FRIEDA RIVER

Frieda River Limited

Sepik Development Project

Environmental Impact Statement

Appendix 7b – Integrated Storage Facility Bioaccumulation/ Biomagnification Analyses - Sepik Development Project

SDP-6-G-00-01-T-003-030

coffey
A TETRA TECH COMPANY

TECHNICAL MEMORANDUM

To:	Nicola Fooks and Marissa Haywood, Coffey
From:	Jerry Diamond, Ph.D., Marcus Bowersox, M.S. (Tetra Tech, Inc.)
Date:	September 17, 2018
Subject:	Integrated Storage Facility Bioaccumulation/Biomagnification Analyses– Sepik Development Project

1.0 Introduction

Tetra Tech has been contracted by Coffey Services Australia Pty Ltd (Coffey) to assess the bioaccumulation and potential biomagnification of metals and other potential contaminants within the aquatic food-chain in an Integrated Storage Facility (ISF) reservoir. The ISF reservoir is part of Frieda River Hydroelectric Project (FRHEP), which is a part of the Sepik Development Project (the Project) and will be used for the generation of power as well as the subaqueous deposition of mine waste rock and tailings (as a part of the Frieda River Copper-Gold Project (FRCGP)). In initial bioaccumulation/biomagnification analyses, the potential food-webs were identified for the trophic transfer of contaminants of concern and the predicted contaminant concentrations to which organisms could be exposed to in the ISF during the life of the Project and beyond. The concentrations of metal contaminants in aquatic resources (e.g., algae (periphyton and phytoplankton), plants, aquatic invertebrates and fish species) were subsequently modeled to inform the assessment of the potential for impacts on human health due to consumption of aquatic resources in the ISF in the health risk assessment (being completed by others).

This Technical Memo outlines the procedures and data used to predict the concentration of metal contaminates in fish tissue under two different time periods of ISF usage (i.e. FRCGP operations and FRCGP post-closure) and in two different spatial zones of the ISF (i.e., littoral and pelagic) and when provided two different flows (i.e., low and average flow). Predicted concentrations in edible aquatic resources are compared with food safety standards identified by Australia and New Zealand as well as other organizations where relevant.

2.0 Scenarios Analyzed

Within the ISF reservoir, the littoral zone and the pelagic or deep-water zone will be the spatial zones from a bioaccumulation and biomagnification perspective, as these are the areas where aquatic resources may be harvested. The littoral zone will include those areas that are less than about 7 meters deep and will cover about 8% of the reservoir area (HydroNumerics 2018). The littoral zone can be accessed by shore line aquatic resource harvesting, whereas the pelagic zone is the zone greater than 7 meters to the full depth of the ISF (~180 meters). For each of these two zones, two different time periods were analyzed: during “active FRCGP operations” (FRCGP operations) and FRCGP post-closure. The active FRCGP operations time-period is defined as approximately 10 years of tailings and waste rock deposition in the ISF. Deposition of waste rock and tailings will continue for another 23 years. The “FRCGP post closure” time-period is defined as approximately 50 years after tailings deposition and active mining has ceased. Thus, four separate zone-time frame combinations were analyzed with respect to bioaccumulation/biomagnification modeling (**Table 1**). These four separate zone-time frame combinations were analyzed using either modeled metal surface water concentrations under average flow, low flow, or both flow conditions, if applicable. A baseline scenario was also assessed for a total of seven different scenarios.

Aquatic Resources Analyzed

Coffey supplied information gathered as part of environmental and social baseline and impact assessments for the Project regarding invertebrates and fish species that currently occur in the river systems near where the ISF will be constructed, as well as fish species that are likely to be established in the ISF over time based on information from other waterbodies in the region. Coffey biologists also noted those fish species that are typically consumed by people in the region and those species that are likely to be harvested from either the pelagic and/or the littoral zones of the ISF reservoir.

Based on information and data from HydroNumerics (2018), the littoral zone is expected to have colonization of macrophytes within 1 – 2 years (Riis et al, 2004) and terrestrial vegetation similar to what is currently observed along the rivers in the region. This zone also is predicted to be colonized by various algae (periphyton and phytoplankton), zooplankton, aquatic invertebrate and fish species (HydroNumerics 2018). **Figure 1** depicts the likely trophic food web structure for the littoral zone for the FRCGP active operations time period (Scenario 1, **Table** 1). The fish species considered likely to be harvested and consumed by people from the littoral zone include Red-bellied pacu (*Piaractus brachypomus*), Papillate catfish (*Neoarius velutinus*), and Rubber mouth (*Prochilodus argenteus*), all of which are considered pioneering fish species that could rapidly colonize the ISF reservoir and inhabit the littoral zone (**Attachment 1**). Available information obtained from Coffey biologists as well as other sources (e.g., Fishbase.org) indicates that all three fish-species of interest are omnivores that consume detritus, plants, and invertebrates. Dietary information was used to determine pathways of contaminant transfer from the water column to fish species of interest as explained in a subsequent section of this memo.

The pelagic zone during the active FRCGP operations time period (Scenario 2, **Table 1**) is predicted to have a simpler food web that is plankton-based (phytoplankton and zooplankton), in contrast to the littoral zone, which is predicted to have multiple sources of energy and food at the base of the food web (**Figure 1**). The fish species that people could consume from the pelagic zone include Red-bellied pacu and Rubber mouth, both of which could inhabit the pelagic zone as well as the littoral zone (**Attachment 1**, Coffey 2018).

Table 1. *Summary of scenarios subject to bioaccumulation/biomagnification analyses for the Integrated Storage Facility as part of the Sepik Development Project.*

Scenario Number	Area of concern	Time-Period**	Flow Condition	Aquatic resources analyzed
1	Littoral	Active operations*	Average flow	Red-bellied pacu; Papillate catfish; Rubber mouth
2	Littoral	Post-closure#	Average flow	Red-bellied pacu; Papillate catfish; Rubber mouth; Tilapia
3	Pelagic	Active operations*	Average flow	Red-bellied pacu; Rubber mouth; Silver barb
4	Pelagic	Active operations*	Low flow	Red-bellied pacu; Rubber mouth; Silver barb
5	Pelagic	Post-closure#	Average flow	Silver barb; Red-bellied pacu; Rubber mouth; Tilapia
6	Pelagic	Post-closure#	Low flow	Silver barb; Red-bellied pacu; Rubber mouth; Tilapia
7	Baseline	Current time period		Red-bellied pacu; Papillated Catfish; Rubber mouth

[*] 10 years of tailings and waste rock deposition in the ISF reservoir. [#] 50 years after tailings deposition and active mining have ceased.
[**] As related to the FRCGP.

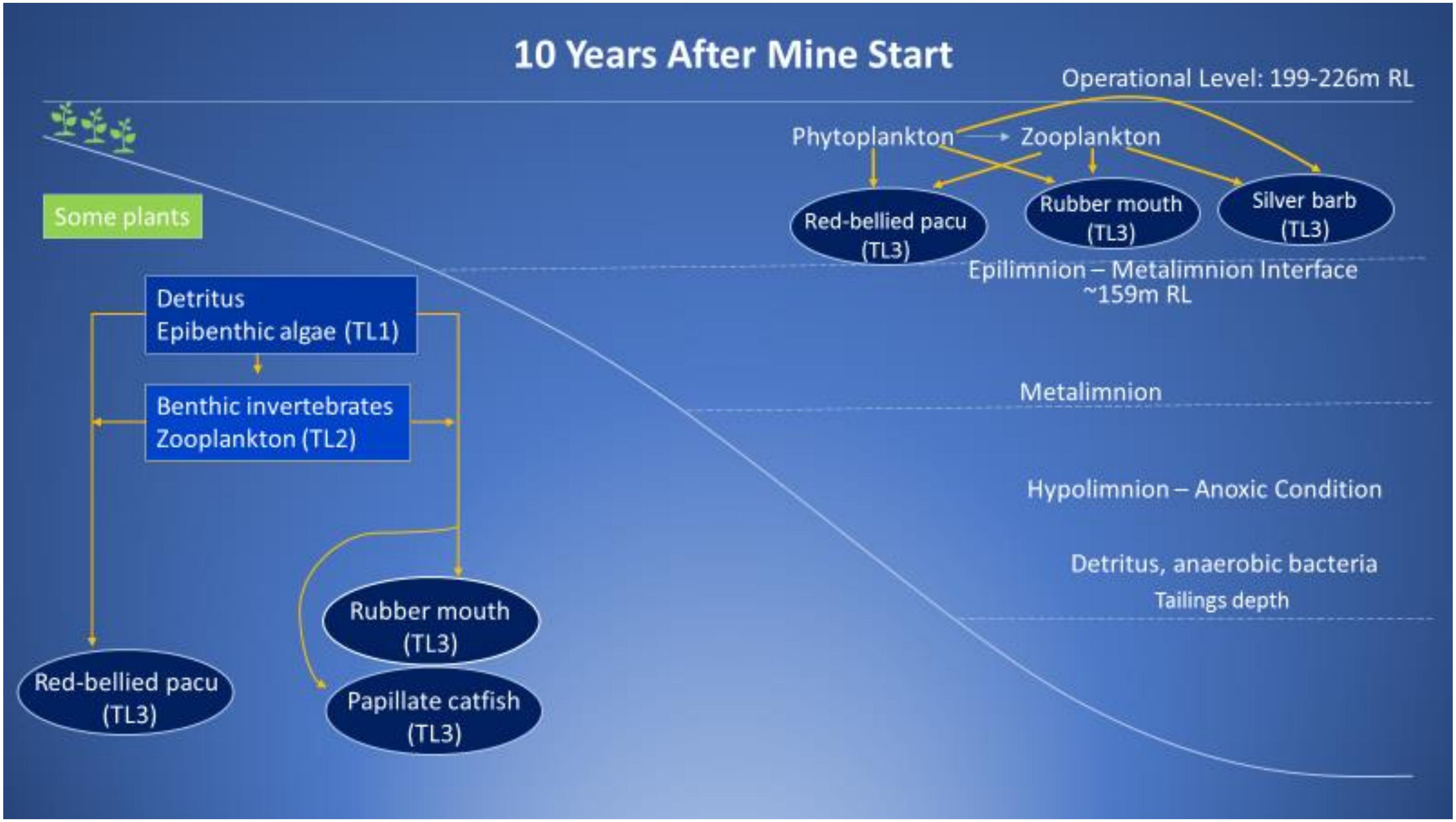

Figure 1. *Food webs modelled in the ISF reservoir for exposure to tailings and waste rock for the active FRCGP operations scenario.*

Benthic invertebrates and benthic-feeding fish species (such as the Papillate catfish) are not likely to be a viable trophic pathway in this scenario because the ISF reservoir is predicted to be more than 90 meters deep at this time (**Figure 1**) and the benthic substrate will consist of nutrient poor waste rock with some fine sediment deposited from upstream during low flows. Therefore, it is expected that there will be limited food sources for invertebrates and fish in the pelagic zone at this time.

During the FRCGP post-closure time-period (Scenarios 3 and 4, **Table 1**), the littoral zone is expected to have mature, natural shoreline vegetation as well as macrophytes, algae, invertebrates, and various fish species (BMT WBM 2018). Although several fish species are likely to occur in the littoral zone for the FRCGP post-closure scenario, most of them are too small for consumption by people (e.g., various goby species; **Attachment 1**, Coffey 2018). The primary species of interest in the littoral zone during FRCGP post-closure are the same species identified for Scenario 1 (**Figure 2**).

The pelagic zone during FRCGP post-closure (Scenario 4, **Table** 1), is expected to have a similar trophic food web as that presumed during the FRCGP active operations time period; however, there may be some potential for certain benthic species (e.g., invertebrates) to interact with the pelagic food web (i.e., bentho-pelagic coupling), including those fish species that people could consume (**Figure 2**). The benthic pathway in this scenario is deemed unlikely but possible because the depth to the benthic substrate will be much less than in the FRCGP active operations scenario (**Figure 2**). Also, the benthic substrate in this scenario is likely to be covered with silts and other fine particle size material as well as detritus accumulated from upstream river sources, making the benthic substrate potentially more hospitable for invertebrate colonization (HydroNumerics 2018). The fish species of interest in this scenario includes the rubber mouth and red-bellied pacu (identified in the active operations scenario) as well as the addition of the silver barb (*Barbonymus gonionotus*) (**Figure 2**), which inhabits pelagic areas of lakes in the region and feeds on plankton as well as other biota (**Attachment 1**; Sokheng et al. 1999; Coffey 2018).

In addition to the above fish species, Tilapia (*Oreochromis mossambicus*) is another fish species that was examined in these analyses. Tilapia, like Red bellied-pacu are known to consume zooplankton (fishbase.org). Tilapia are likely to be present in the ISF reservoir, as they are in other waterbodies in PNG, which represents a long-term pathway for the FRCGP post-closure scenario.

3.0 Contaminants Analyzed

Potential contaminants to which aquatic resources in the ISF could be exposed due to the FRCGP are metals that are in the mine tailings or waste rock that are sub-aqueously deposited in the ISF. During FRCGP operations, water quality in the ISF reservoir will be influenced primarily by the bed deposition of tailings slurry (55% solids and 45% liquor) via pipeline and the barge dumping of waste rock, as well as treated pit water discharges. The main source of dissolved contaminants (about 75%) will be from the barge dumped crushed waste rock in the ISF reservoir and 25% is anticipated to originate from the tailings liquor (which includes the treated pit water component). The waste rock will be flushed with ISF water as it is released from a barge and all contaminants are expected to be released from the waste rock when deposited.

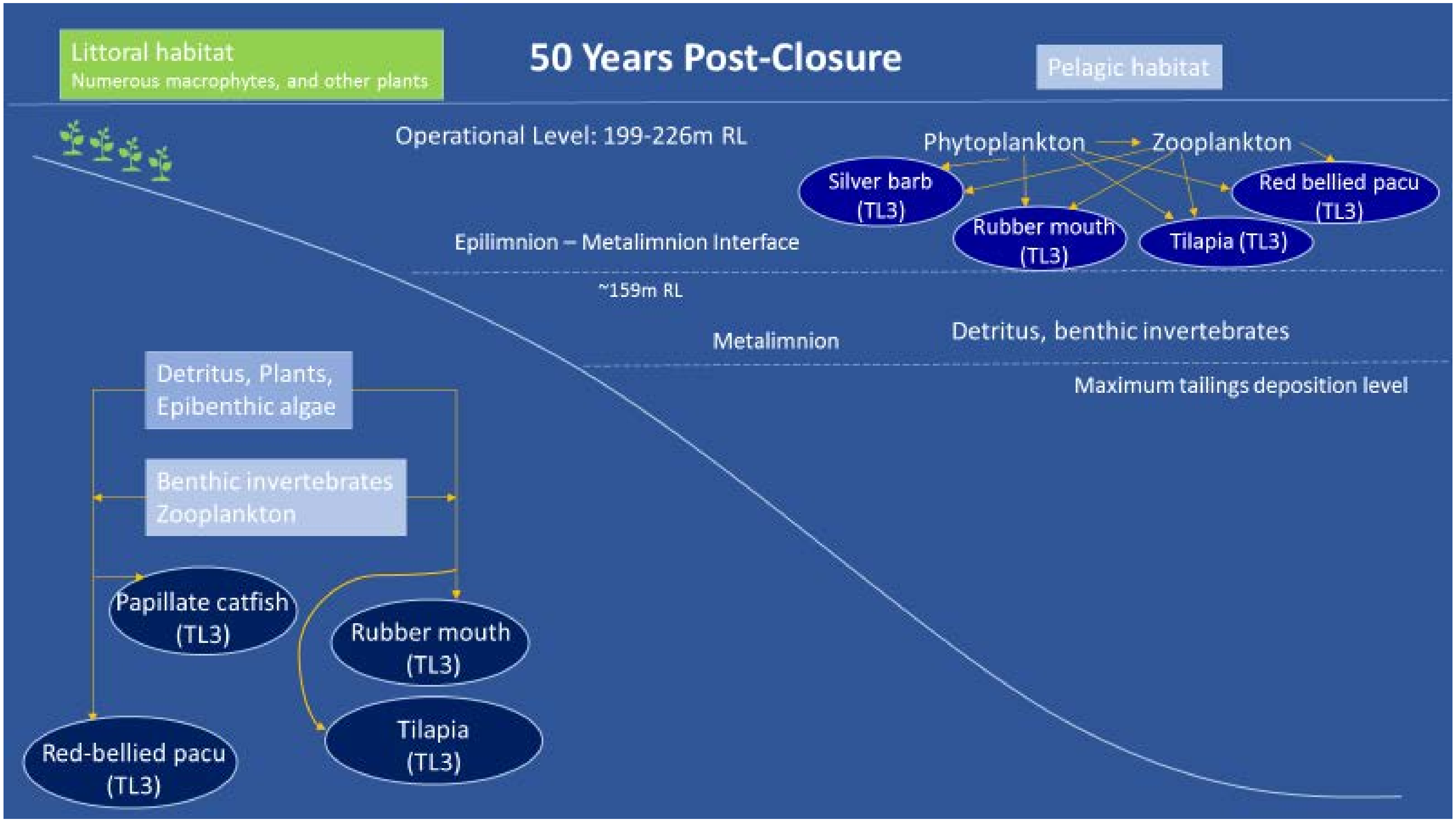

Figure 2. *Food webs modelled in the ISF reservoir for exposure to tailings and waste rock for the* FRCGP *post-closure scenario.*

For the purposes of this analysis, the highest concentrations of metals are assumed to occur nearest where the tailings discharge and waste rock are deposited initially. Predicted concentrations of each metal of interest in the ISF reservoir were estimated from modelling results compiled by Coffey (2018). For input to the bioaccumulation/biomagnification study, baseline (W29) and predicted data for AP4 (ISF Reservoir – Northern Arm) were used because modelled dissolved concentrations for most metals were highest at AP4 under average and low flow conditions. Therefore, bioaccumulation analyses presented in this Technical Memo used modeled data from Site AP4 to represent worst-case metal concentrations; that is, it is a conservative assessment. Bedded sediment concentrations were not modelled and were not directly considered in the potential uptake of metals in the food chain. However, by using baseline tissue concentrations at different trophic levels for metals of concern, all routes of exposure are factored into the trophic transfer factors used in these analyses, including the sediment ingestion pathway.

Table 2 summarizes the modeled water column concentrations of metals that were determined based on chemical and physical evaluations of samples of waste rock and simulated tailings (EGi 2018; SRK Consulting 2018). Metal concentrations were modeled for average and low flow conditions in the ISF reservoir in the pelagic zone, but only under average flow in the littoral zone (**Table 2**). Therefore, bioaccumulation/biomagnification analyses were performed for each of the four-different time period-reservoir zone combinations (**Table 1**) under both average and low flow conditions if applicable to yield a total of six different scenarios analyzed (**Table 1**). In addition, analyses were performed using the baseline data provided by SRK Consulting (2018) for comparison to the six scenarios (**Table 1**).

Aluminum, cadmium, and copper were examined because the dissolved concentration of these metals exceeded water quality criteria during average and low flow conditions and these metals are potentially capable of bioaccumulating (**Table 2**). Bioaccumulation and biomagnification analyses for aluminum, cadmium and copper were conducted for each of the seven scenarios plus baseline conditions listed in **Table 1**. Other metals were excluded from the analyses for the following reasons:

- While total dissolved chromium concentrations are elevated above the respective ANZECC/ARMCANZ (2000) trigger value, the predicted labile concentrations are many times below the trigger value. This is due to the majority (>90%) of the dissolved chromium is predicted to be complexed with organic compounds (SRK Consulting, 2018), rendering the chromium less bioavailable to aquatic biota.
- The concentrations of selenium are a factor of the limit of reporting being higher than the ANZECC/ARMCANZ (2000) trigger value.
- Dissolved zinc concentrations are within the natural variability of the background concentrations of zinc in the Nena River (i.e., AP4).

4.0 Method for the Prediction of Metal Concentrations in Fish

The US EPA (1999) developed guidance for conducting ecological risk assessments that includes a screening methodology for calculating the concentration of a given contaminant in biota based on dietary uptake. The food chain model and associated bioaccumulation methodology used to calculate fish tissue concentrations of metals for this study were developed by the US EPA in conjunction with a rigorous peer review process that involved multiple federal and state environmental agencies, university scientists, and environmental conservation organizations. The US EPA's food chain model is the standard procedure used by all federal and state regulatory agencies in the U.S., Canada, and other countries to predict chemical tissue concentrations in various aquatic species at potential contamination sites and is an accepted practice internationally. This modelling procedure is the standard method used by US EPA and other agencies to calculate predicted tissue concentrations in organisms at all trophic levels given either measured or predicted water concentrations of chemicals of concern.

Table 2. *Predicted average dissolved concentrations for average and low flows during baseline, FRCGP operations and post-closure in the ISF reservoir (northern arm – AP4) (Coffey 2018).*

Location	Flow	Zone within ISF	Project phase	pH	Sulphate	Hardness (as $CaCO_3$)	Total Organic Carbon	Al	As	Cd	Cr	Cu	Fe	Pb	Mn	Ni	Se	Zn
AP4	Average	Littoral zone	Operations	7.3	42	55	1.8	***0.0689***	0.00151	0.00019	0.00125	***0.00547***	0.0582	0.0011	0.0118	0.0040	***0.0103***	0.0053
AP4	Average	Littoral zone	Post-closure	7.3	40	59	1.8	***0.0703***	0.00157	0.00020	0.00132	***0.00555***	0.0587	0.0011	0.0126	0.0044	***0.0103***	0.0053
AP4 (W29 – Lower Nena)	Baseline	NA	NA	7.7	6	23	0.75 (DOC)	***0.055***	0.0005	0.0005	0.0005	***0.00355***	0.025	0.0005	0.0035	0.0005	***0.005***	0.0025
AP4	Average	Pelagic	Operations	7.5	47	58	2.1	***0.332***	0.0017	***0.00028***	0.0001	***0.0063***	0.166	0.0012	0.0136	0.0052	0.0010	***0.0150***
AP4	Low	Pelagic	Operations	7.5	83	88	2.2	***0.5607***	0.0024	***0.0005***	0.00014	***0.0168***	0.261	0.0014	0.0217	0.0088	0.0018	***0.0231***
AP4	Average	Pelagic	Post-Closure	7.7	23	44	1.9	***0.0622***	0.0013	0.0002	***0.0011***	***0.0045***	0.0553	0.0011	0.0084	0.0031	0.0003	0.0052
AP4	Low	Pelagic	Post-Closure	7.7	40	63	1.9	***0.0696***	0.0016	0.0002	***0.0014***	***0.0050***	0.0583	0.0011	0.0122	0.0049	0.0005	0.0051
Water quality guidelines																		
PNG Schedule 1 criteria[a]				[b]	400	-	-	-	0.05	0.01	0.05	1	1	0.005	0.5	1	0.01	5
PNG Standards for Drinking Water standards[c]				6.5 to 9.2	-	600	-	-	0.05	0.01	-	1.5	1	0.5	0.5	-	0.01	15
WHO (2017) drinking water[d]					-	-	-	-	0.01	0.003	0.05	1	0.3	0.01	-	0.07	0.04	3
IFC Effluent Guidelines[e]				6	-	-	-	-	0.1	0.05	0.1	0.3	2	0.2	-	0.5	-	0.5
ANZECC/ARMCANZ[f]				6 to 8[g]	-	-	-	0.055	0.013	0.0002	0.001	0.0014	-	0.0034	1.9	0.011	0.005	0.008

* All units are in mg/L except for pH, which are in standard units.
Exceedances are indicated by: IFC – italics; PNG Schedule 1 – bold; WHO or PNG Drinking Water Standards – underlined, ANZECC/ARMCANZ – bold italics.
Where multiple guidelines are exceeded, the least stringent guideline exceedance is indicated.

The food chain model procedure used in this study is also the standard protocol used by US EPA and other agencies in the U.S. to determine whether wildlife or humans are at potential risk from consuming contaminants of concern in fish and other aquatic life and is a critical component of ecological and human health risk assessments conducted in the U.S.

Based on the design of the ISF for the Project, the primary pathways by which metals may enter the food chain is via direct exposure to the tailings and mine wastes being disposed of in the ISF and via dietary uptake of food items that have accumulated metals from exposure to the tailings and mine waste rock.

Direct Exposure

Direct exposure to the tailings and mine waste being disposed of in the ISF is addressed by calculating the Bioconcentration Factor (BCF) between organism tissue concentration and the ambient water concentration where:

BCF = tissue concentration/water concentration

For this screening methodology, conservative site-specific trophic level BCFs were calculated for each metal by dividing the maximum tissue concentration based on survey data for a given trophic level species that people consume by the dissolved metal water concentration modeled under average flow and low flow (see **Table 2**). Modelled concentrations of metals in tailings and waste rock leachate and surface water were compiled by Coffey from SRK (2018).

For these analyses, phytoplankton (i.e., algae) represents the base of the food-chain (Trophic Level TL1) and are assumed to be constantly exposed to the predicted water metal concentrations. The concentration of metals in the water will not be constant as assumed in these calculations, which likely overestimates the potential exposure of these biota to metals in the tailings and mine wastes. By adding this level of conservatism into the model, any results that indicate no potential to bioaccumulate to concentrations at or above food safety standards can be removed from further action.

Metal concentrations in phytoplankton and plants were calculated assuming direct uptake from the water using a BCF:

$$[Xmetal]_{phytoplankton\ or\ plant} = [Xmetal]_{water} \times BCF_p$$

Where:

$[Xmetal]_{phytoplankton}$ = the concentration of metal in the phytoplankton or plant

$[Xmetal]_{water}$ = the concentration of metal in the surface water of the ISF reservoir for either the littoral or the pelagic zone

BCF_p = literature-based bioconcentration factor for uptake from surface water to phytoplankton

Food-Chain Trophic Transfer

Indirect exposure to metal via the diet is addressed by calculating the Trophic Transfer Factor (TTF) where:

TTF = tissue concentration in trophic level X / tissue concentration in trophic level X-1

Depending on the species under consideration, diet will vary in terms of trophic levels comprising the dietary items consumed, and therefore the potential concentration of metal ingested. Other biological factors that will affect the predicted concentration of metal in fish species of interest are bioaccumulation rate and the degree to which the organism is able to metabolize or excrete the metal. For these analyses, it was assumed that none of the metal ingested is metabolized or excreted to provide a conservative prediction of fish tissue metal concentrations.

Metal concentrations in invertebrates (Trophic Level TL2) that feed on algae, were estimated by applying a site-specific TTF, which accounts for both dietary ingestion and bioconcentration from the surface water. The TTF was obtained from site water and the 90th percentile invertebrate (prawn) concentrations for each metal based on baseline data (**Table 2**) (Coffey 2018). The equation used to calculate this estimated tissue concentration for TL2 is:

$$[Xmetal]_{invertebrates} = ([Xmetal]_{phytoplankton} \text{ x } TTF_{p})$$

Where:

$[Xmetal]_{phytoplankton}$ = the concentration of metal in the phytoplankton

$[Xmetal]_{invertebrates}$ = the concentration of metal in the invertebrate

TTF_{z} = site-specific bioaccumulation factor for uptake from plankton to invertebrate

For fish (TL3) that feed on plankton, plants, and/or invertebrates, fish tissue metal concentrations were calculated based on a site-specific TTF, which considers dietary ingestion and bioconcentration from water. The site-specific TTF was based on the 90th percentile of the measured invertebrate and fish tissue concentrations reported from the waterbodies in or near the proposed ISF reservoir (Coffey 2018). Although the fish diet may have various items, the TTF from invertebrates to fish were used for all uptake components. The equation used to calculate predicted metal concentrations in fish consumed by people from the ISF is:

$$[X]_{TL3fish} = ([X]_{plankton} * TTF_{fish} * FD_{plankton}) + ([X]_{plant} * TTF_{fish} * FD_{plant}) + ([X]_{invertebrates} * TTF_{fish} * FD_{invertebrate})$$

Where:

$[X]_{TL3fish}$ = the concentration of metal in TL3 fish species

$[X]_{plankton}$ = the concentration of metal X in plankton

$[X]_{plant}$ = the concentration of metal X in plants

$[X]_{invertebrate}$ = the concentration of metal X in invertebrates

$FD_{plankton}$ = the fraction of diet that is plankton

FD_{plant} = the fraction of diet that is plants

$FD_{invertebrates}$ = the fraction of diet that is invertebrates

TTF_{fish} = site-specific bioaccumulation factor for uptake from invertebrate to fish

The potential concentration of metals in fish in the ISF that may be consumed by people was modeled by including the uptake of metal from the different food sources of each fish. As noted in the formula above, each fish's diet was conservatively modeled based on a percentage of the food consumed that is plankton, plant, or invertebrate. The diets were modeled based on information provided by Coffey (2018) and in other sources (fishbase.org). **Table 3** summarizes the fish species, scenario, and fraction diet that was used to determine potential metal tissue concentrations.

The following sections outline the variables that are included in the scenarios that were modelled and aid in determining the bounds of the bioaccumulation/biomagnification investigation.

Variables of Fish Tissue Prediction Model

Site-specific BCFs and TTFs were based on baseline water and tissue trace metal data, respectively, previously collected immediately upstream and downstream of the proposed ISF. These data are not influenced by disposal of waste rock and tailings in the ISF and are assumed to represent relevant bioaccumulation dynamics currently in the area where the ISF reservoir will be developed. Modelled water and tissue data from exposures to the tailings and mine waste rock to be disposed of in the ISF were also used to predict fish tissue concentrations during both the FRCGP active operations and FRCGP post-closure scenarios.

Food Chain Modelling for the Different Scenarios

Fish tissue concentrations and the potential for contaminant exposure to humans consuming fish from the ISF reservoir were modelled under two different time periods and two locations within the ISF reservoir as described previously (**Table 1**). In the baseline modelling of near-shore (littoral) zone food webs were examined only, as deep water does not yet exist in the system.

The major difference between the littoral and the pelagic food webs, particularly during the active operations phase, is the number of steps in the food chain (**Figures 1 and 2**), whereby there is a reduced number of steps in the pelagic zone due to the absence of a link to benthic invertebrates. Another major difference between the two zones is the predicted metal concentrations because waste rock and tailings (the source of elevated metals in the ISF) will be deposited at least 400 meters from shore (SRK 2018). Therefore, the littoral zone is predicted to have lower concentrations of metals than the pelagic zone based on the water quality modeling results (**Table 2**).

In terms of the two time periods that were evaluated in these analyses (active FRCGP operations and post-closure), the major differences that affect the food chain modeling are: (1) the lack of a complete benthic pathway in the pelagic zone during the active FRCGP operations scenario and a complete benthic pathway in the pelagic zone post-closure; and (2) greater vegetation and macrophyte density for

Table 3 *Fish species, scenarios, and diet fraction that was used to determine potential metal tissue concentrations in edible fish, likely to be present in the ISF.*

Scenario	**Red Bellied Pacu**	**Papillated Catfish**	**Rubber Mouth**	**Silver Barb**	**Tilapia**
Littoral, Average Flow, Active Operations	33% Plankton 33% Plant 33% Invertebrate	50% Plankton 50% Invertebrate	34% Plankton 66% Plant	NA	NA
Littoral, Average Flow, Post-Closure	33% Plankton 33% Plant 33% Invertebrate	50% Plankton 50% Invertebrate	34% Plankton 66% Plant	NA	50% Plankton 50% Invertebrate
Pelagic, Average Flow, Active Operations	100% Plankton	NA	100% Plankton	100% Plankton	NA
Pelagic, Average Flow, Post-Closure	50% Plankton 50% Invertebrate	NA	100% Plankton	50% Plankton 50% Invertebrate	50% Plankton 50% Invertebrate
Pelagic, Low Flow, Active Operations	100% Plankton	NA	100% Plankton	100% Plankton	NA
Pelagic, Low Flow, Post-Closure	50% Plankton 50% Invertebrate	NA	100% Plankton	50% Plankton 50% Invertebrate	50% Plankton 50% Invertebrate

NA: Not applicable.

biota consumption in the littoral zone FRCGP post-closure scenario than during the early active operations scenario. These differences were addressed using the following approach.

In the littoral zone, during the active FRCGP operations timeframe, metals can be absorbed by plants and algae which are then consumed by invertebrates and by fish species of interest that eat the plants or algae directly as well as invertebrates (**Figure 3**). All of the fish species people may harvest from the ISF reservoir are omnivorous, obtaining their energy and nutrition from plants, algae, and invertebrates to varying extents (Fishbase.org, **Table 4**). Macrophytes and plants in general were presumed to be a lower proportion of the fish diet in the active FRCGP operations scenario as compared to the FRCGP post- closure scenario (**Figures 3 and 4**). Food chain modeling for the littoral zone therefore used the following approach. Initial concentrations of diet items were calculated by multiplying the modelled surface water concentration under each scenario (**Table 2**) by either the literature-based BCF with respect to plankton and plants (**Table 5**) or site-specific TTF for invertebrates (**Table 5**). Fish tissue concentrations were modelled by multiplying the diet items by the calculated fish TTF (**Table 5**) and then multiplying this by the fraction of this diet item in the total diet (**Table 3**). For each fish, the diet was then used to model the total fish concentration by summing the portions of the diet.

In the pelagic zone, metal bioaccumulation in fish during the active FRCGP operations scenario is expected to be primarily plankton-based, because it is highly unlikely that metals from waste rock and tailings deep in the hypolimnion would be capable of being mobilized to the epilimnion (**Figure 3**). In the scenario that is 50 years post-closure, while the water cover over the deposited waste rock will be greater than 40 m at the end of operations, it was conservatively assumed that there is a complete pathway between metals predicted to be in the waste rock and tailings, benthic invertebrates, and metal bioaccumulation in edible aquatic resources (**Figure 4**). Food chain modeling for the pelagic zone scenarios was therefore modeled using the following approach. The approach to calculating fish tissue concentration in the pelagic zone was the same as the littoral zone with different diet fractions based on available diet items. In the pelagic zone, the diet consisted of only plankton during active FRCGP operations and then upon closure, both plankton and invertebrates were modelled. Plants are not expected to be a source of metal uptake in the pelagic zone.

Table 4. *Summary of habitat preferences and mobility of fish species people may consume from the ISF during active FRCGP operations and post-closure.*

Scientific and common name	Habitat	Movement	Source(s)
Prochilodus argentens Rubber mouth	Freshwater; benthopelagic; potamodromous.	Potamodromy indicates the species may move between riverine and lake environments.	**Castro, R.M.C. and R.P. Vari**, 2003. Prochilodontidae (Fannel mouth characiforms). p. 65-70. In R.E. Reis, S.O. Kullander and C.J. Ferraris, Jr. (eds.) Checklist of the Freshwater Fishes of South and Central America*. Porto Alegre: EDIPUCRS, Brasil. *the habitats derive from research done in South America, where this species is native.
Neoarius velutinus Papillate catfish	Adults inhabit rivers and lakes to at least 400 m elevation; Although the data was not readily available, it is presumed this species exhibits an almost 100% benthic life history similar to other Siliuriformes (catfish) species	This species does not appear to move outside of river systems	**Coates, D.**, 1991. Biology of fork-tailed catfishes from the Sepik River, Papua New Guinea. Environ. Biol. Fish. 31:55-74
Piaractus brachypomus Red-bellied pacu	River	Utilizes the floodplain. Sepik River has massive floodplain and the species appears to move into the floodplain to feed (based on studies from its native range in South America).	**Araujo-Lima, C. A. R. M. & M. L. Ruffino.** 2003. Migratory fishes of the Brazilian Amazon. Pp. 233-302. In: Carolsfeld, J., B. Harvey, C. Ross & A. Baer (Eds.). Migratory fishes of South America: biology, fisheries and conservation status. Vitoria, WorldBank

Scientific and common name	Habitat	Movement	Source(s)
Barbonymus gonionotus Silver barb	Occurs at midwater to bottom depths in rivers, streams, floodplains, and occasionally in reservoirs. Seems to prefer standing water habitats instead of flowing waters.	*(Much of the life history research on the B. gonionotus has been done along the Mekong delta where the species is endemic; Movement patterns can be assumed to be similar in areas where it has been introduced).* Inhabits the flooded forest during high water period. Regarded as local migrant which moves from the Mekong up into small streams and canals and onto flooded areas during the rainy season and back again during receding water. Some reports indicated that upstream migration of this fish is triggered by the first rains and rising water levels. When it finds a tributary, canal or stream it moves upstream and eventually onto flooded areas. When water recedes, it migrates back into canals and streams and into the Mekong again	**Rainboth, W.J.**, 1996. Fishes of the Cambodian Mekong. FAO species identification field guide for fishery purposes. FAO, Rome, 265 p. **Sokheng, C., C.K. Chhea, S. Viravong, K. Bouakhamvongsa, U. Suntornratana, N. Yoorong, N.T. Tung, T.Q. Bao, A.F. Poulsen and J.V. Jørgensen**, 1999. Fish migrations and spawning habits in the Mekong mainstream: a survey using local knowledge (basin-wide). Assessment of Mekong fisheries: Fish Migrations and Spawning and the Impact of Water Management Project (AMFC). AMFP Report 2/99. Vientiane, Lao, P.D.R
Chilatherina fasciata Barred rainbowfish	Freshwater, pelagic. Lowlands to elevations 400-500m	*Chilatherina fasciata* have been collected mainly in clear, slow-flowing rainforest streams, generally inhabiting deeper pools that are exposed to sunlight for most of the day. These streams usually have a substrate consisting mainly of gravel or sand and littered with leaves and other debris. The natural pH and temperature ranges have been reported as 6.2-8.1 and 27-32° Celsius. Typically these fishes prefer sections of the stream which afford maximum exposure to sunlight	**http://rainbowfish.angfaqld.org.au/Fasciata.htm (accessed 08-17-2018)** **Allen, G.R.,** 1991. Field guide to the freshwater fishes of New Guinea. Publication, no. 9. 268 p. Christensen Research Institute, Madang, Papua New Guinea.
Hephaestus transmontanus Sepik grunter	Freshwater, demersal	Common in rainforest creeks flowing through hilly or mountainous terrain. Occur at altitude of 120-1500 m	**Allen, G.R.,** 1991. Field guide to the freshwater fishes of New Guinea. Publication, no. 9. 268 p. Christensen Research Institute, Madang, Papua New Guinea.

Scientific and common name	Habitat	Movement	Source(s)
Glossogobius koragensis Koragu tank goby	Freshwater; demersal.	Occurs mainly in lakes and backwaters of the lowland plain, but also occasionally found in main river chanels	**Allen, G.R.,** 1991. Field guide to the freshwater fishes of New Guinea. Publication, no. 9. 268 p. Christensen Research Institute, Madang, Papua New Guinea.

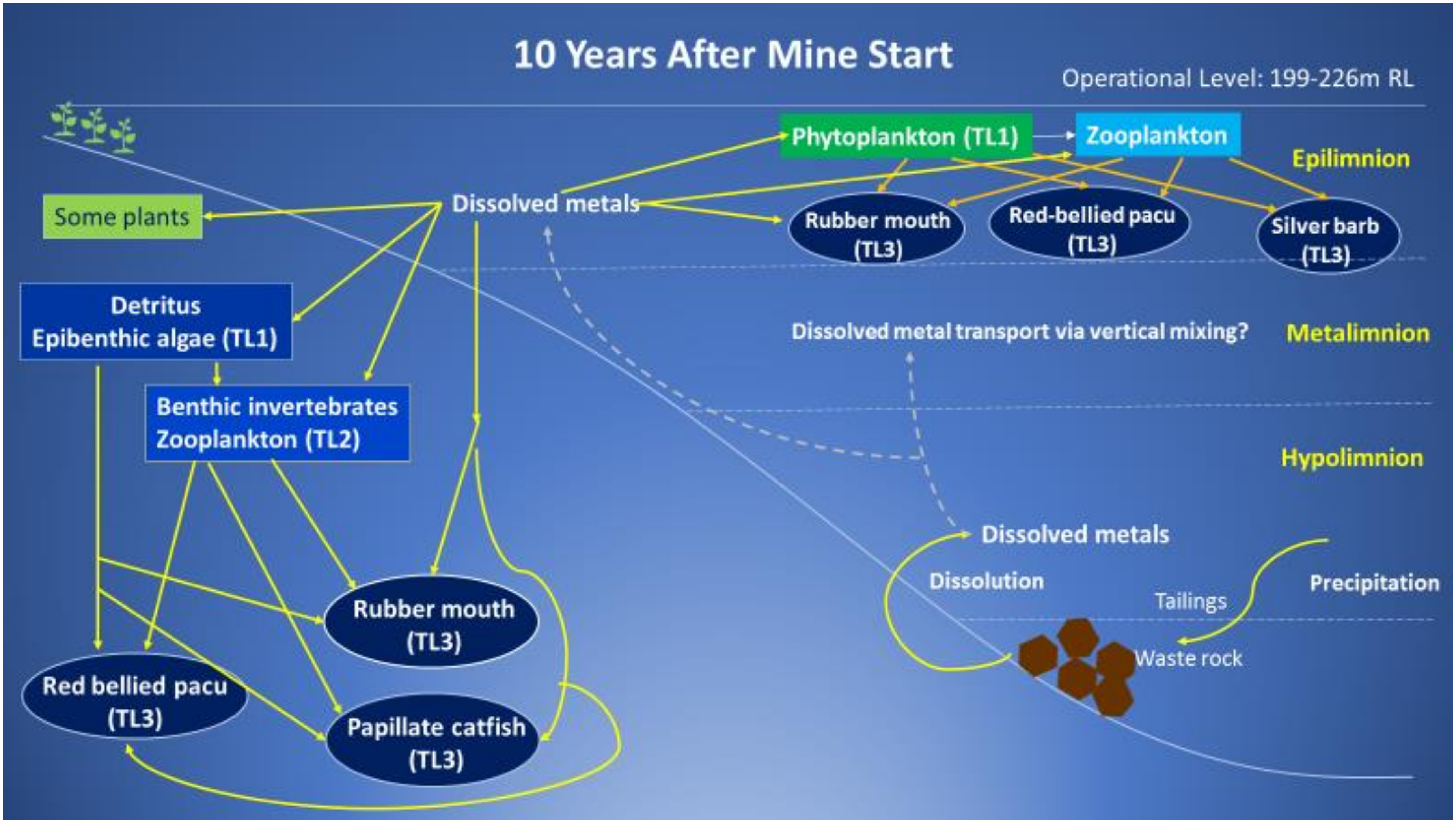

Figure 3. *Conceptual model of metal fate and transport in the ISF reservoir for the active FRCGP operations scenario.*

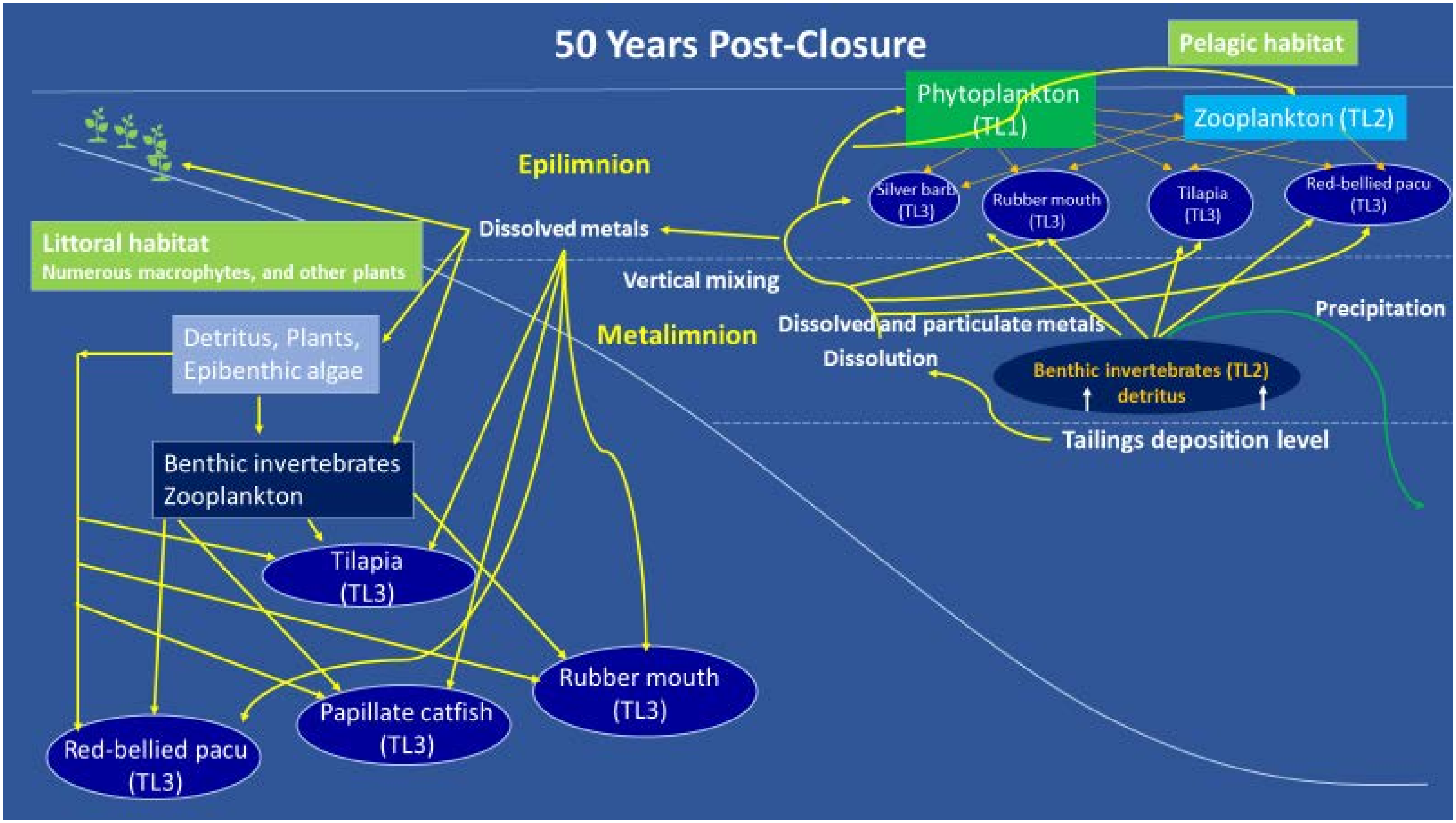

Figure 4. *Conceptual model of metal fate and transport in the ISF reservoir for the* FRCGP *post-closure scenario.*

Table 5. *TTFs calculated for each trophic level and each of the three metals examined using site baseline data and literature based BCFs for plankton/plants (US EPA 1999).*

Trophic Level	Aluminium			Cadmium			Copper		
	Mean	P90	Maximum	Mean	P90	Maximum	Mean	P90	Maximum
Plankton/Plant (TL1) [a]	833			782			541		
Invertebrates (TL2) [b]	0.34	0.60	0.91	1.02	1.92	3.2	0.04	0.05	0.09
Fish (TL3) [b]	0.11	0.05	0.16	0.07	0.03	0.60	1.08	1.50	2.25

[a] – literature-based BCF (US EPA 1999).

[b] – site-specific TTF derived by dividing measured invertebrate tissue concentration by calculated plankton/plant concentration or measured fish tissue concentration by measured invertebrate concentration.

The detailed model inputs and outputs are provided Appendix 1.

5.0 Literature Review

Table 5 summarizes the TTFs calculated for each trophic level and each of the three metals examined using site baseline surface water metal data. As part of its evaluation of metals that will likely be released from FRCGP tailings and waste rock being disposed of in the ISF, Tetra Tech compiled relevant information from its collection of field bioaccumulation and laboratory bioconcentration studies originally collected to support other recent metals bioaccumulation evaluation projects for US EPA. Tetra Tech performed an additional literature search for metals bioaccumulation data, including information on food chain exposures and lower trophic level bioaccumulation data that were not already available in this collection. Searches for bioaccumulation data were focused on studies using freshwater organisms, waterbodies receiving mining wastes, and waterbodies in tropical locations. Most of the most relevant data were obtained from the United States, Canada, Mexico, UK, Thailand, China, Malaysia, and India.

Aquatic organism BCF data from Tetra Tech's original collection and from studies identified through additional literature searches are summarized in **Attachment 2**. These data are organized by organism trophic level for each metal. Although BCF data are variable, in general, larger BCFs are observed at trophic level (TL) 1 (algae) or 2 (Invertebrates) than at higher trophic levels (fish) due to the lower trophic level more readily absorbing and retaining metals from the water column due to lower metabolism of metals. The calculated BAFs for TL1 – TL3 from the Frieda River sites used in this study are also included in **Attachment 2**. It should be noted that the BCFs in Attachment 2 are not comparable to the BAFs obtained in the present analyses because the latter are based on trophic transfer factors for metals that were derived using measured baseline (pre-activity) tissue data. BCFs are often reported to be higher than BAFs for most metals, particularly if dissolved metal concentrations in water are low in comparison with water quality standards or guidelines (USEPA 2007). BAFs that incorporate site-specific trophic transfer of metals, as used in these analyses, are usually more realistic in terms of actual bioaccumulation and biomagnification potential of metals.

The TTFs obtained using site data in this study generally conform to the patterns observed in the literature in that fish have lower TTFs for each of the metals as compared to either algae or invertebrates. For aluminum, Mo et al. (1988) indicated that 59 to 93% of aluminum in water was accumulated by duckweed. Signal crayfish accumulated approximately 78% of the aluminum from its prey (freshwater snails) that had accumulated aluminum from water (Walton et al. 2010). Handy (1993) found that bioavailability of aluminum from food sources to rainbow trout was low (< 1% uptake). These food chain study results are consistent with the aluminum BAF predictions summarized in **Table 5**.

For cadmium, Campenhout et al. (2009) evaluated sources of cadmium accumulation in carp and found that the majority of cadmium accumulation was primarily from food (20%) in comparison to water (0.11%). In addition, Kay (1984) indicated that cadmium does not generally biomagnify in freshwater systems, consistent with the BAF predictions for cadmium in **Table 5**.

For copper, Patrick and Loutit (1978) reported that tropical fish accumulated 55 to 73% copper from tubificid worms and that the bioaccumulation factor for fish was much lower than that for worms. These results are consistent with the lower TTF predictions for copper in fish observed in this analysis as compared to invertebrates.

The results summarized from the literature and calculated based on site-specific data indicate much lower bioaccumulation rates in fish people would harvest than at lower trophic levels, and therefore, do not support food chain biomagnification of these metals in freshwater lentic systems such as the proposed ISF reservoir. Furthermore, as shown in Attachment 2, all calculated 90th percentile BAF/BCF ratios were well below the BCF median ratios calculated for other projects around the world.

6.0 Results

Using the site-based BAFs and modelled metal concentrations shown in **Table 2**, predicted tissue concentrations were calculated for the seven different scenarios and baseline for each trophic level based on the food chain models depicted in **Figures 1-4** and described in Section 3 above. **Table 6** summarizes the predicted fish tissue concentrations for each of the three metals examined and both average and low flow conditions, where applicable, based on the food chain modeling described previously. Relevant Australian and New Zealand Food Safety Standards (FSANZ 2011), European Commission (2010) and Hong Kong Centre for Food Safety standards are also presented in **Table 6** for comparison.

Based on food chain modeling in these analyses, using conservative assumptions regarding exposure concentrations and bioaccumulation dynamics (no metabolism or excretion of metals ingested), aluminum is predicted to have the highest fish tissue concentrations relative to cadmium and copper, regardless of time frame (**Table 6**). This is directly due to the relatively high predicted dissolved aluminum concentrations as compared to other metals analyzed (**Table 2**). All three metals examined are predicted to have higher fish tissue concentrations in the majority of scenarios examined than what is predicted under the baseline condition (**Table 6**).

Aluminum and cadmium fish tissue concentrations are predicted to be higher than the current measured baseline concentrations while fish tissue copper is predicted to be lower than measured baseline concentrations (**Table 6**). These differences between predicted and measured concentrations in fish people may harvest may be due to the combining of all trophic-level 3 fish in the assessment of measured baseline fish tissue concentrations as concentrations were highly variable, and where concentrations were below the limit of detection, the value of the detection limit was used as the assumed concentration.

Table 6. *Predicted fish tissue concentrations for each of the three metals examined for each scenario in comparison with available food safety standards.*

Scenario	Food Safety Standard (mg/kg)	Red Bellied Pacu Tissue Concentration (mg/kg)	Papillated Catfish Tissue Concentration (mg/kg)	Rubber Mouth Tissue Concentration (mg/kg)	Silver Barb Tissue Concentration (mg/kg)	Tilapia Tissue Concentration (mg/kg)
Baseline[1]	Al – NE Cd – 0.05[2] Cu – 2.0[3]	Al – 1.88 (1.60) Cd – 0.002 (0.01) Cu – 0.16 (0.51)	Al – 1.75 (1.60) Cd – 0.002 (0.01) Cu – 0.23 (0.51)	Al – 2.19 (1.60) Cd – 0.001 (0.01) Cu – 0.04 (0.51)	NA	NA
Littoral, Average Flow, Active FRCGP Operations	Al – NE Cd – 0.05[2], 2.0[4] Cu - 2.0[3]	Al – 2.35 Cd – 0.006 Cu – 0.25	Al – 2.19 Cd – 0.007 Cu – 0.35	Al – 2.74 Cd – 0.005 Cu – 0.06	NA	NA
Littoral, Average Flow, FRCGP Post-Closure	Al – NE Cd – 0.05[2], 2.0[4] Cu - 2.0[3]	Al – 2.4 Cd – 0.007 Cu – 0.25	Al – 2.24 Cd – 0.008 Cu – 0.36	Al – 2.8 Cd – 0.005 Cu – 0.06	NA	Al – 2.24 Cd – 0.008 Cu – 0.36
Pelagic, Average Flow, FRCGP Active Operations	Al – NE Cd – 0.05[2], 2.0[4] Cu - 2.0[3]	Al – 13.21 Cd – 0.007 Cu – 0.066	NA	Al – 13.21 Cd – 0.007 Cu – 0.066	Al – 13.21 Cd – 0.007 Cu – 0.066	NA
Pelagic, Average Flow, FRCGP Post-Closure	Al – NE Cd – 0.05[2], 2.0[4] Cu - 2.0[3]	Al – 1.98 Cd – 0.008 Cu – 0.29	NA	Al – 2.47 Cd – 0.005 Cu – 0.05	Al – 1.98 Cd – 0.008 Cu – 0.29	Al – 1.98 Cd – 0.008 Cu – 0.29
Pelagic, Low Flow, Active FRCGP Operations	Al – NE Cd – 0.05[2], 2.0[4] Cu - 2.0[3]	Al – 22.31 Cd – 0.013 Cu – 0.18	NA	Al – 22.31 Cd – 0.013 Cu – 0.18	Al – 22.31 Cd – 0.013 Cu – 0.18	NA
Pelagic, Low Flow, FRCGP Post-Closure	Al – NE Cd – 0.05[2], 2.0[4] Cu - NE	Al – 2.21 Cd – 0.008 Cu – 0.32	NA	Al – 2.77 Cd – 0.005 Cu – 0.05	Al – 2.21 Cd – 0.008 Cu – 0.32	Al – 2.21 Cd – 0.008 Cu – 0.32

[1] - calculated fish tissue concentrations with 90th percentile measured TL3 fish tissue concentration in parentheses (Coffey 2018; BMT WBM, 2018). For measured baseline data results below the limit of detection, the value of the detection limit has been assumed.

[2] - EC (2010) and Food Safety Authority of Ireland (2018).

[3] - FSANZ (2011)

[4] - Centre for Food Safety, Hong Kong (2018).

NA Not applicable. NE Not Established.

Baseline

For the baseline conditions, both measured trophic level 3 fish tissue concentrations and predicted species-specific fish tissue concentrations are included in **Table 6**. The measured fish tissue concentration is the 90th percentile of all trophic level 3 fish tissue concentrations reported by Hydrobiology (2009 and 2010) and BMT WBM (2011). As noted in Table 6, the predicted concentration of aluminum (1.75 – 2.19 mg/kg) is higher than the measured fish tissue concentration, 1.6 mg/kg. This may be due to combining all trophic level 3 fish when evaluating the measured fish tissue concentration and also due to the conservative model used for predicting fish tissue concentrations.

Littoral Zone

For the littoral zone, only the average flow condition was provided and modeled in predicting fish tissue concentration. Fish tissue concentrations of aluminum, cadmium, and copper in the littoral zone are predicted to be nearly the same for the active FRCGP operations and the FRCGP post-closure scenarios (**Table 6**). This result is directly related to the very slight – if any – difference in predicted metal concentrations in the littoral zone for the two different time periods based on water quality modeling and the placement of waste rock and tailings far from (> 400 meters) the littoral zone (**Table 2**; SRK Consulting 2018). Relative to the measured and predicted fish tissue concentration under baseline conditions, the predicted fish tissue concentrations in the littoral zone under average flow and during both active FRCGP operations and the FRCGP post-closure scenarios were higher for all three metals but were below concentrations thought to indicate potential risk from consumption (**Table 6**), where established.

Pelagic Zone

For the pelagic zone, both the average flow and low flow conditions were modeled and resulted in marked difference in predicted fish tissue concentrations. Low-flow conditions (occurring 10% of the time or 36 days a year) under active FRCGP operations resulted in the highest fish tissue concentrations for aluminum and cadmium of any of the scenarios modeled. Relative to baseline, aluminum was more than 10 times higher and cadmium was 6 times higher than the predicted baseline metal concentration. Predicted pelagic fish tissue concentrations for copper were only slightly higher in the Red-bellied pacu but 4 times higher in the rubber mouth. This difference was due to the different diet of these fish as Red-bellied pacu have a diet of 33% invertebrates and rubber mouth do not have as significant a portion of diet consisting of invertebrates. Predicted copper concentrations in fish tissue pelagic zone during operations, however, were reduced compared to calculated (and measured) baseline tissue copper concentrations due to a change in diet (i.e., no pathway to benthic invertebrates) limiting uptake of copper within this zone at this time.

In the pelagic zone, there is a marked decrease in predicted fish tissue aluminum concentrations between the active FRCGP operations and the post-closure scenarios (**Table 6**). This result is due to the predicted decrease in metal concentrations in the epilimnion during the FRCGP post-closure scenario (**Table 2**). Fish tissue concentrations of aluminum in the pelagic zone during the active FRCGP operations scenario are predicted to be higher than tissue concentrations in the same species in the littoral zone for the post-closure scenario (**Table 6**). This is especially the case for the Red-bellied pacu and for aluminum and cadmium (**Table 6**).

Table 6 also lists available food safety standards that are available from the Australian and New Zealand Food Safety Standards (FSANZ 2011) for copper. The total copper food safety standard for 2.0 mg/kg is not predicted to be exceeded for any of the fish examined in any of the scenarios (**Table 6**). Thus, fish should be safe to eat in terms of copper concentration during and after active FRCGP operations for fish caught in either the littoral or pelagic zones. Furthermore, a proportion of the total dissolved copper concentration in the ISF reservoir is expected to form stable complexes with dissolved organic matter, rendering the complexed copper not bioavailable to aquatic biota.

FSANZ does not currently have a food safety standard for aluminum or cadmium in fish. The Hong Kong food safety guideline for cadmium in fish is 2 mg/kg (Centre for Food Safety, 2018), which is higher than predicted cadmium concentrations in edible aquatic resources in the ISF reservoir (**Table 6**). The European Commission (2010) standard for cadmium and the Food Safety Authority of Ireland, both have a guideline for cadmium in fish (excluding marine fish) of 0.05 mg/kg (FSAI, 2009), which is much lower than the Hong Kong standard. Using even the lower EC and Ireland cadmium food safety standards, all fish are predicted to be safe to eat by people (**Table 6**).

Conclusions

Using US EPA's internationally-accepted methodology with conservative food chain assumptions was used to model predicted concentrations of metals for a location in the proposed ISF considered to be worst-case in terms of water quality. Aluminum, cadmium and copper were selected for analysis based on their exceedance of water quality criteria (dissolved concentrations) in the ISF reservoir, and also because these metals are potentially capable of bioaccumulating. This study (based on results summarized from the literature and calculated site-specific data) indicates much lower bioaccumulation rates in fish people would harvest than at lower trophic levels, and therefore, do not support food chain biomagnification of aluminum, cadmium and copper in freshwater lentic systems, such as the proposed ISF reservoir. The study also predicts that metal concentrations of aluminum, cadmium, and copper in edible fish will generally be below safe maximum thresholds (where available) established by FSANZ and other agencies during both FRCGP operations and post-closure.

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Attachments

Attachment 1. Summary of native fish and prawn species that are known to occur in Papua New Guinea (PNG) and their associated diet, likelihood of occurrence in the ISF, and likelihood of consumption by the local community (from Coffey 2018).

Scientific and common name	Diet	Likelihood of presence in ISF reservoir	Likelihood of consumption by local community
Native fish and prawn species:			
Melanotaenia affinis North New Guinea rainbowfish	Omnivorous. Benthic diatoms, algae, and detritus; and benthic and surface macroinvertebrates	Yes, mainly river inflows and flow intrusions within arms of the reservoir and littoral zone.	Unlikely eaten due to small size but known in PNG to be collected by women and children tending gardens to supplement diet in the field.
Chilatherina crassispinosa Silver rainbowfish	Omnivorous. Benthic diatoms, algae, and detritus; and benthic and surface macroinvertebrates	Yes, mainly river inflows and flow intrusions within arms of the reservoir and littoral zone.	Unlikely eaten due to small size but known in PNG to be collected by women and children tending gardens to supplement diet in the field.
Chilatherina fasciata Barred rainbowfish	Omnivorous. Benthic diatoms, algae, and detritus; and benthic and surface macroinvertebrates	Yes, mainly river inflows and flow intrusions within arms of the reservoir and littoral zone.	Unlikely eaten due to small size but known in PNG to be collected by women and children tending gardens to supplement diet in the field.
Glossamia gjellerupi Gellerup's mouth almighty	Omnivorous. Benthic algae, detritus and benthic and surface macroinvertebrates	Yes. Both lotic and lentic species likely to be found mainly river inflows, but also within the littoral zone and main body of the reservoir.	Yes. Likely to be eaten due to moderate size
Hephaestus transmontanus Sepik grunter	Omnivorous. Benthic algae, detritus and benthic and surface macroinvertebrates	Yes. Both lotic and lentic species likely to be found mainly river inflows, but also within the littoral zone and main body of the reservoir.	Yes. Likely to be eaten due to moderate size
Glossogobius coatesi Coates' goby	Omnivorous. Benthic diatoms, algae and detritus and benthic macroinvertebrates	Yes but this lotic species likely to be confined to flowing waters in rivers and streams, as well as	Generally unlikely eaten due to small size but may be eaten if caught by women or children

Scientific and common name	Diet	Likelihood of presence in ISF reservoir	Likelihood of consumption by local community
		flowing reaches of river inflow intrusions to the reservoir.	using bilum nets and in sufficient quantity.
Glossogobius koragensis Koragu tank goby	Omnivorous. Benthic diatoms, algae and detritus and benthic macroinvertebrates including small crustaceans and other larval and small juvenile fish.	Yes. This lentic species is likely to be found in the littoral margin, inflow arms and shallow water in the main body of the ISF reservoir. Medium and long-term establishment or self-reproducing populations.	Generally unlikely eaten due to small size but may be eaten if caught by women or children using bilum nets and in sufficient quantity.
Macrobrachium latidactylus Scissor river prawn	Detritivorous. Benthic diatoms, algae, plant particulate matter (debris) debris.	Yes, found at elevations between 57 and 197 m, but initially only in the short term (<3 years). An amphidromous[#] species, so not surviving in the medium to long term. Populations expected to die out as the ISF dam is a barrier to migration. Mainly in river inflows and reservoir arms, as well as the littoral margin.	Generally unlikely eaten due to small size but may be eaten if caught by women or children using bilum nets and in sufficient quantity.
Macrobrachium weberi Weber's river prawn	Detritivorous. Benthic diatoms, algae, plant particulate matter (debris) debris.	No. A euryhaline species caught along the Sepik River and unlikely to be found at elevated or within the ISF reservoir. If present, the ISF dam will be a barrier to migration.	Unlikely eaten due to absence in ISF reservoir.
Macrobrachium sp. Unnamed river prawn	Detritivorous. Benthic diatoms, algae, plant particulate matter (debris) debris.	No. A euryhaline species caught along the Sepik River and unlikely to be found at elevated or within the ISF reservoir. If present, the ISF dam will be a barrier to migration.	Unlikely eaten due to absence in ISF reservoir.
Neoarius velutinus Papillate catfish	Omnivorous. Benthic algae and plant debris; benthic macroinvertebrates	Yes. Self-reproducing populations expected to be maintained in the ISF reservoir, including the	Yes. Most likely to be eaten given moderate to large size

Scientific and common name	Diet	Likelihood of presence in ISF reservoir	Likelihood of consumption by local community
	and terrestrial insects swept or falling into water; and juvenile or small fish.	long-term post-closure period.	
Introduced fish species*:			
Piaractus brachypomus Red-bellied pacu	Benthic macroinvertebrates, detritus, terrestrial plants; and juvenile or small fish.	Yes. Likely to be a pioneering fish. Self-reproducing populations expected to be maintained in the ISF reservoir initially as a pioneering species building up biomass in the medium to long term.	Yes. Known to be eaten (noted in 2011 Social Impact Assessment study)
Barbonymus gonionotus Silver barb	Diatoms, green algae, zooplankton (copepods and ostracods), terrestrial insects (on water)	Yes. Likely to be a pioneering fish. Self-reproducing populations expected in the ISF reservoir initially as a pioneering species building up biomass in the medium to long term.	Yes. Likely to be eaten due to moderate to large size.
Prochilodus argenteus Rubber mouth	Omnivorous but predominantly herbivorous benthic diatoms, algae and plant debris; some zooplankton (copepods and ostracods)	Yes. Likely to be a pioneering fish. Self-reproducing populations expected in the ISF reservoir initially as a pioneering species building up biomass in the medium to long term.	Yes. Known to be eaten (noted in 2011 Social Impact Assessment study)

Attachment 2. Summary of literature-based BCF values for TL1 – TL3 for aluminum, cadmium, and copper.

Metal	Trophic Level	Count	Literature Max BCF on WW-basis (L/kg)	Literature Min BCF on WW-basis (L/kg)	Literature Median BCF on WW-basis (L/kg)	Literature Geometric Mean BCF on WW-basis (L/kg)	Project 90th Percentile BAF/BCF (L/kg)
Aluminum	1	8[a]	108000	2000	19900	17773	833[j]
Aluminum	2	6[b]	18000	65	12850	5658	0.6[k]
Aluminum	3	1[c]	N/A	N/A	N/A	36	0.05[k]
Cadmium	1	4[d]	8400	1320	3100	3171	782[j]
Cadmium	2	5[e]	8	7	8	7	1.92[k]
Cadmium	3	3[f]	6	3	4	4	0.03[k]
Copper	1	12[g]	15000	10	12	108	541[j]
Copper	2	5[h]	4680	8	4050	391	11.30[k]
Copper	3	9[i]	76	5	10	17	0.02[k]

a – Quiroz-Vazquez et al., 2010; Carter and Porter 1997
b – Havas, 1985; Walton et al., 2010
c – Cleveland et al., 1991
d – Carter and Porter, 1997
e – Luz Vazquez-Sauceda et al., 2011; Zhang et al., 2007
f – Intamat et al., 2016
g – Carter and Porter, 1997; Jain et al., 1989
h – Tirupurasundary and Ramamoorthy 2009; Lim et al., 1995
i - Tirupurasundary and Ramamoorthy 2009; Baker and King, 1994; Intamat et al., 2016
j – wet weight basis
k – dry weight basis

Appendices

Appendix 1. Detailed model inputs and outputs

Phytoplankton Concentration

Scenario (Flow, Zone, Phase)	Chemical	Phytoplankton BCF[1] (mg Chemical/kg wet tissue)/(mg chemical/L)	Water Concentration (mg/L)	Phytoplankton Concentration (mg Chemical/kg wet tissue)
Baseline Littoral	Aluminum	833	0.055	45.815
	Cadmium	782	0.00005	0.0391
	Copper	541	0.00355	1.92055
Average Littoral Operations	Aluminum	833	0.0689	57.3937
	Cadmium	782	0.00019	0.14858
	Copper	541	0.00547	2.95927
Average Littoral Post-Closure	Aluminum	833	0.0703	58.5599
	Cadmium	782	0.0002	0.1564
	Copper	541	0.00555	3.00255
Average Pelagic Operations	Aluminum	833	0.332	276.556
	Cadmium	782	0.00028	0.21896
	Copper	541	0.0063	3.4083
Average Pelagic Post-Closure	Aluminum	833	0.0622	51.8126
	Cadmium	782	0.0002	0.1564
	Copper	541	0.0045	2.4345
Low Pelagic Operations	Aluminum	833	0.5607	467.0631
	Cadmium	782	0.0005	0.391
	Copper	541	0.0168	9.0888
Low Pelagic Post-Closure	Aluminum	833	0.0696	57.9768
	Cadmium	782	0.0002	0.1564
	Copper	541	0.005	2.705

1 USEPA 1999. SLERA Protocol for Hazardous Waste Combustion Facilities. Appendix C - Surface Water to Algae BCFs

Plant Concentrations

Scenario (Flow, Zone, Phase)	Chemical	Phytoplankton BCF[1] (mg Chemical/kg wet tissue)/(mg chemical/L)	Water Concentration (mg/L)	Plant Concentration (mg Chemical/kg wet tissue)
Baseline Littoral	Aluminum	833	0.055	45.815
	Cadmium	782	0.00005	0.0391
	Copper	541	0.00355	1.92055
Average Littoral Operations	Aluminum	833	0.0689	57.3937
	Cadmium	782	0.00019	0.14858
	Copper	541	0.00547	2.95927
Average Littoral Post-Closure	Aluminum	833	0.0703	58.5599
	Cadmium	782	0.0002	0.1564
	Copper	541	0.00555	3.00255
Average Pelagic Operations	Aluminum	833	0.332	276.556
	Cadmium	782	0.00028	0.21896
	Copper	541	0.0063	3.4083
Average Pelagic Post-Closure	Aluminum	833	0.0622	51.8126
	Cadmium	782	0.0002	0.1564
	Copper	541	0.0045	2.4345
Low Pelagic Operations	Aluminum	833	0.5607	467.0631
	Cadmium	782	0.0005	0.391
	Copper	541	0.0168	9.0888
Low Pelagic Post-Closure	Aluminum	833	0.0696	57.9768
	Cadmium	782	0.0002	0.1564
	Copper	541	0.005	2.705

1 USEPA 1999. SLERA Protocol for Hazardous Waste Combustion Facilities. Appendix C - Surface Water to Algae BCFs

Invertebrate Concentration

Scenario	Chemical	Site Specific Invertebrate BAF (mg Chemical/kg wet tissue)/(mg chemical/L)	Plankton Concentration	Invertebrate Concentration from Diet (Invertebrate BAF * Plankton Concentration)
Baseline Littoral	Aluminum	0.60	45.815	27.41815476
	Cadmium	1.92	0.0391	0.075
	Copper	11.30	1.92055	21.69444444
Average Littoral Operations	Aluminum	0.60	57.3937	34.34747024
	Cadmium	1.92	0.14858	0.285
	Copper	11.30	2.95927	33.42777778
Average Littoral Post-Closure	Aluminum	0.60	58.5599	35.0453869
	Cadmium	1.92	0.1564	0.3
	Copper	11.30	3.00255	33.91666667
Average Pelagic Operations	Aluminum	0.60	276.556	165.5059524
	Cadmium	1.92	0.21896	0.42
	Copper	11.30	3.4083	38.5
Average Pelagic Post-Closure	Aluminum	0.60	51.8126	31.00744048
	Cadmium	1.92	0.1564	0.3
	Copper	11.30	2.4345	27.5
Low Pelagic Operations	Aluminum	0.60	467.0631	279.515625
	Cadmium	1.92	0.391	0.75
	Copper	11.30	9.0888	102.6666667
Low Pelagic Post-Closure	Aluminum	0.60	57.9768	34.69642857
	Cadmium	1.92	0.1564	0.3
	Copper	11.30	2.705	30.55555556

TL3 Fish Concentration

Scenario	Chemical	Plankton Concentration (mg Chemical/kg wet tissue)	Fish BAF (mg Chemical/kg wet tissue)/(mg chemical/kg)	Fish Concentration from Ingestion of Plankton (Plankton Conc. * Inv to Fish BAF)	Invertebrate Concentration (mg Chemical/kg wet tissue)	Fish BAF (mg Chemical/kg wet tissue)/(mg chemical/kg)	Fish Concentration from Ingestion of Invertebrates (Invertebrate Conc. * Inv. To Fish BAF)	Plant Concentration (mg Chemical/kg wet tissue)	Fish BAF (mg Chemical/kg wet tissue)/(mg chemical/kg)	Fish Concentration from Ingestion of Plants (Plankton Conc. * Inv. To Fish BAF)
Baseline Littoral	Aluminum	45.82	0.05	2.19	27.42	0.05	1.31	45.82	0.05	2.19
	Cadmium	0.04	0.03	0.001	0.08	0.03	0.003	0.04	0.03	0.001
	Copper	1.92	0.02	0.04	21.69	0.02	0.42	1.92	0.02	0.04
Average Littoral Operations	Aluminum	57.39	0.05	2.74	34.35	0.05	1.64	57.39	0.05	2.74
	Cadmium	0.15	0.03	0.00	0.29	0.03	0.01	0.15	0.03	0.00
	Copper	2.96	0.02	0.06	33.43	0.02	0.65	2.96	0.02	0.06
Average Littoral Post-Closure	Aluminum	58.56	0.05	2.80	35.05	0.05	1.67	58.56	0.05	2.80
	Cadmium	0.16	0.03	0.01	0.30	0.03	0.01	0.16	0.03	0.01
	Copper	3.00	0.02	0.06	33.92	0.02	0.66	3.00	0.02	0.06
Average Pelagic Operations	Aluminum	276.56	0.05	13.21	165.51	0.05	7.90	276.56	0.05	13.21
	Cadmium	0.22	0.03	0.01	0.42	0.03	0.01	0.22	0.03	0.01
	Copper	3.41	0.02	0.07	38.50	0.02	0.74	3.41	0.02	0.07
Average Pelagic Post-Closure	Aluminum	51.81	0.05	2.47	31.01	0.05	1.48	51.81	0.05	2.47
	Cadmium	0.16	0.03	0.01	0.30	0.03	0.01	0.16	0.03	0.01
	Copper	2.43	0.02	0.05	27.50	0.02	0.53	2.43	0.02	0.05
Low Pelagic Operations	Aluminum	467.06	0.05	22.31	279.52	0.05	13.35	467.06	0.05	22.31
	Cadmium	0.39	0.03	0.01	0.75	0.03	0.03	0.39	0.03	0.01
	Copper	9.09	0.02	0.18	102.67	0.02	1.98	9.09	0.02	0.18
Low Pelagic Post-Closure	Aluminum	57.98	0.05	2.77	34.70	0.05	1.66	57.98	0.05	2.77
	Cadmium	0.16	0.03	0.01	0.30	0.03	0.01	0.16	0.03	0.01
	Copper	2.71	0.02	0.05	30.56	0.02	0.59	2.71	0.02	0.05

Fish Concentration Based on Diet

Red-bellied Pacu (33/33/33 Plankton/Invert/Plant Lit Op/Clos; 100 Plankton Pel Ops; 50/50	Papillated Catfish (50/50 Plankton and Invert Lit Op)	Rubber Mouth (33/66 Plankton/Plant Lit Op/Clos; 100 Plankton Pel Ops/Clos)	Silver Barb (100 Plankton Pel Ops; 50/50 Plankton/Inver Pel Closure)	Tilapia (50/50 Plankton/Invert Pel/Lit Clos)
1.88	1.75	2.19	NA	NA
0.002	0.002	0.001	NA	NA
0.16	0.23	0.04	NA	NA
2.35	2.19	2.74	NA	NA
0.0064	0.007	0.005	NA	NA
0.25	0.35	0.06	NA	NA
2.40	2.24	2.80	NA	2.24
0.007	0.008	0.005	NA	0.008
0.25	0.36	0.058	NA	0.36
13.21	NA	13.21	13.21	NA
0.007	NA	0.007	0.007	NA
0.066	NA	0.07	0.07	NA
1.98	NA	2.47	1.98	1.98
0.008	NA	0.005	0.008	0.008
0.29	NA	0.05	0.29	0.29
22.31	NA	22.31	22.31	NA
0.013	NA	0.013	0.013	NA
0.18	NA	0.18	0.18	NA
2.21	NA	2.77	2.21	2.21
0.008	NA	0.005	0.008	0.008
0.32	NA	0.05	0.32	0.32

Table B2 - Summary of baseline dissolved metal concentrations at key assessment points

Site	Location	Stat	Al	Cd	Cu
Base C	Frieda Base Camp (AP1)	Average	0.0271	0.0001	0.0049
		p90	0.042	0.0001	0.0072
		Max	0.06	0.0001	0.009
W43	Lower Ok Binai	Average	0.0151	0.0001	0.0011
		p90	0.026	0.0001	0.001
		Max	0.03	0.0003	0.002
W18	Nena River upstream of Koki Creek (AP3)	Average	0.0675	0.0001	0.0031
		p90	0.114	0.0002	0.004
		Max	0.22	0.0006	0.005
W29	Lower Nena (AP4)*	p50	0.055	0.00005	0.00355
		p80	0.062	0.00008	0.004
		Max	0.1	0.0006	0.007
W23	Frieda River downstream of airstrip (AP7)	Average	0.0273	0.0001	0.0011
		p90	0.047	0.0002	0.001
		Max	0.05	0.0002	0.002
W28	Upper Nena River (AP3)	Average	0.0331	0.0001	0.0011
		p90	0.04	0.0001	0.001
		Max	0.074	0.0002	0.003
W38A	Lower Freida River (AP11)	Average	0.0229	0.0001	0.0011
		p90	0.047	0.0001	0.001
		Max	0.05	0.0003	0.002
W71	Freida River road Crossing (AP10)	Average	0.0267	0.0001	0.0013
		p90	0.045	0.0001	0.002
		Max	0.05	0.0001	0.002
W114		Sample	0.02	0.0001	0.001
W115		Sample	0.01	0.0001	0.001

Plankton Concentration (mg/kg) = Water Concentration (mg/L) * Plankton BCF (L/kg)

		Al	Cd	Cu
	Plankton BCF	833	782	541
Calculated Plankton Concentration	Base C	34.986	0.0782	3.8952
	W43	21.658	0.0782	0.541
	W18	94.962	0.1564	2.164
	W29	51.646	0.06256	2.164
	W23	39.151	0.1564	0.541
	W28	33.32	0.0782	0.541
	W38A	39.151	0.0782	0.541
	W71	37.485	0.0782	1.082
	W114	16.66	0.0782	0.541
	W115	8.33	0.0782	0.541
	Mean	37.7349	0.092276	1.25512
	P90	55.9776	0.1564	2.33712
	Max	94.962	0.1564	3.8952

Table D1&2 - Baseline fish and crustacean tissue metals/metalloid (mg/kg) data – 2009 and 2010 campaigns (Hydrobiology, 2010), 2011 campaigns (BMT WBM, 2018)

Site-Specific BCFs (Fish Concentration/Baseline Water (Percentile))

Date	Species	Site name	Catchment	Type	Tissue*	Al	Cd	Cu	TL	Al	Cd	Cu
2/12/2009	***Macrobrachium latidactylus***	W23	Nena/Frieda	MCR	Tail	0.3	0	3.6	2	6.382979	0	3600
2/12/2009	***Macrobrachium latidactylus***	W23	Nena/Frieda	MCR	Tail	1.1	0	2.5	2	23.40426	0	2500
2/12/2009	***Macrobrachium latidactylus***	W23	Nena/Frieda	MCR	Tail	0.5	0	3.5	2	10.6383	0	3500
1/12/2009	***Macrobrachium latidactylus***	W43	Nena/Frieda	ULC	Tail	0.1	0	4.1	2	3.846154	0	4100
1/12/2009	***Macrobrachium latidactylus***	W43	Nena/Frieda	ULC	Tail	0.1	0	6.7	2	3.846154	0	6700
1/12/2009	***Macrobrachium latidactylus***	W43	Nena/Frieda	ULC	Tail	0.9	0	4.2	2	34.61538	0	4200
13/01/2009	***Macrobrachium sp***	W21	Nena/Frieda	ULC	Tail	-	-	5.1	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Head	19	0.5	31	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Head	34	0.3	21	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Head	23	0.3	30	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Head	33	0.2	26	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Head	86	0.2	17	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Tail	1.5	0	4	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Tail	1.6	0	3.4	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Tail	1.5	0	4	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Tail	1.5	0	4.7	2			
27/08/2010	***Macrobrachium sp***	W70	Nena/Frieda	MCR	Tail	1.5	0	3.7	2			
13/01/2009	***Macrobrachium weberi***	W21	Nena/Frieda	ULC	Tail	-	-	5.4	2			
13/01/2009	***Macrobrachium weberi***	W21	Nena/Frieda	ULC	Tail	-	-	2.8	2			
13/01/2009	***Macrobrachium weberi***	W21	Nena/Frieda	ULC	Tail	-	-	4	2			
12/8/2010	***Barbonymus gonionotus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.15	3	31.91489	0	150
12/8/2010	***Barbonymus gonionotus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.23	3	31.91489	0	230
12/8/2010	***Barbonymus gonionotus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.44	3	31.91489	0	440
12/8/2010	***Barbonymus gonionotus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.16	3	31.91489	0	160
12/8/2010	***Barbonymus gonionotus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.14	3	31.91489	0	140
10/8/2010	***Barbonymus gonionotus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.18	3	33.33333	0	90
10/8/2010	***Barbonymus gonionotus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.23	3	33.33333	0	115
10/8/2010	***Barbonymus gonionotus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.17	3	33.33333	0	85
10/8/2010	***Barbonymus gonionotus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.16	3	33.33333	0	80
10/8/2010	***Barbonymus gonionotus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.17	3	33.33333	0	85
2/12/2009	***Chilaterina crassispinosa***	W23	Nena/Frieda	MCR	Hind	5	0	0.2	3	106.383	0	200
2/12/2009	***Chilaterina crassispinosa***	W23	Nena/Frieda	MCR	Hind	4.2	0	0.29	3	89.3617	0	290
30/11/2009	***Chilaterina crassispinosa***	W29	Nena/Frieda	MCR	Hind	0.6	0	0.23	3	9.677419	0	57.5
30/11/2009	***Chilaterina crassispinosa***	W29	Nena/Frieda	MCR	Hind	0.3	0	0.18	3	4.83871	0	45
30/11/2009	***Chilaterina crassispinosa***	W29	Nena/Frieda	MCR	Hind	0.4	0	0.25	3	6.451613	0	62.5
30/11/2009	***Chilaterina crassispinosa***	W29	Nena/Frieda	MCR	Hind	0.1	0	0.27	3	1.612903	0	67.5
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.3	3			
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.3	3			
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.29	3			
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.27	3			
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.32	3			
13/01/2009	***Chilaterina fasciata***	W21	Nena/Frieda	ULC	Hind	-	-	0.36	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.27	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.25	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.27	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.26	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.27	3			
13/01/2009	***Chilaterina fasciata***	W22	Nena/Frieda	MCR	Hind	-	-	0.28	3			
14/01/2009	***Chilaterina fasciata***	W23	Nena/Frieda	MCR	Hind	-	-	0.39	3			390
14/01/2009	***Chilaterina fasciata***	W23	Nena/Frieda	MCR	Hind	-	-	0.34	3			340
14/01/2009	***Chilaterina fasciata***	W23	Nena/Frieda	MCR	Hind	-	-	0.44	3			440
14/01/2009	***Chilaterina fasciata***	W23	Nena/Frieda	MCR	Hind	-	-	0.37	3			370
14/01/2009	***Chilaterina fasciata***	W23	Nena/Frieda	MCR	Hind	-	-	0.4	3			400
15/01/2009	***Chilaterina fasciata***	W29	Nena/Frieda	MCR	Hind	-	-	0.84	3			210
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.42	3			
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.24	3			
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.33	3			
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.31	3			
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.31	3			
15/01/2009	***Chilaterina fasciata***	W42	Nena/Frieda	ULC	Hind	-	-	0.29	3			
8/1/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.22	3			220
8/1/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.2	3			200
8/1/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.34	3			340
8/1/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.25	3			250
8/1/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.29	3			290
22/01/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.56	3			560
22/01/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.51	3			510
22/01/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.51	3			510
22/01/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.64	3			640
22/01/2009	***Chilaterina fasciata***	W43	Nena/Frieda	ULC	Hind	-	-	0.65	3			650
16/10/2010	***Chilatherina crassipinosa***	W114	Nena/Frieda	ULR	Hind	1.6	0	0.28	3	80	0	280
16/10/2010	***Chilatherina crassipinosa***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.26	3	150	0	260
16/10/2010	***Chilatherina crassipinosa***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.25	3	150	0	250
16/10/2010	***Chilatherina crassipinosa***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.3	3	150	0	300
26/06/2011	***Chilatherina crassipinosa***	W23			Flesh	1.3	0.01	0.33	3	27.65957	50	330
26/06/2011	***Chilatherina crassipinosa***	W23			Flesh	14	0.01	0.34	3	297.8723	50	340
26/06/2011	***Chilatherina crassipinosa***	W23			Flesh	0.85	0.01	0.33	3	18.08511	50	330
26/06/2011	***Chilatherina crassipinosa***	W23			Flesh	4.4	0.01	0.34	3	93.61702	50	340

26/06/2011	***Chilatherina crassipinosa***	W23			Flesh	0.98	0.01	0.37	3	20.85106	50	370
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.21	3	150	0	210
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.21	3	150	0	210
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.6	0	0.22	3	160	0	220
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.19	3	150	0	190
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.19	3	150	0	190
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.28	3	150	0	280
16/10/2010	***Chilatherina fasciata***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.22	3	150	0	220
1/7/2011	***Chilatherina fasciata***	W48			Flesh	0.63	0.01	0.41	3			
1/7/2011	***Chilatherina fasciata***	W48			Flesh	0.63	0.01	0.25	3			
1/7/2011	***Chilatherina fasciata***	W48			Flesh	3.9	0.01	0.32	3			
1/7/2011	***Chilatherina fasciata***	W48			Flesh	2.1	0.01	0.31	3			
1/7/2011	***Chilatherina fasciata***	W48			Flesh	0.54	0.01	0.32	3			
16/10/2010	***Melanotaenia affinis***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.22	3	150	0	220
16/10/2010	***Melanotaenia affinis***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.25	3	150	0	250
16/10/2010	***Melanotaenia affinis***	W115	Nena/Frieda	ULC	Hind	1.7	0	0.28	3	170	0	280
16/10/2010	***Melanotaenia affinis***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.24	3	150	0	240
28/11/2009	***Melanotaenia affinis***	W17	Nena/Frieda	ULC	Hind	0.1	0	0.28	3			
28/11/2009	***Melanotaenia affinis***	W17	Nena/Frieda	ULC	Hind	0.8	0	0.3	3			
28/11/2009	***Melanotaenia affinis***	W17	Nena/Frieda	ULC	Hind	0.1	0	0.42	3			
28/11/2009	***Melanotaenia affinis***	W17	Nena/Frieda	ULC	Hind	0.1	0	0.3	3			
10/1/2009	***Melanotaenia affinis***	W28	Nena/Frieda	ULR	Hind	-	-	0.38	3			380
10/1/2009	***Melanotaenia affinis***	W28	Nena/Frieda	ULR	Hind	-	-	0.33	3			330
10/1/2009	***Melanotaenia affinis***	W28	Nena/Frieda	ULR	Hind	-	-	0.44	3			440
10/1/2009	***Melanotaenia affinis***	W28	Nena/Frieda	ULR	Whole Body	-	-	1.4	3			1400
15/01/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	-	-	0.41	3			102.5
30/11/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	0.2	0	0.3	3	3.225806	0	75
30/11/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	0.3	0	0.27	3	4.83871	0	67.5
30/11/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	0.1	0	0.42	3	1.612903	0	105
30/11/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	0.3	0	0.23	3	4.83871	0	57.5
30/11/2009	***Melanotaenia affinis***	W29	Nena/Frieda	MCR	Hind	0.2	0	0.29	3	3.225806	0	72.5
8/1/2009	***Melanotaenia affinis***	W41	Nena/Frieda	ULC	Hind	-	-	0.3	3			
8/1/2009	***Melanotaenia affinis***	W41	Nena/Frieda	ULC	Whole Body	-	-	0.87	3			
15/01/2009	***Melanotaenia affinis***	W42	Nena/Frieda	ULC	Hind	-	-	0.38	3			
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.25	3			250
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.29	3			290
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.35	3			350
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.37	3			370
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.37	3			370
8/1/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.27	3			270
22/01/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	-	-	0.56	3			560
1/12/2009	***Melanotaenia affinis***	W43	Nena/Frieda	ULC	Hind	0.4	0	0.23	3	15.38462	0	230
30/06/2011	***Melanotaenia affinis***	BC			Flesh	1.4	0.02	1	3	33.33333	200	138.8889
30/06/2011	***Melanotaenia affinis***	BC			Flesh	1.2	0.02	0.51	3	28.57143	200	70.83333
30/06/2011	***Melanotaenia affinis***	BC			Flesh	1	0.02	0.98	3	23.80952	200	136.1111
30/06/2011	***Melanotaenia affinis***	BC			Flesh	0.97	0.01	0.82	3	23.09524	100	113.8889
30/06/2011	***Melanotaenia affinis***	BC			Flesh	0.89	0.02	0.79	3	21.19048	200	109.7222
5/12/2011	***Melanotaenia affinis***	W28			Hind	0.5	0.01	0.65	3	12.5	100	650
5/12/2011	***Melanotaenia affinis***	W28			Hind	0.5	0.01	0.38	3	12.5	100	380
5/12/2011	***Melanotaenia affinis***	W28			Hind	0.5	0.01	0.45	3	12.5	100	450
5/12/2011	***Melanotaenia affinis***	W28			Hind	0.5	0.01	0.33	3	12.5	100	330
5/12/2011	***Melanotaenia affinis***	W28			Hind	0.5	0.01	0.52	3	12.5	100	520
27/08/2010	***Piaractus brachypomus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.11	3			
27/08/2010	***Piaractus brachypomus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
27/08/2010	***Piaractus brachypomus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
27/08/2010	***Piaractus brachypomus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.09	3			
27/08/2010	***Piaractus brachypomus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.12	3			120
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.19	3			190
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.18	3			180
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.14	3			140
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.12	3			120
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.13	3			130
14/01/2009	***Potamosiluras velutinus***	W23	Nena/Frieda	MCR	Flesh	-	-	0.12	3			120
19/01/2009	***Potamosiluras velutinus***	W38a	Nena/Frieda	LLR	Flesh	-	-	0.16	3			1600
19/01/2009	***Potamosiluras velutinus***	W38a	Nena/Frieda	LLR	Flesh	-	-	0.13	3			1300
27/08/2010	***Potamosiluras velutinus***	W70	Nena/Frieda	MCR	Liver	6.9	0.3	1.5	3			
27/08/2010	***Potamosiluras velutinus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
27/08/2010	***Potamosiluras velutinus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
27/08/2010	***Potamosiluras velutinus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.12	3			
27/08/2010	***Potamosiluras velutinus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.11	3			
10/8/2010	***Potamosiluras velutinus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.13	3	33.33333	0	65
25/12/2009	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	0.1	0	0.18	3	2.12766	0	180
26/12/2009	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	0.3	0	0.1	3	6.382979	0	100
27/12/2009	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	0.1	0	0.13	3	2.12766	0	130
28/12/2009	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	2.9	0	0.11	3	61.70213	0	110
12/8/2010	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.09	3	31.91489	0	90
12/8/2010	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3	31.91489	0	100
12/8/2010	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.13	3	31.91489	0	130
12/8/2010	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3	31.91489	0	100

12/8/2010	***Prochilodus argenteus***	W23	Nena/Frieda	MCR	Flesh	1.5	0	0.08	3	31.91489	0	80
26/06/2011	***Prochilodus argenteus***	W23			Flesh	1.6	0.04	0.18	3	34.04255	200	180
26/06/2011	***Prochilodus argenteus***	W23			Flesh	1.3	0.01	0.19	3	27.65957	50	190
26/06/2011	***Prochilodus argenteus***	W23			Flesh	1.6	0.01	0.17	3	34.04255	50	170
26/06/2011	***Prochilodus argenteus***	W23			Flesh	0.5	0.01	0.16	3	10.6383	50	160
26/06/2011	***Prochilodus argenteus***	W23			Flesh	0.5	0.01	0.16	3	10.6383	50	160
19/01/2009	***Prochilodus argenteus***	W38a	Nena/Frieda	LLR	Flesh	-	-	0.1	3			1000
19/01/2009	***Prochilodus argenteus***	W38a	Nena/Frieda	LLR	Flesh	-	-	0.09	3			900
19/01/2009	***Prochilodus argenteus***	W38a	Nena/Frieda	LLR	Flesh	-	-	0.12	3			1200
22/01/2009	***Prochilodus argenteus***	W43	Nena/Frieda	ULC	Flesh	-	-	0.18	3			180
22/01/2009	***Prochilodus argenteus***	W43	Nena/Frieda	ULC	Flesh	-	-	0.26	3			260
22/01/2009	***Prochilodus argenteus***	W43	Nena/Frieda	ULC	Flesh	-	-	0.17	3			170
22/01/2009	***Prochilodus argenteus***	W43	Nena/Frieda	ULC	Flesh	-	-	0.15	3			150
22/01/2009	***Prochilodus argenteus***	W43	Nena/Frieda	ULC	Flesh	-	-	0.23	3			230
27/08/2010	***Prochilodus argenteus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.12	3			
27/08/2010	***Prochilodus argenteus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.09	3			
27/08/2010	***Prochilodus argenteus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.13	3			
27/08/2010	***Prochilodus argenteus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.1	3			
27/08/2010	***Prochilodus argenteus***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.05	3			
10/8/2010	***Prochilodus argenteus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.12	3	33.33333	0	60
10/8/2010	***Prochilodus argenteus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.12	3	33.33333	0	60
10/8/2010	***Prochilodus argenteus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.14	3	33.33333	0	70
10/8/2010	***Prochilodus argenteus***	W71	Nena/Frieda	LLR	Flesh	1.5	0	0.11	3	33.33333	0	55
16/10/2010	***Glossamia gjellerupi***	W114	Nena/Frieda	ULR	Hind	1.5	0	0.22	3	75	0	220
16/10/2010	***Glossamia gjellerupi***	W114	Nena/Frieda	ULR	Hind	1.5	0	0.21	3	75	0	210
16/10/2010	***Glossamia gjellerupi***	W115	Nena/Frieda	ULC	Hind	1.5	0	0.22	3	150	0	220
13/01/2009	***Glossamia gjellerupi***	W22	Nena/Frieda	MCR	Hind	-	-	0.27	3			
13/01/2009	***Glossamia gjellerupi***	W22	Nena/Frieda	MCR	Whole Body	-	-	0.59	3			
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.19	3			190
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.17	3			170
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.2	3			200
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.2	3			200
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.29	3			290
14/01/2009	***Glossamia gjellerupi***	W23	Nena/Frieda	MCR	Hind	-	-	0.18	3			180
15/01/2009	***Glossamia gjellerupi***	W29	Nena/Frieda	MCR	Hind	-	-	0.28	3			70
15/01/2009	***Glossamia gjellerupi***	W29	Nena/Frieda	MCR	Whole Body	-	-	0.64	3			160
15/01/2009	***Glossamia gjellerupi***	W29	Nena/Frieda	MCR	Whole Body	-	-	1	3			250
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.26	3			
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.26	3			
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.3	3			
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.29	3			
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.32	3			
8/1/2009	***Glossamia gjellerupi***	W41	Nena/Frieda	ULC	Hind	-	-	0.32	3			
15/01/2009	***Glossamia gjellerupi***	W42	Nena/Frieda	ULC	Hind	-	-	0.26	3			
8/1/2009	***Glossamia gjellerupi***	W43	Nena/Frieda	ULC	Hind	-	-	0.2	3			200
10/8/2010	***Glossamia gjellerupi***	W43	Nena/Frieda	ULC	Hind	1.5	0	0.29	3	57.69231	0	290
26/08/2010	***Glossamia gjellerupi***	W70	Nena/Frieda	MCR	Hind	1.5	0	0.17	3			
26/08/2010	***Glossamia gjellerupi***	W70	Nena/Frieda	MCR	Hind	1.5	0	0.14	3			
5/12/2011	***Glossobius koragenis***	W28			Hind	0.5	0.02	0.73	3	12.5	200	730
5/12/2011	***Glossobius koragenis***	W28			Hind	0.5	0.02	0.37	3	12.5	200	370
5/12/2011	***Glossobius koragenis***	W28			Hind	0.5	0.02	0.23	3	12.5	200	230
5/12/2011	***Glossobius koragenis***	W28			Hind	0.5	0.01	0.22	3	12.5	100	220
5/12/2011	***Glossobius koragenis***	W28			Hind	0.5	0.01	0.82	3	12.5	100	820
27/08/2010	***Glossogobius coatesi***	W70	Nena/Frieda	MCR	Flesh	1.5	0	0.08	3			
30/06/2011	***Glossogobius koragenis***	BC			Flesh	0.94	0.01	0.19	3	22.38095	100	26.38889
30/06/2011	***Glossogobius koragenis***	BC			Flesh	1.4	0.01	0.24	3	33.33333	100	33.33333
30/06/2011	***Glossogobius koragenis***	BC			Flesh	0.58	0.01	0.2	3	13.80952	100	27.77778
1/7/2011	***Glossogobius koragenis***	W48			Flesh	1.4	0.01	0.2	3			
1/7/2011	***Glossogobius koragenis***	W48			Flesh	0.62	0.01	0.15	3			
1/7/2011	***Glossogobius koragenis***	W48			Flesh	3.5	0.01	0.23	3			
1/7/2011	***Glossogobius koragenis***	W48			Flesh	1.9	0.01	0.19	3			
1/7/2011	***Glossogobius koragenis***	W48			Flesh	1.1	0.01	0.13	3			
15/01/2009	***Hephaestus transmontanus***	W42	Nena/Frieda	ULC	Hind	-	-	0.48	3			

Tissue Concentrations					
	Plankton	Mean	37.7349	0.092276	1.25512
		P90	55.9776	0.1564	2.33712
		Max	94.962	0.1564	3.8952
	Invertebrates	Mean	12.85	0.09375	9.335
		P90	33.5	0.3	26.4
		Max	86	0.5	31
	Fish	Mean	1.431565	0.006783	0.293731
		P90	1.6	0.010	0.51
		Max	14	0.3	1.5

BAF = Trophic Level Tissue Concentration / (Trophic Level - 1 Tissue Concentration)

		Al	Cd	Cu
TL 1	Mean	NA	NA	NA
	P90	NA	NA	NA
	Max	NA	NA	NA
TL 2	Mean	0.34	1.02	7.44
	P90	0.60	1.92	11.30
	Max	0.91	3.20	7.96
TL3	Mean	0.11	0.07	0.03
	P90	0.05	0.03	0.02
	Max	0.16	0.60	0.05

Plankton concentrations derived from surface water concentration (P90) multilied by plankton BCF - See BCF_BAF Calculations tab.
TL2 - TL3 concentrations are from measured invertebrate and fish samples prior to ISF impoundment.