seepage from embankments;
- Runoff/seepage from natural ground (area that hasn't yet been covered with tailings); and
- Direct rain into the pond.

The discharge of bleed water will be production dependent, whereas runoff discharges will depend on the respective areas and climatic conditions (i.e. rainfall). It is understood the pond represents a relatively small area, so the rain it directly intercepts will not be a major contributor to the overall water mix within the TSF circuit. The discharge of beach runoff will increase as the beach area develops with time, and correspondingly the discharge of runoff from natural ground will decrease.

For preliminary modelling, only two points in time were considered, the first when Cell 1 is completed, and the second when Cell 2 is completed. This means natural runoff can be ignored, as by definition there won't be any natural runoff reporting to the pond from which water will be discharged to the Ok Tedi. Based on KCB (2025b), Cell 1 will have a footprint of 921 ha, and Cell 2 will be 510 ha, giving a combined area of 1,431 ha. For preliminary modelling, these

areas were nominally partitioned into sub-areas based on 85% beach, 10% embankment and 5% pond. These areas can be revised as necessary for future model runs.

Table 3 gives the relative contributions of different source waters to the discharge from the TSF that were used for preliminary modelling. The bleed water component was based on information in KCB's water balance for the 2024 Pre-Feasibility Study. The runoff/seepage components were based on an annual rainfall of 6.5 m and assumed runoff/seepage equates to 65% of rainfall for the TSF beach, 85% of rainfall for the embankment, and 100% for the pond.

It should be noted that the runoff/seepage contributions from the beach area and the embankment are themselves mixes of leachate generated within the respective zones of oxidising tailings (as established from column leach tests) plus dilution water added to achieve the overall runoff discharges based on rainfall.

Table 3: Relative contributions to discharge from the TSF

TSF INPUT	Discharge (m3/sec)	
	Cell 1	Cells 1 & 2
Tailings Bleed Water	0.33	0.33
Runoff-Beach	1.05	1.63
Runoff-Embankment	0.16	0.25
Runoff-Natural Ground	0	0
Rain direct to Pond	0.09	0.15
Total	1.64	2.36

The source term chemistries assigned to the various TSF inputs to OkChem-TSF are given in Table 4.

Table 4: Chemistries assigned to input water sources included in the OkChem-TSF model

Parameter ¹	Unit	Tailings Bleed Water	TSF Natural Runoff	Rain into Pond	TSF Beach Leach ¹	TSF Embank Leach ¹
pH		9.5	8.1	6.5	7.1	7.1
Al	mg/L	0.1	0.04	0	0.05	0.05
Ca	mg/L	250	35	0.2	540	540
Cd	mg/L	0.0001	0.0001	0	0.0003	0.0003
Cu	mg/L	0.003	0.006	0	0.09	0.09
Fe	mg/L	0.02	0.02	0.01	0.08	0.08
K	mg/L	40	1.3	0	25	25
Mg	mg/L	2.0	2.1	0.1	20	20
Mn	mg/L	0.01	0.05	0	0.2	0.2
Na	mg/L	50	3	0	10.0	10.0
SO ₄	mg/L	700	37	0.1	1400	1400
Zn	mg/L	0.002	0.001	0	0.025	0.025
Humate	mg/L	0.1	1	0	0	0
Alkalinity	mg HCO ₃ /L	200	90	1	57	57

1. These values have been derived from leach column tests and are adjusted in the model to reflect differences in lab and field solid liquid ratios.

6. RIVER AND OTHER INPUTS

The *OkChem-TSF* model computes water chemistry at various locations in the Ok Tedi and Fly River for four different flow conditions as per previous *OkBalARD* / *OkChem* modelling for the 2011-12 MLE study. The four flow conditions

are informally described as representing El Nino, Low flow, Median flow and High flow. Ok Tedi and Fly River discharges currently used in *OkChem-TSF* for each of the four flow conditions are given in Table 5. The discharges nominally equate to 90%, 75%, 50% and 25% of measured river flows exceeding the flow rate used for El Nino, Low, Median and High flow conditions, respectively.

Table 5: River discharges for different flow conditions included in OkChem-TSF

River	Site	Flow (m3/sec)			
		El Nino	Low	Median	High
Ok Tedi	Ningerum (u/s TSF)	83	137	229	542
	logi	247	407	679	1605
	Atkamba (d/s BIGE)	271	546	919	1893
Fly River	Nukumba	731	1419	2099	3283
	Obo	1075	1861	2649	3939
	Ogwa	2338	4046	5759	7593
	Lewada	2744	4749	6759	8769

The individual inputs to *OkChem-TSF* that contribute to river discharge are as follows:

- Ok Tedi (u/s of the TSF);
- BIGE Discharge;
- Fly River (u/s of the confluence with the Ok Tedi);
- Strickland River (u/s of the confluence with the Fly River); and
- Un-named Lowland Streams/Rivers (which enter in each river segment).

The chemistries assigned to input sources are given in Table 6.

Table 6: Chemistries assigned to input river waters included in the OkChem-TSF model

Parameter	Unit	Ok Tedi (u/s TSF)	BIGE Discharge	Upper Fly River	Strickland River	Lowland Streams
pH		8.1	6.5	7.7	7.9	7.5
Al	mg/L	0.04	0.02	0.03	0.03	0.03
Ca	mg/L	35	361	20	23	18
Cd	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001
Cu	mg/L	0.006	0.004	0.0005	0.001	0.0005
Fe	mg/L	0.02	0.13	0.002	0.001	0.001
K	mg/L	1.3	5	0.3	0.6	0.4
Mg	mg/L	2.1	18	1	2.3	1.6
Mn	mg/L	0.05	2.0	0.04	0.04	0.04
Na	mg/L	3	3.8	1	2.1	1.6
SO4	mg/L	37	1041	7	13	16
Zn	mg/L	0.001	0.004	0.0005	0.0005	0.0005
Humate	mg/L	1	0.1	1	1	2
Alkalinity	mg HCO ₃ /L	90	200	60	70	45

7. MODEL CALIBRATION BASED ON EXISTING RIVER (NO TSF)

As noted in Section 4.3, a key factor affecting the concentration of dissolved copper is likely to be adsorption/desorption from suspended sediment, and in *OkChem-TSF* this process is modelled via the inclusion of ferrihydrite and associated ferrihydrite-copper complex, which serves as a source of "reactive" solid phase copper and which, in some circumstances, provides a solubility control for copper via formation of an equilibration reaction between the solid and dissolved phases. As there are currently no empirical data to quantify this input to the model, values were assigned to the mass loading of ferrihydrite and corresponding adsorption sites that are referred to as Hfo-s and Hfo-w.

As also noted in Section 4.3, the input parameters required to model metal-sediment interaction in *Phreeqc* include the amount of solid-phase ferrihydrite present in the water (as moles/L) which determines the amounts of binding capacity (i.e., Hfo-s and Hfo-w), and also the amount of copper (as moles/L) that is initially bound to the ferrihydrite (i.e. Hfo-wCu+).

There are currently no empirical data to quantify this input to the model, hence for model calibration a range of values were specified for the Ok Tedi at Ningerum assuming existing conditions (without a TSF) and the predicted copper concentrations at Ningerum and at sites downstream were compared with recent water quality monitoring data for copper. Based on this best-fit approach, values were assigned to the key parameters affecting the partitioning of copper between solid and dissolved phases for subsequent predictive modelling of the river system with a TSF.

A comparison of predicted dissolved copper versus monitoring data following model calibration is shown in Figure 5, and water quality predictions for other key parameters at various locations within the existing river system (without TSF) are shown graphically in **Appendix A-1**.

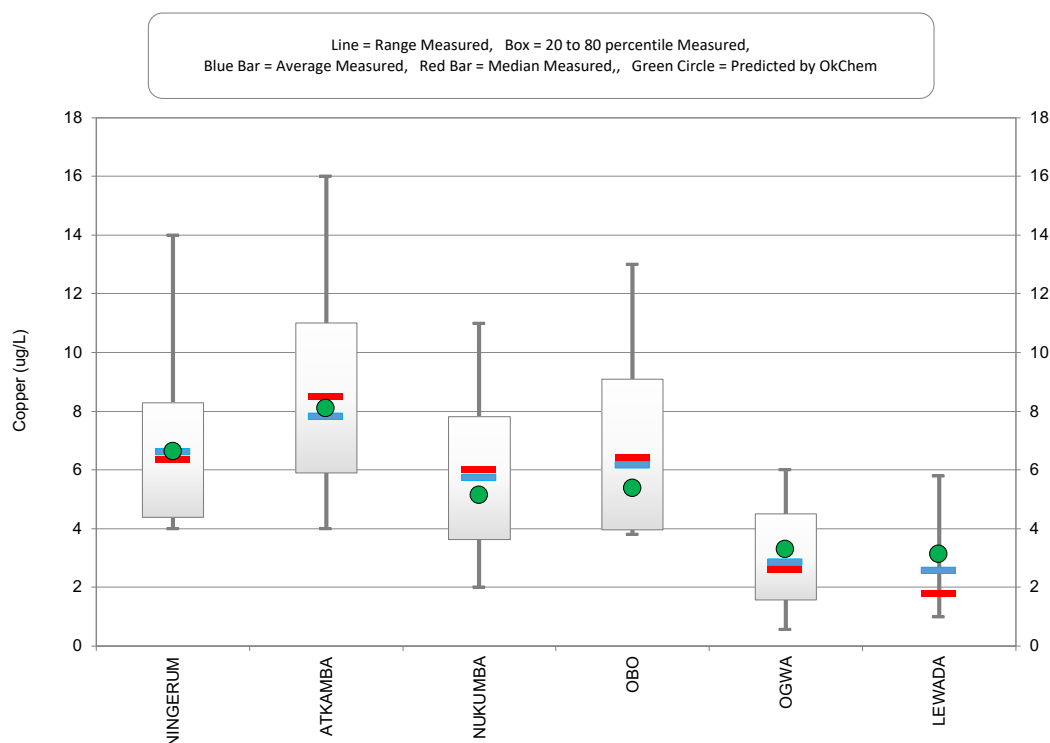


Figure 5: Predicted versus measured copper concentrations for the current Ok Tedi and Fly River (no TSF)

8. PRELIMINARY OKCHEM-TSF PREDICTIONS

OkChem-TSF was used to predict the water quality of the Ok Tedi and Fly River for Stage 1 (completion of Cell 1) and Stage 2 (completion of Cell 2), when the beach areas of the cells are close to maximum. The two stages adopted for preliminary modelling included the following:

- Tailings associated with the TSF beach and exposed riverine sediments were assumed to be NAF.
- TSF beach areas above the water table and embankments were assumed to be unsaturated (i.e., moist only at 5% gravimetric). This is a conservative assumption as it means most of the pore space of the near surface deposited tailings is air-filled and hence available for ingress of atmospheric oxygen. Much higher moisture contents will likely persist, especially close to active tailings deposition, which will markedly limit the potential for sulphide oxidation to occur.
- The depth of oxidation is determined by CIOR (based on IOR and subject to any imposed depth-to-water table constraints), and the mass of tailings within this zone is used to estimate loadings of sulphate and metals released from the beach area.
- For riverine sediments, the exposed areas, moisture contents, and depths-to-water table were based on data previously used in *OkBaIARD* modelling for the 2011-12 MLE study (as per Table 1).
- Four river system flow scenarios were modelled (as per Table 5). Flow has implications for the area of exposure of riverine sediments but in the current version of *OkChem-TSF* the composition and discharge of water from the TSF are assumed to be independent of climatic conditions.

8.1 TSF Discharge

As described above, the CIOR method was used to calculate the depth of sulphide oxidation within the TSF beach and embankment. Based on a moisture content of 5%, and assuming an IOR for the tailings of $5.0 \times 10^{-8} \text{ kgO}_2/\text{m}^3/\text{s}$, the depth of oxidation could theoretically extend to around 7m, (i.e. ingress of oxygen could potentially extend to this depth before being consumed by sulphide oxidation). This could potentially be the case for the embankment given it will comprise coarse sand and would be expected to dewater readily.

However, a depth of this magnitude would seem unrealistic for the beach area given the high rainfall environment and the periodic overtopping by fresh tailings discharge. Therefore, the oxidation depth for the tailings beach was constrained to 1m, which implies the tailings below 1m remain permanently saturated (i.e., not influenced by surface drying).

The model predicts an average discharge from the TSF to the Ok Tedi of 1.64 m³/s at the end of Stage 1 (completion of Cell 1), and 2.36 m³/s at the end of Stage 2 (completion of Cell 2).

The predicted water quality of discharge from the TSF at the end of Stage 1 is given in Table 7. This discharge represents a mix of tailings bleed water, runoff/leachate from the tailing beach, and runoff/leachate from the embankment. The TSF discharge quality at the end of Stage 2 differs only slightly from that given in Table 7 for Stage 1.

Table 7: Predicted Chemistry of discharge from the TSF for Stage 1 (completion of Cell 1)

pH	TDS (mg/L)	SO ₄ (mg/L)	Ca (mg/L)	K (mg/L)	Mg (mg/L)
6.3	1318	925	343	22	11
Al	Cd	Cu	Fe	Mn	Zn
0.001	0.0002	0.049	0.050	0.11	0.014

The main findings with respect to sulphate and copper release are as follows:

Stage 1 - Completion of Cell 1

- The sulphur generation rates (SGR) estimated using the CIOR method were approximately 27 t(SO₄)/ha/y for the beach area and 195 t(SO₄)/ha/y for the embankment. The difference reflects the greater depth of oxidation assumed for the embankment.
- The combined release of sulphate from the beach and embankment at the completion of Cell 1 is predicted to be approximately 1,240 g (SO₄)/s, based on beach and embankment areas of 783 ha and 92 ha, respectively.
- To provide some perspective, a release rate of 1,240 g (SO₄)/s would theoretically increase the sulphate concentration of the Ok Tedi at the discharge point by approximately 5 mg/L with a median flow¹ of 229m³/s.
- The actual discharge from the TSF will also have a small sulphate contribution associated with bleed water runoff, but it will be relatively minor in comparison to sulphate release from the beach and embankments. Overall, the model estimates that the concentration of sulphate in the Ok Tedi will increase from approximately 37 mg/L upstream of the TSF discharge to 43 mg/L downstream under median flow, (i.e. an increase of around 6 mg/L).
- The predicted leach rate for copper from the beach and embankments at the completion of Cell 1 is 0.08 g Cu/s, which theoretically could increment the copper concentration in the Ok Tedi by approximately 0.3 µg/L with median flow. This is a relatively small addition given a copper concentration of 6.0 µg/L is assumed for the current Ok Tedi immediately upstream of the proposed TSF at Ningerum, which is based on monitoring data for that location.
- More than half the dissolved copper in TSF discharge water will revert to solid phase again upon mixing with Ok Tedi water because of adsorption onto ferrihydrite that is associated with the TSS load being transported down the Ok Tedi. hence, the predicted incremental rise in dissolved copper in the Ok Tedi is much less than 0.3 µg/L at only 0.1 µg/L.

Stage 2 - Completion and Cells 1 and 2

- At the completion of Cell 2, the release of sulphate from the combined Cells 1 and 2 beach areas and embankment is estimated to be approximately 1,930 g (SO₄)/s, which increases the predicted concentration of sulphate in the Ok Tedi by approximately 9 mg/L under median flow (i.e., from 37 mg/L upstream of TSF discharge to 46 mg/L downstream).
- For copper, the estimated release rate is 0.12 g Cu/s. This release rate of copper equates to a nominal increase of approximately 0.5 µg/L for the Ok Tedi under median flow, which again is relatively minor in comparison to the dissolved copper concentration of 6 µg/L upstream of the discharge point. OkChem-TSF predicts an incremental increase in dissolved copper of only 0.2 µg/L, as most of the added copper (around 60%) adsorbs to suspended solids.

8.2 Water Quality Predictions for the Ok Tedi and Fly River

Water quality predictions for key parameters at various locations within the Ok Tedi and Fly River system are shown graphically in **Appendix A-2** for Stage 1 representing the completion of Cell 1, and in **Appendix A-3** for Stage 2 representing the completion of Cell 2. The main findings are as follows:

- The commissioning of the TSF will result in a significant reduction in the TSS in the Ok Tedi at Ningerum as well as further downstream. Calibration of *OkChem-TSF* model was based on the load of "reactive" solid phase copper being associated with a median TSS of 2,500 mg/L for the river without a TSF (as discussed in Section 4.3 and 4.4). The TSS at Ningerum was reduced to 1,000 mg/L to represent sediment load with a TSF.

¹ The modelled increase in sulphate concentration is a conservative estimate since the actual TSF discharge point is downstream of the Ok Birim confluence, which has a significant impact on flow (median flow 180 m³/s during 2023/2024). Similarly, modelled increases in copper concentration are likely conservative.

- The model predicts that commissioning of a TSF will only have a minor effect on the quality of the Ok Tedi immediately downstream of the discharge point, irrespective of flow condition.

Water pH

- The predicted pH of the Ok Tedi immediately downstream of the TSF discharge remains virtually unchanged from the input pH assigned to the Ok Tedi at Ningerum under high and median flow conditions (i.e. the pH remains at pH 8.1) and decreases only very slightly under low flow and El Nino conditions. The model also predicts a very slight downward trend in pH with distance downstream for all flow conditions but rising again after the confluence of the Fly and Strickland rivers. However, all these changes are within 0.1 of a pH unit and therefore of no significance.

Sulphate

- Sulphate concentration is predicted to increase slightly due to TSF discharge. For Stage 1 the concentrations predicted for the Ok Tedi immediately downstream of TSF discharge are between 3 to 17 mg/L higher than upstream at Ningerum, depending on river flow (i.e. greater increase with lower flow). For Stage 2 the increases range from 4 to 25 mg/L, depending on river flow.
- Further downstream, sulphate concentrations typically trend lower reflecting significant dilution by inflows of natural rivers and streams. However, under El Nino the sulphate concentrations in the Ok Tedi at Atkamba are significantly higher (up to around 60 mg/L). This elevation in sulphate concentration is the result of sulphate release of exposed mine-derived sediments in the middle and lower Ok Tedi, the areas of which are significantly greater under the very low flows assigned to El Nino. Downstream of the confluence of the Ok Tedi with the Fly River the predicted concentrations of sulphate are lower, typically around 15 to 20 mg/L for low to high flow conditions, and 20 to 30 mg/L for El Nino.

Copper

- Figure 6 shows predicted copper concentrations in the river system without a TSF (current river) and with a TSF at the end of Stage 2. The model predicts there will be negligible change in copper concentration in the Ok Tedi immediately downstream of the TSF discharge irrespective of whether there is a TSF or not (i.e., copper concentration remains between 6 to 7 µg/L).

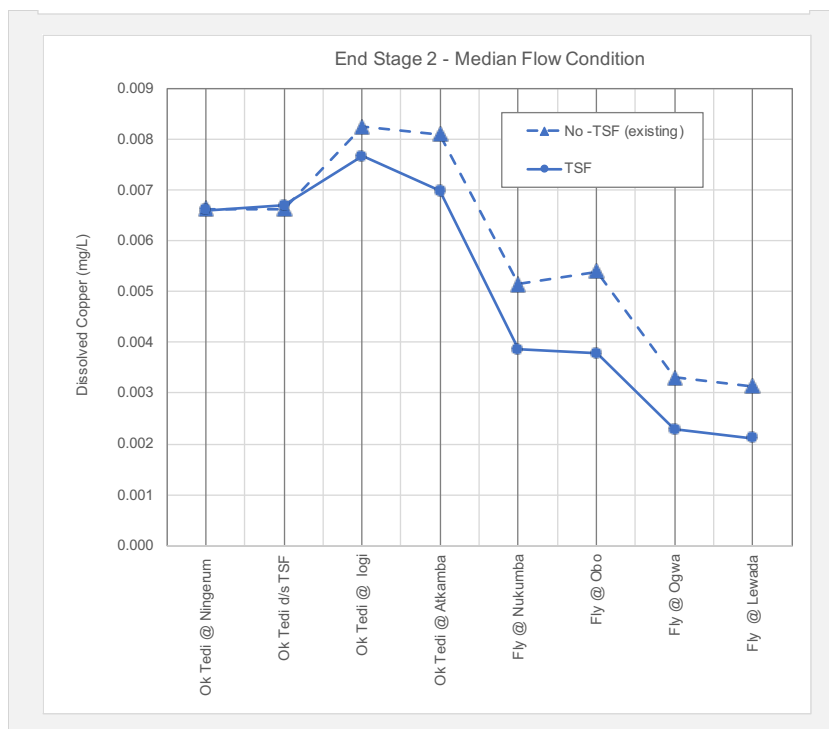


Figure 6: Comparison of predicted copper concentrations without and with TSF

- Further downstream, predicted copper concentrations mimic the pattern that currently exists, albeit with concentrations being around 1 µg/L lower than concentrations predicted for the current river without a TSF.
- Predicted copper concentrations for the Ok Tedi at logi and Atkamba are slightly higher than Ningerum at between 7 to 8 µg/L, but then decrease significantly below the confluence of the Ok Tedi and Fly River, consistent with the large dilution effect provided by the upper Fly. Predicted copper concentrations in the Fly River at Lewada are between 2 to 3 µg/L, which is comparable to the range of concentrations currently observed.
- Although predicted copper concentrations in the Ok Tedi show little variation with distance downstream, the load of dissolved copper being carried by the river (expressed as mass per unit time) increases significantly because of increasing flow. For example, under median flow the predicted dissolved copper load increases from 1.5 g/s in the Ok Tedi immediately downstream of the TSF discharge to 6.5 g/s at Atkamba. Predicted copper and sulphate loadings in the river system are shown graphically in **Appendix A-4**.
- Potential sources contributing to dissolved copper load include discharge from BIGE and leachate from mine derived sediments exposed in the lower Ok Tedi. However, the model predicts these sources account for only a small fraction to the dissolved copper load. For example, the discharge from BIGE accounts for less than 0.01 g/s, and exposed mine-derived sediments account for approximately 0.1 g/s under median flow conditions. Refinements of these inputs are required, but the model in its current form indicates a major contributor to dissolved copper load of lower Ok Tedi is desorption from fine colloidal material (modelled as ferrihydrite) that is a component of the TSS being carried by the river.

9. SUMMARY

This memorandum describes development of a hydrogeochemical model to predict potential impacts of the proposed lowland TSF on the water qualities of the Ok Tedi and the Fly River downstream of the TSF. The model, referred to as *OkChem-TSF*, has been developed specifically for the TSF project and is now fully functional, but will be refined as the conceptual design of the TSF evolves and new data on inputs to the model become available. The framework and chemical principals incorporated into *OkChem-TSF* are founded on concepts that were initially formulated for



OkBaIARD and *OkChem*, which were models first developed around 2005, then updated in 2011-12, to assist OTML with mine planning.

OkChem-TSF predictions of water quality are presented in this memorandum for two stages; the first representing the situation at completion of Cell 1, and the second at completion of Cell 2. The results of preliminary modelling suggest the TSF will have minimal effect on Ok Tedi water quality. Depending on river flow, there could be a minor increase in sulphate concentration, but little or no change is predicted for dissolved copper concentration. With copper, the main determinant of concentration within the river system would appear to be adsorption/desorption from mine derived sediment fines being transported by the river, rather than loadings of copper associated with TSF discharge or leachates from exposed sand bars or levees. Factors that will affect adsorption/desorption processes include the mass of fine colloidal material (modelled as ferrihydrite) in the Ok Tedi upstream of the TSF, the mass of copper already bound to such material, and ambient water quality characteristics such as pH and TOC.

The TSF project is still at the concept stage, and background data for some inputs to the model are limited or unknown. As such, water quality predictions given in this memorandum should be regarded as preliminary, with a level of accuracy best described as indicative rather than quantitative. It is expected refinements to the model and input data will be made for future reporting.

10. REFERENCES

- Apte, S. C. (2008).** Biogeochemistry of copper in the Fly River. Published in: *Developments in Earth & Environmental Sciences* Vol 9, pp. 321-373, 2008.
- CSIRO (2005).** Copper speciation and toxicity in the Fly River: A Review. Authors NJ Rogers, SC Apte, JL Stauber and AW Storey). Report Prepared for Ok Tedi Mining Ltd, No. ET/IR745RMay 2005.
- EGi. (2012).** Modelling the ARD characteristics of mine derived sediments in the Ok Tedi and Fly River system and prediction of river water. chemistry during operations and post-closure. Mine Life Extension Project - Mine Plan Revision 4. Report prepared by EGi and Dr Geoff Pickup, Consulting Geomorphologist for Ok Tedi Mining Limited. Report No. 2404/1012. July 2012.
- Gibson, D. K., Pantelis, G. & Ritchie A. I. M. (1994).** The relevance of the intrinsic oxidation rate to the evolution of polluted drainage from a pyritic waste rock dump. Published in: *Proceedings of the 3rd International Conference on the Abatement of Acidic Drainage, Pittsburgh, Pennsylvania, April 24-29, 1994, Vol. 2, pp. 258-264.*
- KCB (2024).** Ok Birim TSF Pre-Feasibility Study Design Update. Ok Tedi Mine. Report prepared by Klohn Crippen Berger Australia Pty Ltd. Ref 01D09135A83.730. 14 June 2024.
- KCB (2025).** OTML Lowlands TSF - Ok Birim Option C Concept Design Memorandum. Report prepared by Klohn Crippen Berger Australia Pty Ltd. Ref 01D09135A95. 31 July 2025.
- KCB (2025).** TFS Concept Design C5. Technical Memorandum prepared by Klohn Crippen Berger Australia Pty Ltd. Ref 01D09135A95. 16 October 2025.
- Pickup, G. (2025).** Impact of a tailings storage facility at the lower Ok Tedi (Ok Birim) site: Geomorphology, sediment transport and riverine geochemistry, 12 December 2025.
- Pickup, G. and Cui, Y. (2010).** 2010 Sediment modelling study: Sediment deposition and water level changes for mine closure in 2013 and mine life extension to 2024. Environment Dept., Ok Tedi Mining Ltd.
- Pickup, G., Pile, J., Kundapen, H. and Nanuk, J. (2010a).** A review of the acid neutralising capacity and sulphur content of mine-derived sediments in the Ok Tedi upstream of Bige. Environment Dept., Ok Tedi Mining Ltd.
- Ritchie A. I. M. (1994).** Sulphide oxidation mechanisms: Controls and rates of oxygen transport. Published in: *Mineralogical Association of Canada, Short Course Handbook on Environmental Geochemistry of Sulfide Mine-Wastes, Waterloo, Ontario, May 1994. Chapter 8, pp. 201-245.*
- Tetra Tech (2025).** Ok Birim Tailings Storage Facility Project. Project Conventions. Ref: 754-POMEN374244C_PM04_ Project Conventions. 23 September 2025.

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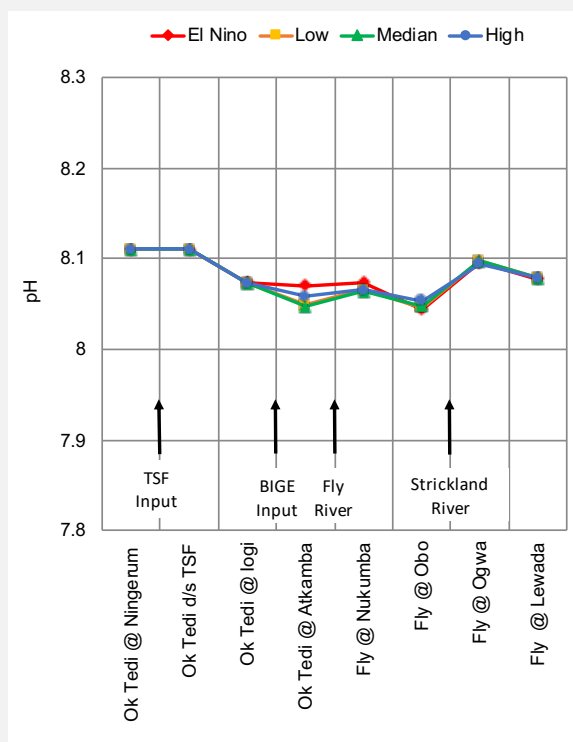
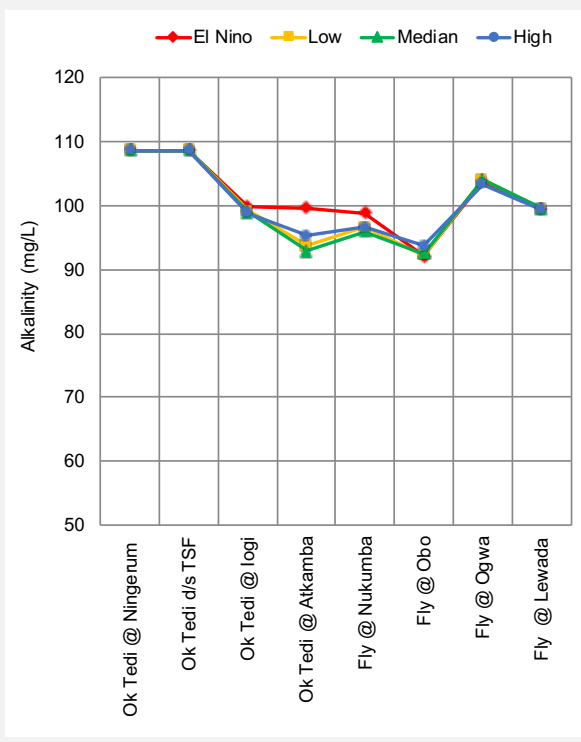
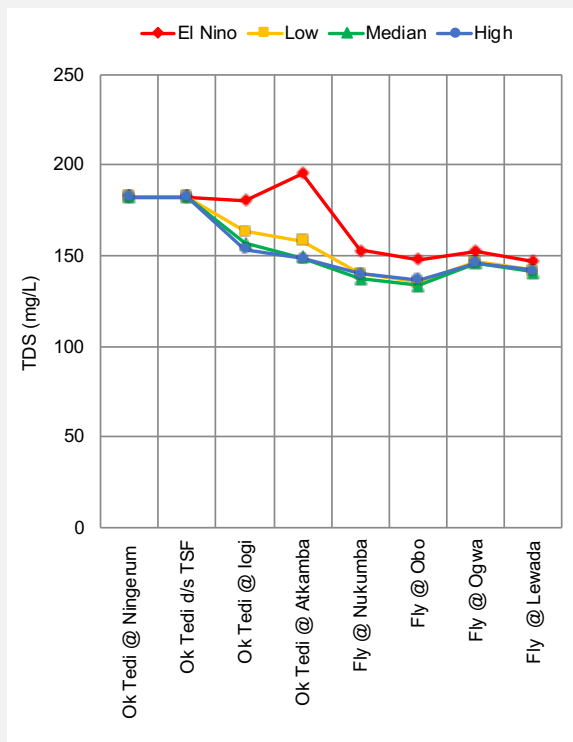
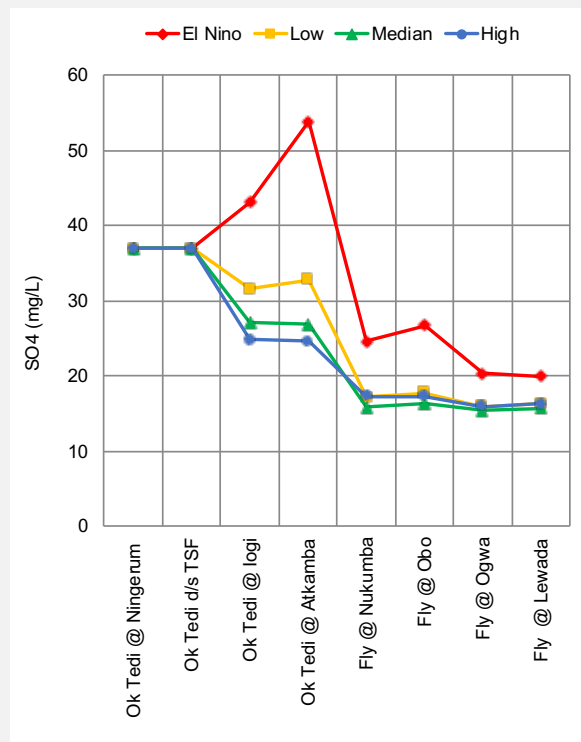
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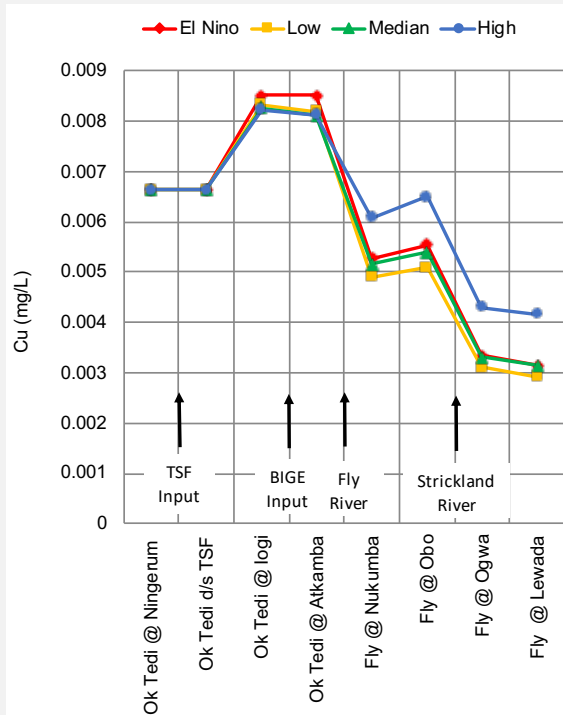
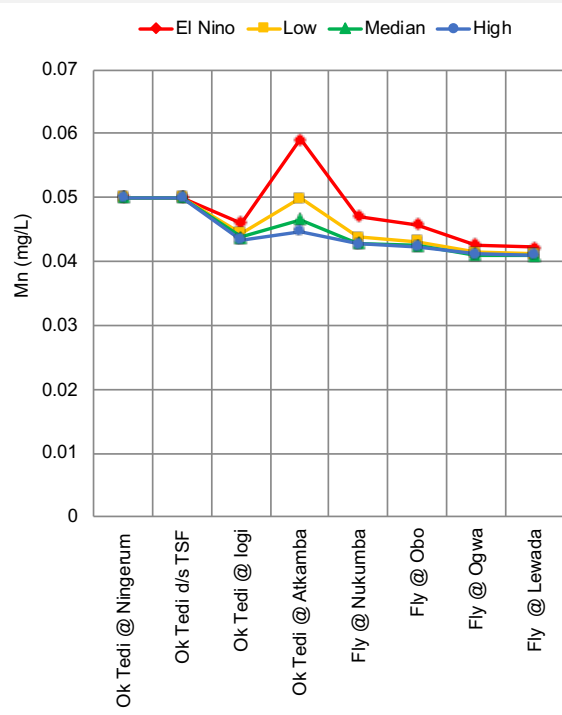
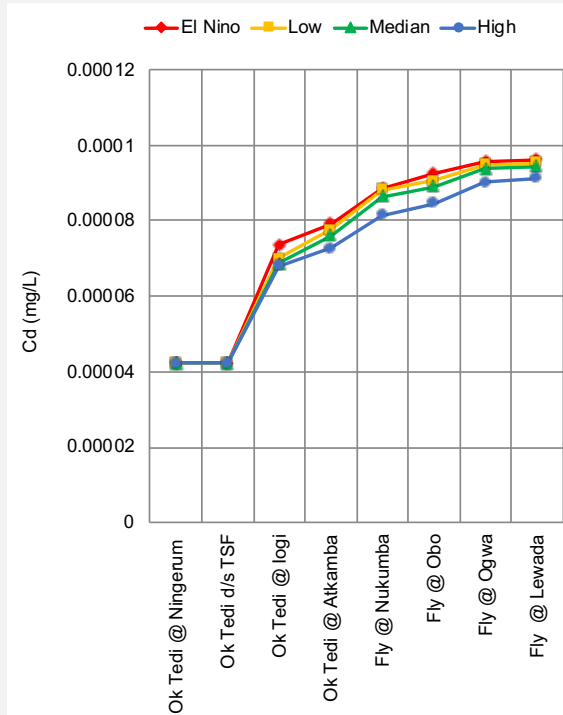
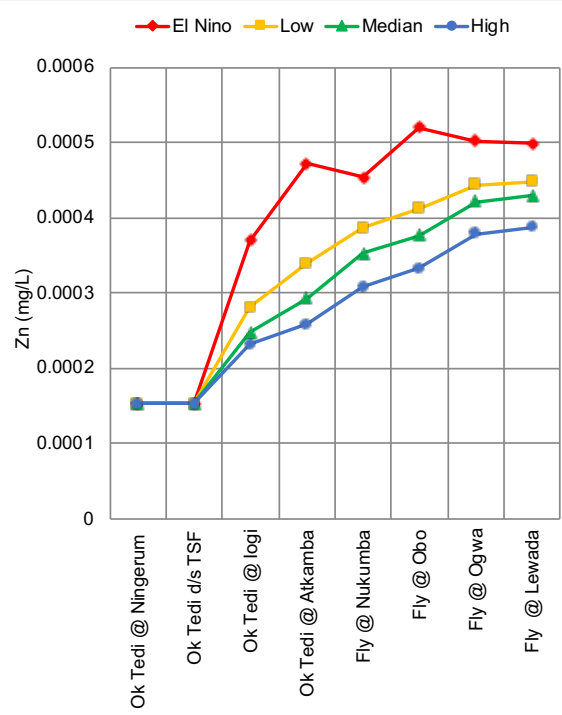
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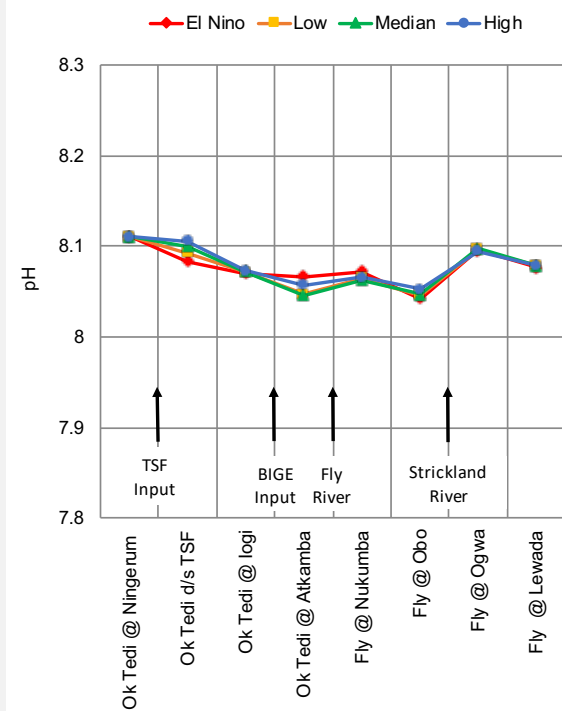
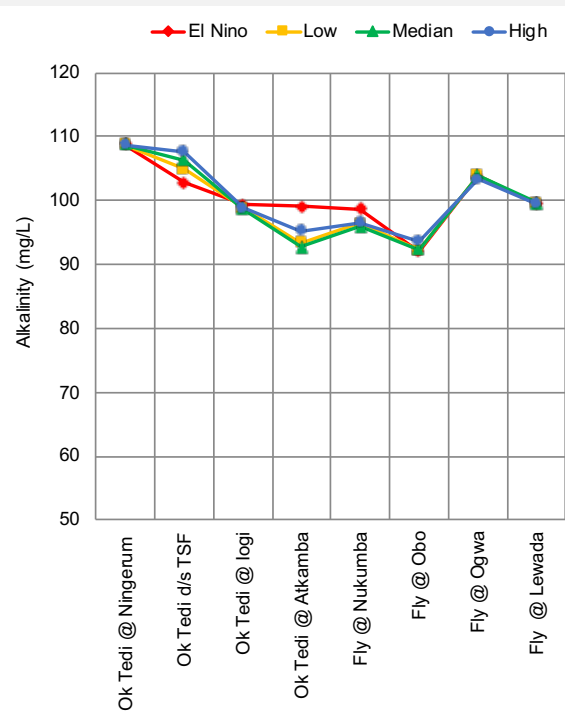
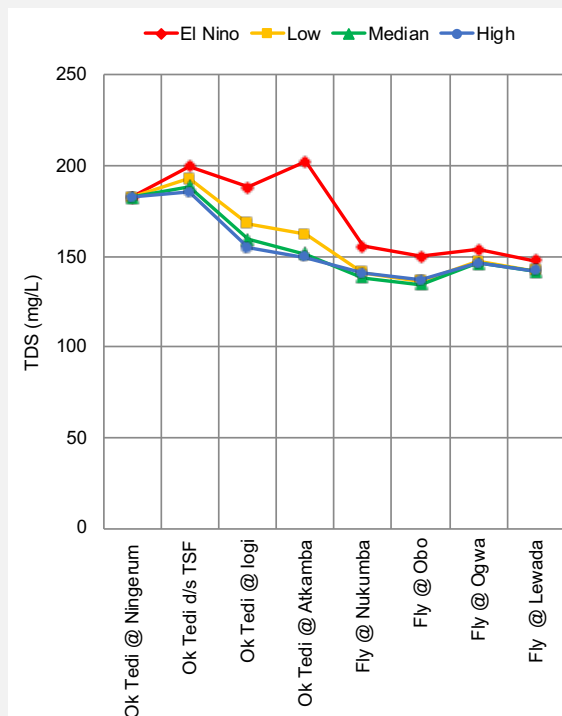
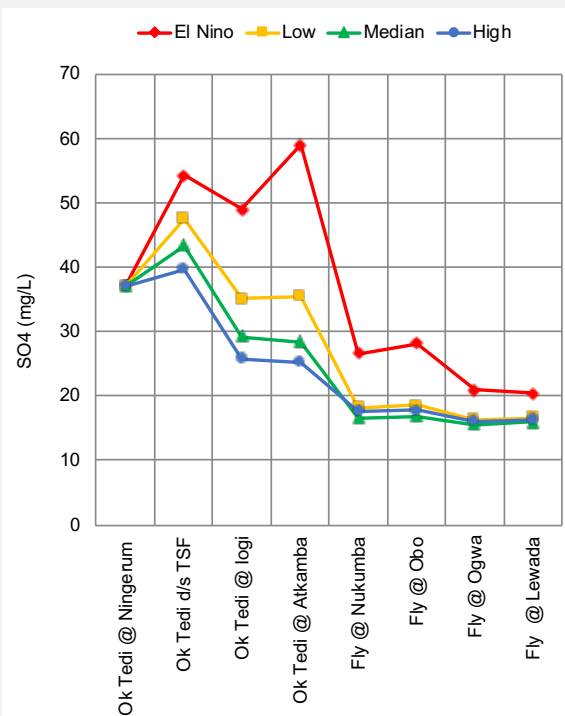
Appendices



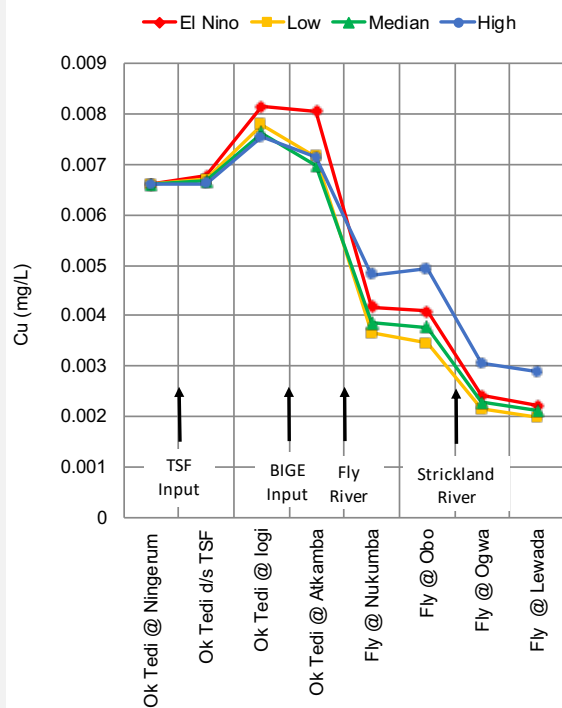
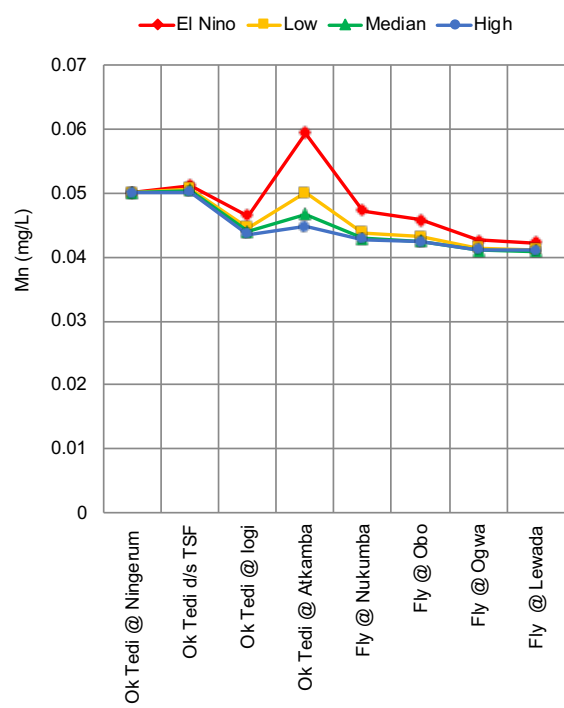
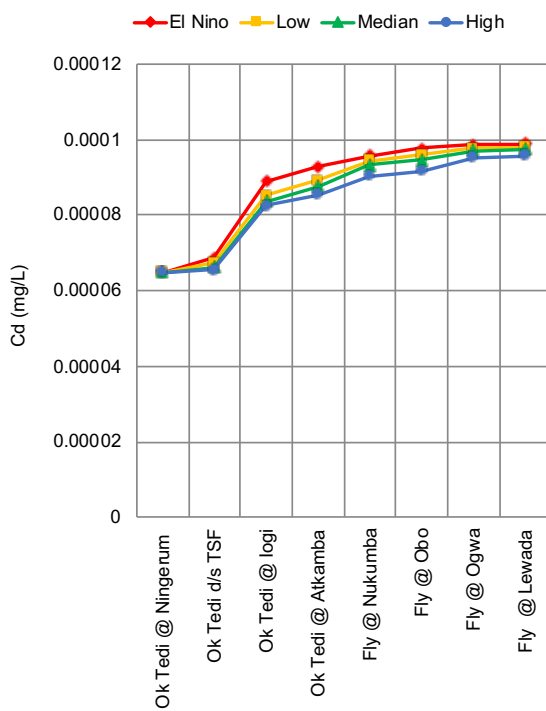
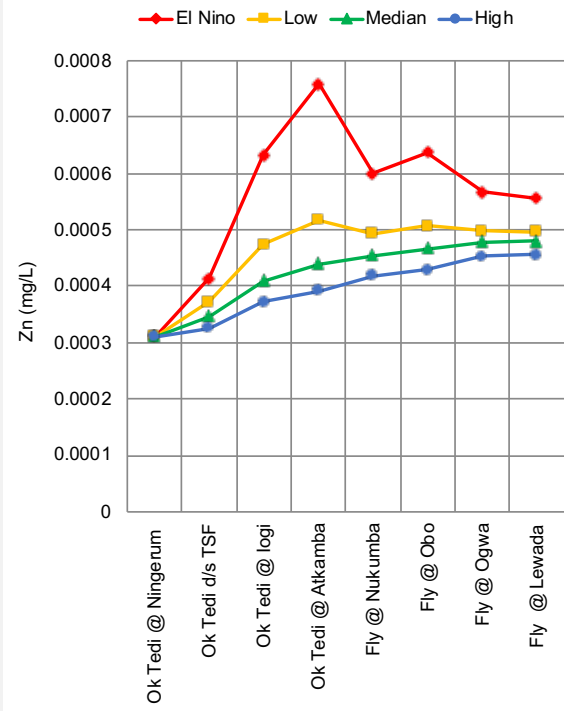
Appendix A-1. Predicted river water chemistries - No TSF (Current)



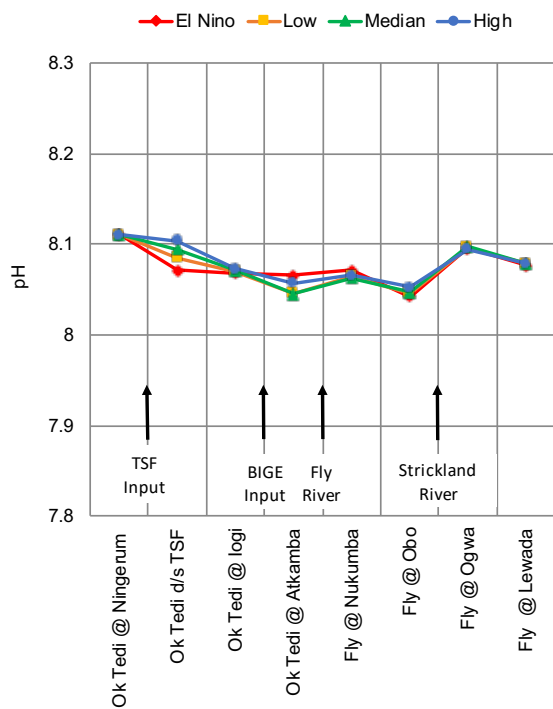
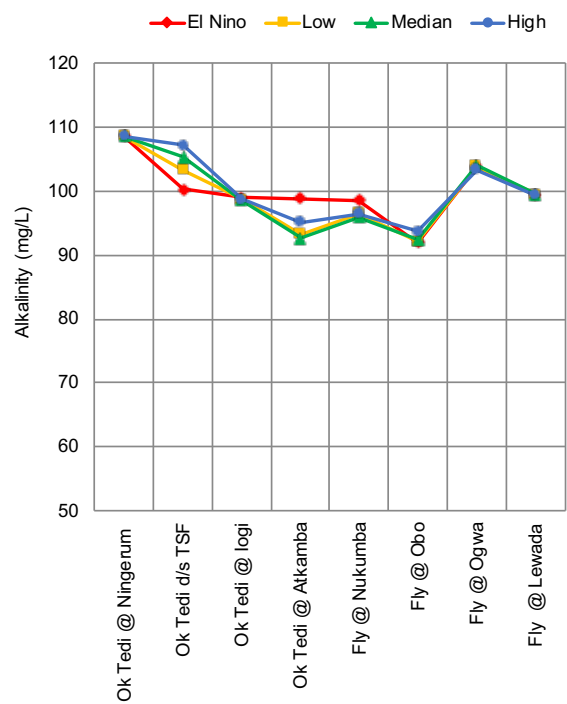
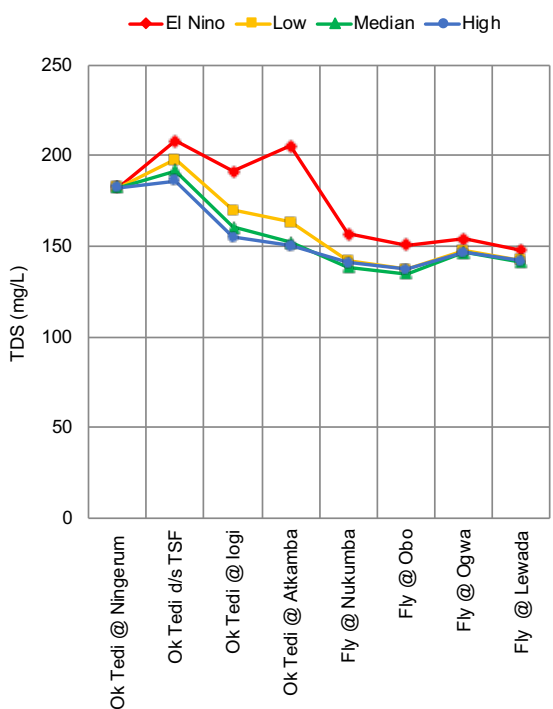
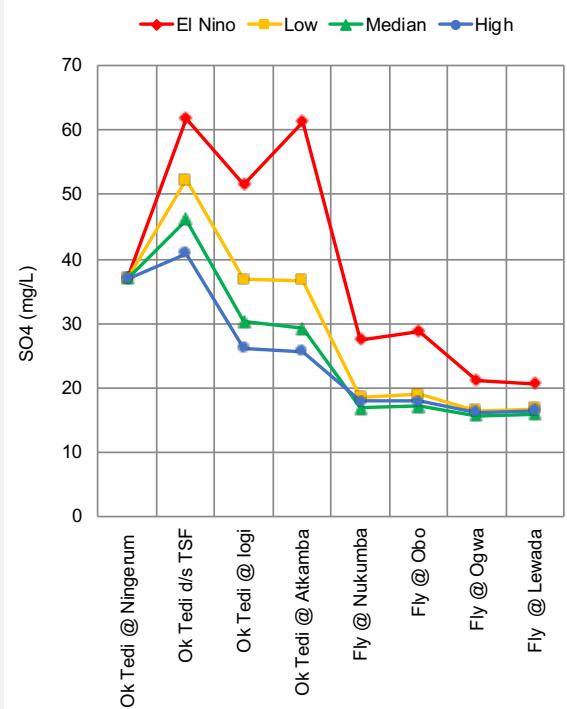
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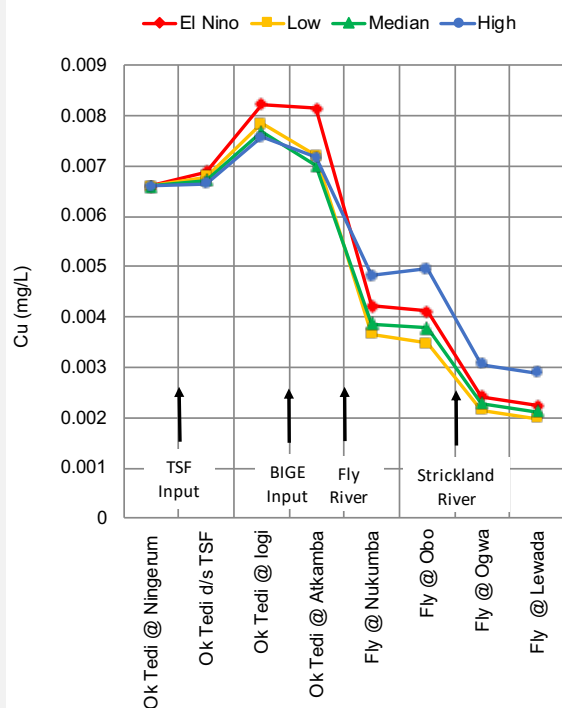
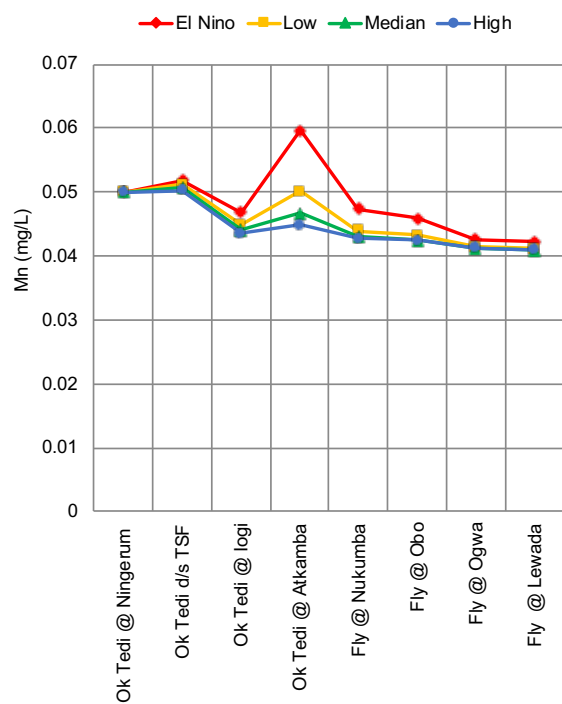
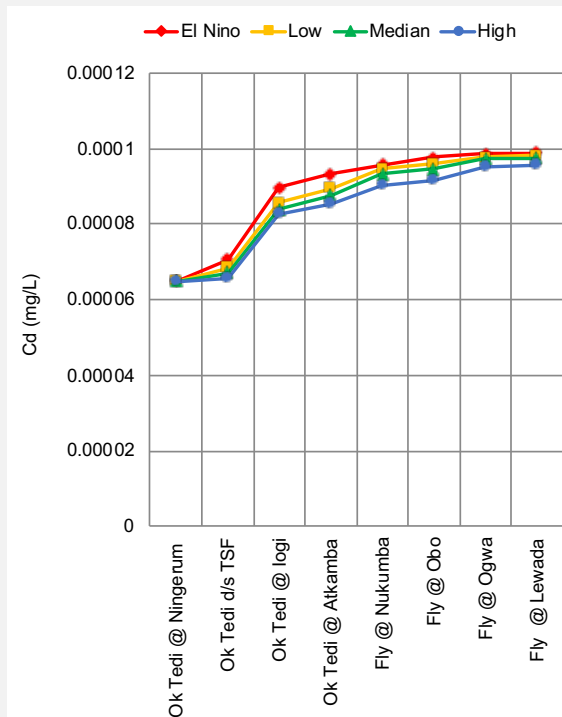
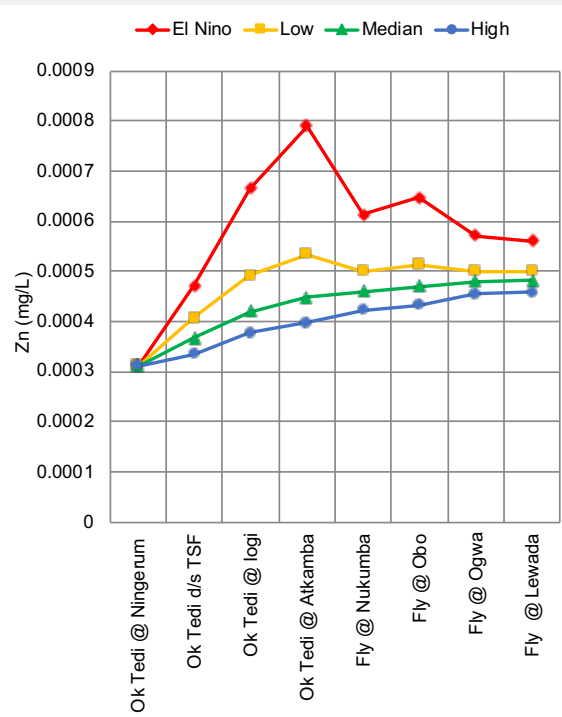
Appendix A-2. Predicted river water chemistries - With TSF at completion of Cell 1 (Stage 1)



Appendix A-2. Continued

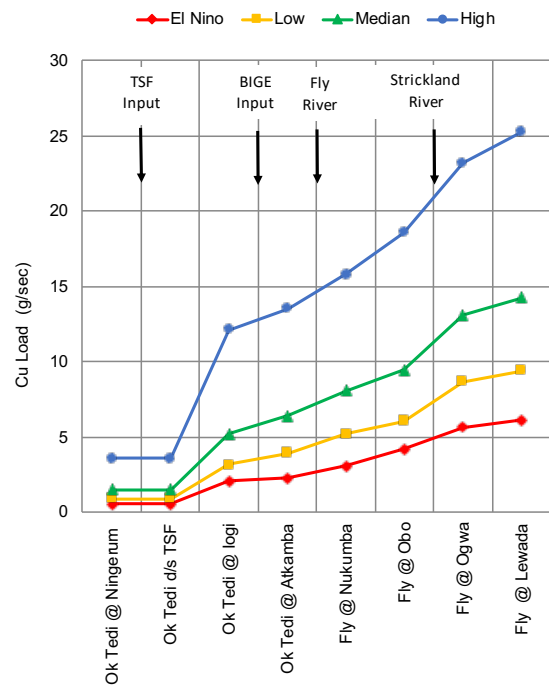
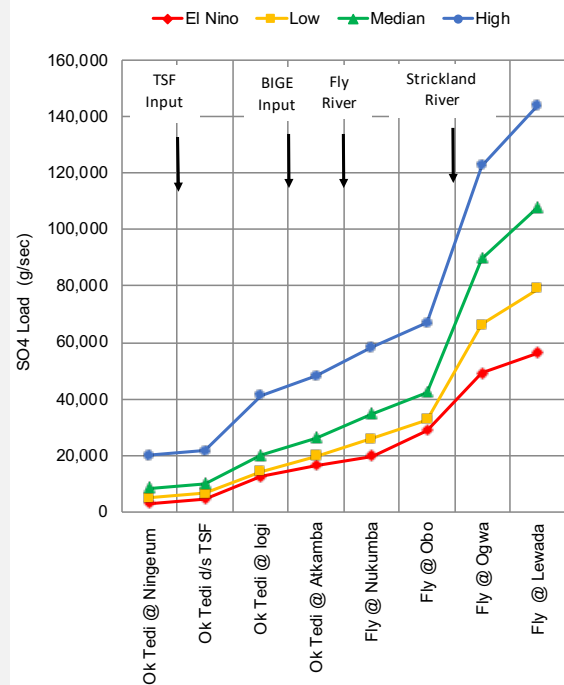


Appendix A-3. Predicted river water chemistries - With TSF at completion of Cell 2 (Stage 2)

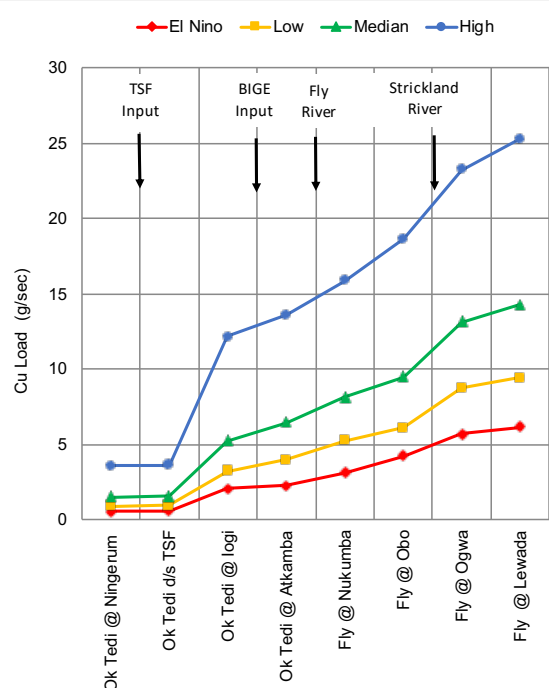
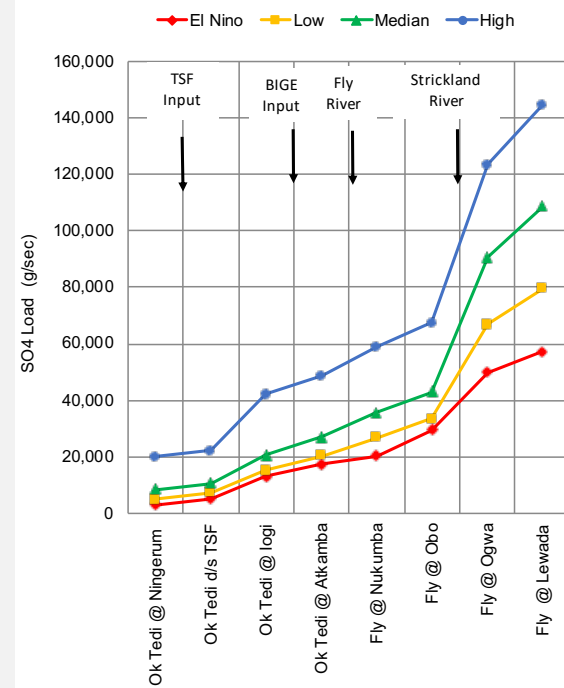


Appendix A-3. Continued

Completion of Cell 1



Completion of Cell 2



Appendix A-4. Predicted copper and sulphate loads in the Ok Tedi-Fly River system