Drinking Water Risk Assessment

Serpentine, Serpentine Pipehead, South Dandalup, and Wungong Brook Catchments

Alcoa of Australia Limited

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→ The Power of Commitment

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Executive summary

Background

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery (Refinery) by 5 per cent from 5.0 million tonnes per annum (Mtpa) to 5.25 Mtpa by transitioning the Huntly Bauxite Mine into the proposed Myara North and Holyoake mine regions (the Proposal). The Proposal is located in the Peel region of Western Australia (WA), approximately 100 km south-east of Perth.

The Huntly Mine operations will transition into the Myara North and Holyoake regions, which primarily lie within the Serpentine Main Dam and South Dandalup Dam Public Drinking Water Source Areas (PDWSAs). A small portion of the Myara North region lies within the Serpentine Pipehead Dam (herein referred to as Pipehead Dam) PDWSA and in the upper catchments of the Canning River and Wungong Brook PDWSAs. The Huntly Mine currently operates within the Serpentine Main Dam, Pipehead Dam and North Dandalup Dam PDWSAs.

The Proposal will be subject to environmental impact assessment under under Part IV of the WA *Environmental Protection Act 1986* (EP Act), and the *Environmental Protection Biodiversity and Conservation Act 1999* (EPBC Act). The environmental impact assessment will be via a Public Environmental Review (PER) and have identified Inland Waters as a preliminary key environmental factor. The assessment of the Inland Waters factor is to include a public drinking water risk assessment in accordance with contemporary standards and guidance. The risk assessment should consider potential contaminants arising from mining activities and infrastructure, as well as mobilisation of existing contaminants from past catchment activities. Where high risks to public drinking water beneficial uses are identified, the assessment is required to detail potential impacts to human health.

Contemporary guidance regarding the human health aspects of drinking water has been used throughout this report. The primary sources included the Australian Drinking Water Guidelines (ADWG), the World Health Organisation guidelines for drinking water quality, the Australian and New Zealand Guidelines for Fresh and Marine Water Quality, and the Water Services Association of Australia (WSAA) Health Based Targets (HBT) Manual.

The Serpentine, South Dandalup and Pipehead Dam PDWSAs constitute a single “source water”, culminating at the point of supply to the Pipehead Dam Water Treatment Plant (WTP). Desalination inputs from the Integrated Water Supply Scheme (IWSS) to Pipehead Dam are substantial, and are projected to make up an increasing proportion of the source water in the future. Catchment access is restricted, with permissible activities listed in Source Water Protection plans for each PDWSA. The PDWSAs are predominantly managed as priority 1 with small areas of private land managed as priority 2. The source water is treated with chlorine, and then transferred to the IWSS for distribution to downstream customers.

The potential hazards from the Proposal to water quality were identified, based on proposed land uses. Those uses included:

– construction
– mine development, mining and rehabilitation stages of the Huntly Mine operations
– associated mine facilities and infrastructure.

The identified potential hazards from the Proposal included:

– generation and discharge of pathogenic microorganisms from increased human activity;
– increases in sediment, suspended solids and turbidity from erosion during mining activities;
– increases in stream salinity as a result of mining-induced saline groundwater discharge; and
– contamination from spills, leaks, and/or emissions from the storage, handling and use of hazardous materials and waste.

Long term hazards (following the completion of Proposal activities) were identified, associated with mine rehabilitation and climate change, including:

– potential increase in large scale wildfires that generate sediment, suspended solids, turbidity, organic matter and nutrients

– long term resilience of mine rehabilitation and un-mined vegetation and erosion of rehabilitation areas that generate sediment, suspended solids and turbidity
– remobilisation of sediment from deposition areas on slopes, streams and reservoir floors.

Pathogen risks during mining

Examination of pathogen hazards included a source vulnerability assessment for the three PDWSAs, using the methodology described in the WSAA HBT Manual (2015). The source vulnerability assessment of human settlement and stock animal challenges of microbial risk aligned well with category 1 source waters. Some challenges presented from itinerant human activity could be regarded as category 1 or 2, however with the consideration of existing mitigation factors, the source water could be considered as a category 1 source. This was consistent with the current treatment applied to the source water. The assessment was verified with a desktop sanitary survey using the methodology described in Baker et al (2016), applied to sewage treatment systems and mobile work teams typically associated with construction, mining and rehabilitation activities. The worst-case outputs from this survey assessment produced medium or low-risk results, in line with the outcomes of the vulnerability assessment.

Further examination of pathogen hazards included a quantitative microbial risk assessment (QMRA), conducted to estimate the impacts of pathogen inputs from the Proposal and other sources in the three PDWSAs that will sometimes be entrained in the source waters for drinking water supply. This examined the concentration of the reference pathogen *Cryptosporidium* through to potential exposure to the local population, estimated the risk of illness from such exposure, and expressed this risk as Disability Adjusted Life Years (DALYs). Pathogen inputs to the catchment were examined as hazardous events, including:

– sewage overflow during on-site treatment
– washout of treated effluent from an irrigation area
– subsurface leaching of treated effluent
– direct faecal deposition in a riparian zone by a staff member with asymptomatic cryptosporidiosis.

A reasonable design worst case of each of these events was considered, with the assumption of steep terrain, little vegetation coverage, and heavy rainfall resulting in high rates of transport of contamination into the receiving reservoir. Hydrological modelling described in GHD (2021) examined subsequent pathogen transport and survival through the reservoirs, and pathogen exposure and dose response estimates (AGWR, 2020) were applied to calculate the risk from the use of each dam as a source water. The risk was then compared with an acceptance threshold of
10^{-6} DALYs/ person/ year.

The QMRA outputs identified that the risk from the most hazardous tested event, of direct faecal deposition in the Pipehead Dam catchment, was elevated above the threshold of acceptable risk. As an elevated risk, this hazard requires attention through additional preventative barriers to reduce the risk to an acceptable level. In addition to the averaged annual concentration of *Cryptosporidium* resulting from the examined hazards, GHD (2021) predicted the peak concentrations of this organism resulting the hazards. For the highest risk hazards presented in the Pipehead Dam PDWSA, these included concentrations of ~0.00001 oocysts/L and ~0.01 oocysts/L, based on the location of faecal deposition within that PDWSA. From these calculated concentrations, the latter hazard presents an unacceptable short-term high risk of cryptosporidiosis, in addition to the annualized risk. This observation supports the conclusion that the mitigation of this hazard to a level of acceptable risk requires attention through additional preventative barriers.

Turbidity risks during mining

Erosion risks were examined in an assessment of turbidity as a water quality parameter in the Serpentine, South Dandalup and Pipehead PDWSAs. While not hazardous in itself, turbidity is able to reduce the efficacy of treatment processes in inactivating or removing pathogens, and the existing water treatment processes at the Pipehead Dam WTP do not include a mechanism to reduce turbidity in the raw water. The ADWG notes that where the turbidity of a source exceeds 1 nephelometric turbidity units (NTU), adequate disinfection may be more difficult to maintain, but may still be achievable. Generally, the lower the turbidity of a source water, the more effective chlorination will be, and validation is required to demonstrate that disinfection of higher turbidity water is effective. The literature basis for turbidity as an indicator of disinfection efficacy was examined, including the demonstrated finding that turbidity-generating compounds such as clays, humic acids and fulvic acids have no effect on disinfection. Where high turbidity (20 NTU) waters containing organic particles generated from

wastewater were examined, these waters could still be effectively disinfected for chlorine-resistant viruses, but required longer chlorine contact times to factor in the chlorine demand from wastewater particulates. In practice, challenge testing can be performed to validate and optimise virus disinfection, where a source water is outside the tested range for disinfection parameters such as turbidity.

In the case of the Serpentine, South Dandalup and Pipehead PDWSAs, turbidity challenges were modelled in GHD (2021) in the form of inorganic clay and silt particles, simulating turbidity inputs associated with natural waterways and mining sumps. It is noted that these inorganic particles would not be expected to affect disinfection efficacy. The key results and conclusions regarding turbidity challenges from GHD (2021) were that Serpentine Main Dam turbidity concentrations were sensitive to changes in sump failure suspended solids concentrations, as mining comprises a sufficient proportion of the catchment landscape to do so. This contrasted with South Dandalup Dam sump failure suspended solids concentrations, as the proposed mining area is a small proportion of the overall catchment area, and there is no existing mining in that catchment and previous mining areas are assumed to be fully rehabilitated.

Fuel spill risks during mining

The Huntly Mine is a diesel only fuel site, with no storage or handling of unleaded petrol. Diesel is predominantly used for haul trucks, excavators and other large earthmoving equipment, and to a lesser extent for light vehicles. The storage and handling of diesel creates a potential hazard for spillage of diesel that may enter reservoirs. GHD (2021) examined the effect of mining activity-related diesel spill incidents in the catchments, with the assumption that a 15 m^3 fuel tanker load was directly discharged into a stream at a haul road crossing. The modelled processes leading to decreased diesel concentrations were river dilution, reservoir mixing and dispersion, and withdrawals from the dams. The modelled diesel spill incidents in Serpentine Main Dam and South Dandalup Dam were predicted to result in peak concentrations at the dam offtakes at up to 1 µg/L, whilst a mid-reservoir spill in Pipehead Dam was predicted to result in peak concentrations at the dam offtake at up to 5 µg/L. These concentrations did not exceed the ADWG health based guideline limits for components of diesel fuel. The ADWG notes that diesel contamination in drinking water has a taste and odour threshold of 5 µg/L. This could be reached, with the largest predicted peak diesel concentration of up to 5 µg/L for the Pipehead Dam.

PFAS risks

Alcoa have committed to using PFAS-free firefighting foams for the Myara North and Holyoake regions. All water supplies to construction and operations in the Myara North and Holyoake regions will be sourced from public water supply reservoirs or borefields that are tested and verified as free of detectable PFAS. PFAS would be limited to minor quantities in materials such as workforce clothing, paper packaging, carpets or wire insulation, which are unlikely to be discharged to the environment as all wastes will be recycled or disposed off-site at licensed waste facilities. Accordingly, the direct discharge of PFAS from construction and mining is expected to pose a low risk to drinking water quality.

The existing land uses and baseline monitoring program (GHD 2021) do not indicate the presence of substantial PFAS contamination within the Myara North or Holyoake regions. PFAS are relatively persistent and water-soluble compounds which readily mobilise through the unsaturated zone and into groundwater, which discharges into streams. It is therefore expected that any existing substantial PFAS contamination of the catchments would be detectable in stream flows. Due to the absence of existing substantial contamination, any hydrological changes from construction and mining (i.e. the clearing of vegetation causing groundwater mounding and increased stream flows) are not expected to mobilise substantial quantities of PFAS into reservoirs. Accordingly, the indirect mobilisation of historical PFAS from catchments due to construction and mining is expected to pose a low risk to drinking water quality.

Other hazardous materials

Diesel is the predominant hazardous material used at the Huntly Mine, and to a lesser extent hydraulic and lubricating oils. Minor quantities of other hazardous materials include solvents, adhesives and other chemicals are used for vehicle and equipment maintenance or water treatment.

Haul trucks, some wheeled earthmoving equipment and light vehicles are refuelled at fuel bays. Planned maintenance of haul trucks, light vehicles and some earthmoving equipment is undertaken at workshops. The fuel bay and workshop buildings are located at mine facilities and have roofs and sealed floors, which are expected to capture spills or leaks during refuelling or maintenance. Diesel and oil storage tanks are located at mine facilities and are double-lined and above ground to minimise and detect leaks. Smaller quantities of hazardous materials stored at mine facilities inside buildings or on sealed floors.

Excavators, bulldozers and other earthmoving equipment are refuelled and maintained in the field. Refuelling and maintenance in the field have potential to cause spills and leaks that contaminate soils. There is also potential for ongoing, low level oil leaks from vehicles and equipment, and rare collisions that result in fuel or oil spills.

The majority of spills and leaks, particularly those from major incidents and involving large volumes, are expected to be identified quickly and the contaminated soils excavated and disposed off-site at a licensed waste facility. Smaller spills and leaks may potentially be missed and the contaminants leach through the unsaturated zone. The smaller spills and leaks are expected to remain predominantly adsorbed to soil particles beneath the spill site. Diesel and particularly oil contain larger chain hydrocarbons that are weakly water soluble and readily adsorb to soils with organic matter and clay content. Accordingly small volumes of diesel and oil that escape detection and remediation are unlikely to result in substantial migration of hydrocarbons that reach streams and can be transported into the reservoirs. This is verified by site investigation at the Huntly Mine, which did not detect hydrocarbons in stream flows downstream of existing mine pits, haul roads and mine facilities. Accordingly, the storage and handling of hazardous materials during construction or operations is expected to pose a low risk to drinking water quality.

Long term fire risks

The evidence reviewed by Australian authors and the impact of 2005 Perth Hills and 2016 Waroona-Yarloop fires suggest that the Serpentine Main Dam, South Dandalup Dam and Wungong Dam reservoirs may be susceptible to water quality impacts from bushfires. Such an event may include a high intensity wildfire that covers a large proportion of a catchment, occurs over steep terrain and in the year prior to heavy rainfall events.

A major wildfire and heavy rainfall sequence may result in widespread ash deposition, runoff and erosion that generate substantial discharges of ash and sediment into the catchment's reservoir. Depending on the severity and location of fire and rainfall, there is potential for the scale of discharges to exceed the attenuating capacity of the reservoir and cause elevated contaminant levels at the offtake that exceed drinking water quality criteria.

It is expected that the transition of mining into the Myara North and Holyoake regions will continue to enable DBCA's prescribed burning program to be effectively planned, funded and implemented, as has been demonstrated within the Huntly Mine to date. Accordingly, the Proposal is expected to maintain and support the State Government's program to limit fuel accumulation in the Northern Jarrah Forest, thereby reducing the likelihood of large wildfires occurring in the Serpentine Main Dam, South Dandalup Dam or Wungong Brook PDWSAs.

Long term erosion of rehabilitation

The net effect of bauxite mining of Jarrah forest soils is the removal of an approximately 4-6 m thick layer of caprock and friable fragmental material, and replacement of the seed rich topsoil and overburden over a ripped, friable substrate of sandy loams and clays. The total depth of friable material created is about 1.5 m, including topsoil, overburden and ripped substrate.

The establishment of a 1.5 m thick friable stratum provides a comparable, though generally thicker, stratum than the topsoil and overburden present above the caprock prior to mining. The friable layer enables development of a dense root structure of Jarrah forest vegetation as occurs in the topsoil and overburden present prior to mining. Deeper rooted vegetation establishing within the friable layer is expected to re-colonise ancient root channels present in the underlying regolith materials, as have been used by successive generations of trees prior to mining. There is expected to be a partial loss of soil water capacity due to the removal of the bauxite friable fragmental layer, which represents approximately 10 per cent of the regolith thickness.

Loss of the bauxite friable fragmental layer has not been observed to result in impaired growth or health of rehabilitation. Monitoring of rehabilitation has demonstrated the successful establishment and persistence of overstorey, floristic diversity and understorey coverage, including during drought periods such as 2010/11. The results of monitoring collectively demonstrate that Alcoa's rehabilitation establishes and persists, including during drought and heat wave events, indicating that the 1.5 m thick friable substrate over regolith containing ancient root channels is an effective growth medium.

Accordingly, mine rehabilitation vegetation is expected to be sustained over the long term with resilience to climate change comparable to that of un-mined Jarrah forest. Mine rehabilitation is therefore expected to provide long term protection of soils from erosion and associated sediment discharge to streams and reservoirs.

Preventative risk management

Alcoa implements preventative risk management at the Huntly Mine, which incorporates multiple barriers to prevent hazards to drinking water from occurring or reduce them to acceptable levels. The multiple barriers are established to control hazards relating to pathogens, sediment discharge and hydrocarbons. The barriers act to prevent and minimise the discharge of pathogens, sediment and hydrocarbons into downstream reservoirs, which are themselves barriers to contaminant transport to the offtakes.

Review of the existing barrier network at the Huntly Mine indicates that some barriers are likely to fail under certain conditions and with multiple barrier failures result in varying quantities of contaminants reaching the downstream reservoirs. Key conditions that can cause barrier failure include workforce behaviour in the case of discharge of pathogens, and major storm events during wet catchment conditions in the case of sediment and hydrocarbons. Additional barriers and improvements to existing barriers are proposed to reduce the likelihood of barrier failure and potential for discharge of contaminants into reservoirs. Key improvements proposed include:

– Avoidance of mining in the Serpentine Pipehead PDWSA
– Workforce education and monitoring
– Incident reporting / response
– Application of risk-based Mine drainage controls in all disturbed areas, in accordance with Alcoa Drainage Manual and Haul road Sump Design Manual
– Rehabilitated mine pits to be designed and executed to prevent overflow during a 1 per cent 24hr AEP event.

Residual risk assessment

The Proposal will result in an increase in the mine workforce, area open and mine fleet operations at the Huntly Mine compared to current operations in the Myara mine region. These increases have the potential to increase the risk of pathogen, sediment and hydrocarbon discharge into downstream reservoirs and the IWSS.

Subject to the improvements proposed, the residual risk from the proposed Huntly Mine operations at the Myara North and Holyoake regions is expected to reduce from the risk posed by the existing Huntly Mine operations to the IWSS.

Limitations

This report is subject to, and must be read in conjunction with, the limitations set out in section 1.2 and the assumptions and qualifications contained throughout the Report.

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Appendix I Barriers
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Terminology

Terminology	Definition
Alcoa of Australia Limited (Alcoa)	The proponent of the Proposal.
GHD Pty Ltd (GHD)	Consultant engaged by Alcoa to prepare environmental approvals documentation and supporting technical studies for the Proposal.
Myara North Development Envelope	Myara North mine region and associated infrastructure corridor within the Huntly mine region. 22,703 ha total
Myara North Infrastructure Corridor	Corridor adjacent to Myara North mine region in which a conveyor, haul road and other infrastructure may be developed. May also be referred to as a transport study area or conveyor/haul road corridor. 5,254 ha
Holyoake Development Envelope	Holyoake mine region and associated infrastructure corridor within the Huntly mine region. 18,700 ha total
Holyoake Infrastructure Corridor	Corridor adjacent to Holyoake mine region in which a conveyor, haul road, access road and other infrastructure may be developed. May also be referred to as a transport study area or conveyor/haul road corridor. 9,542 ha
Mine Development Envelope	Total Mine Development Envelope for the Proposal, this being Myara North and Holyoake mine regions and associated infrastructure corridors. 41,403 ha
Mining region	Sub-regions that comprise the Huntly Mine, including current (Myara), past (O'Neil, McCoy) and future (Myara North, Holyoake), etc.
Haul Road	Truck and mine infrastructure access road linking into existing corridors.
Huntly Mine	Huntly Bauxite Mine within ML1SA. This includes the previous and current mine regions of Del Park, Huntly, White Road, McCoy, O'Neil, and Myara, and the transition to the future mine regions of Myara North and Holyoake.

Abbreviations

Abbreviations	Definition
ADWG	Australian Drinking Water Guidelines
AEP	Annual Exceedance Probability
ANZG	Australia New Zealand Guidelines
ARI	Average Recurrence Interval
BoM	Bureau of Meteorology
CSM	Conceptual Site Model
DALY	Disability Adjusted Life Years
DBCA	Department of Biodiversity, Conservation and Attractions
DE	Development Envelope
DFES	Department of Fire and Emergency Services
DOC	Dissolved Organic Carbon
DWER	Department of Water and Environmental Regulation
DWRA	Drinking Water Risk Assessment
DWSPP	Drinking water Source Protection Plan
EP Act	Environmental Protection Act 1986
EPA	Environmental Protection Authority Western Australia
EPBC Act	Environmental Protection and Biodiversity Conservation Act
ERD	Environmental Review Document
ESD	Environmental Scoping Document
EY	Exceedances per Year
FMP	Forest Management Plan
FPC	Forest Products Commission
GL	Gigalitre
ha	Hectare
HBT	Health Based Target
HRZ	High Rainfall Zone
IRZ	Intermediate Rainfall Zone
IWSS	Integrated Water Supply Scheme
km	Kilometres
LAI	Leaf Area Index
LRV	Log Removal Value
mg/L	Milligrams per Litre
ML	Megalitre
MMP	Mining and Management Program
MMPLG	Mining and Management Program Liaison Group
MWSSD Act	Metropolitan Water Supply, Sewerage, and Drainage Act 1909
NTU	Nephelometric Turbidity Units
PDWSA	Public drinking water source area

Abbreviations	Definition
PER	Public Environmental Review
PFAS	Per- and Polyfluoroalkyl Substances
QMRA	Quantitative Microbial Risk Assessment
RFA	Regional Forest Agreement
ROM	Run of Mine
RPZ	Reservoir Protection Zone
RUSLE	Revised Universal Soil Loss Equation
SDD	South Dandalup Dam
SDPD	South Dandalup Pipehead Dam
SMD	Serpentine Main Dam
SPD	Serpentine Pipehead Dam
SS	Suspended Solids
STP	Sewage Treatment Plant
TCU	True Colour Units
WHO	World Health Organisation
WQPN	Water Quality Protection Note
WTP	Water Treatment Plant
WWTP	Waste Water Treatment Plant

1. Introduction

1.1 Purpose of this report

Alcoa of Australia Ltd (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery by 5 per cent from 5.0 million tonnes per annum (Mtpa) to 5.25 Mtpa and transition the Huntly Bauxite Mine (Mine) to the proposed Myara North and Holyoake mine regions (the Proposal). The proposed Myara North and Holyoake mine regions primarily lie within the Serpentine Main Dam and South Dandalup Dam Public Drinking Water Source Areas (PDWSAs). A small portion of the Myara North region lies within the Serpentine Pipehead Dam (Pipehead Dam) PDWSA and in the upper catchments of the Canning River and Wungong Brook PDWSAs. The Mine currently operates within the Serpentine Main Dam, Pipehead Dam and North Dandalup Dam PDWSAs and has previously operated within the South Dandalup Dam PDWSA.

The Proposal will be assessed by the WA Environmental Protection Authority (EPA) under Part IV of the *Environmental Protection Act 1986* (EP Act), and the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act) via the bilateral agreement. The Proposal will be assessed via a Public Environmental Review (PER).

The EPA has identified Inland Waters as a preliminary key environmental factor, noting that the proposed mining areas intersect with PDWSAs. The assessment will be undertaken in accordance with an Environmental Scoping Document (ESD). This report presents a drinking water risk assessment for the Serpentine, Serpentine Pipehead, South Dandalup, and Wungong Brook PDWSA, to meet the requirements of ESD work item 50 (provided below), to support the PER of the Proposal.

"50. Undertake a public drinking water risk assessment for the Serpentine, Pipehead and South Dandalup reservoirs and upper Wungong Brook catchment, including source vulnerability assessment, in accordance with the Australian Drinking Water Quality Standards and relevant contemporary guidance. The risk assessment should consider potential contaminants arising from mining activities and infrastructure, as well as mobilisation of existing contaminants from past catchment activities. For identified high risks to public drinking water beneficial uses, undertake a detailed assessment of potential impacts to human health in accordance with contemporary guidance."

Separate reports address the baseline hydrology and water quality for the proposed Myara North and Holyoake mine regions and potential water related environmental impacts of the Proposal.

1.2 Scope and limitations

This report: has been prepared by GHD for Alcoa of Australia Limited and may only be used and relied on by Alcoa of Australia Limited for the purpose agreed between GHD and Alcoa of Australia Limited as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Alcoa of Australia Limited arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described throughout this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Alcoa of Australia Limited and others who provided information to GHD (including Government authorities), which GHD has not independently verified or

checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

2. Background

2.1 Alcoa operations

The following description of Alcoa's current and future operations is drawn from the Environmental Scoping Document for the Proposal.

The Pinjarra Alumina Refinery is located approximately 6 km east of Pinjarra town site on South West Highway within the Shire of Murray in the Peel Region of Western Australia. It lies on cleared land on the Swan Coastal Plain. The Huntly Mine is located predominantly within the Shires of Murray, Serpentine Jarrahdale and Boddington within the Peel Region of Western Australia. The Huntly Mine lies on the Jarrah Forest of the Darling Plateau.

The refinery is subject to approvals under environmental legislation including Ministerial Statement 646 (MS 646) under Part IV of the EP Act. Mining operations at Huntly Mine are undertaken in accordance with a five-year Mining and Management Program (MMP) that is approved by the Minister for State Development on advice of the Minister for Environment and the Mining and Management Program Liaison Group (MMPLG).

Alcoa has gradually increased alumina production at the refinery through ongoing efficiency upgrades and expects that production will exceed the 5.0 Mtpa authorised under MS 646, reaching 5.25 Mtpa over the next decade (5 per cent increase from existing 5.0 Mtpa approved rate). The current rate of alumina production at the refinery is approximately 4.75 Mtpa.

The current approved MMP for 2020-2024 authorises mining of an average of just over 16.0 Mtpa (dry tonnes) of bauxite per year at Huntly Mine with associated vegetation clearing at an average of approximately 350 ha/year over the five-year period. The MMP also includes mining for up to 2.0 Mtpa (dry tonnes) of bauxite for export in 2020 and 2021.

The Huntly Mine will be making a progressive transition from the current Myara mining area to the Myara North and Holyoake mining areas starting from about 2023, on receipt of relevant approvals This is an inherent part of bauxite mining and consistent with previous mining area transitions within ML1SA. This will enable continuity of bauxite supply to the Pinjarra Alumina Refinery as well as bauxite export.

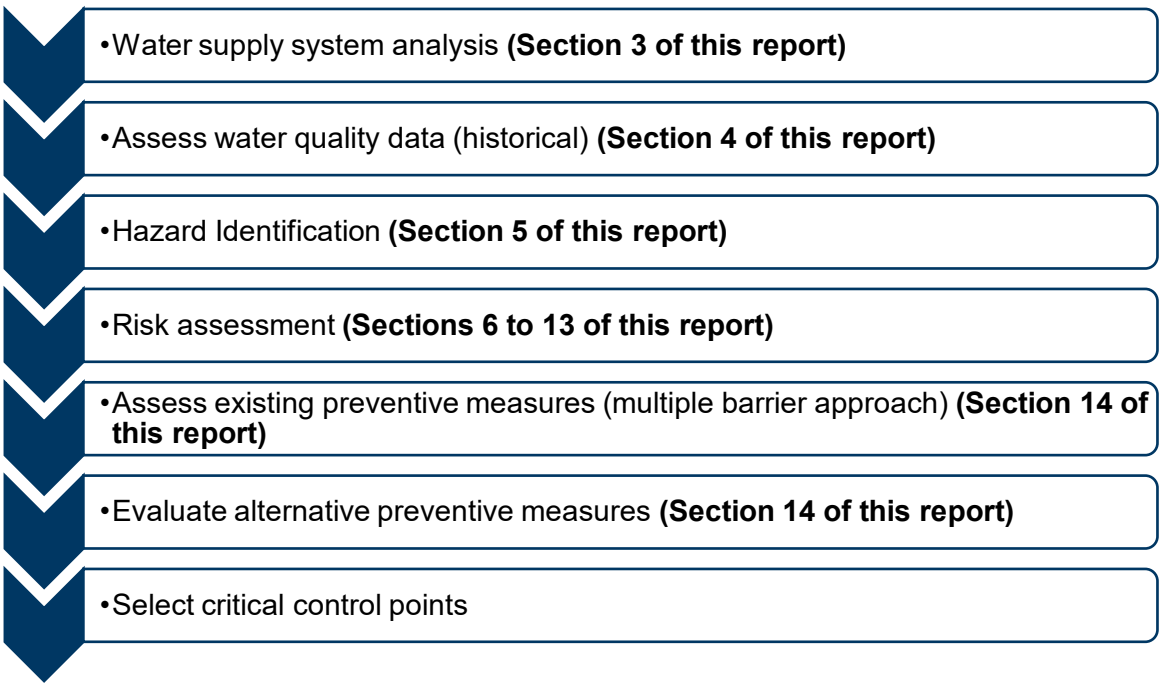
2.2 Regulatory and policy framework

This DWRA has been prepared in accordance with contemporary guidance including:

- Australian Drinking Water Guidelines (ADWG) (National Health and Medical Research Council, 2011)
- Guidelines for drinking-water quality (World Health Organization, 2017)
- Australian and New Zealand Guidelines for Fresh and Marine Water Quality (ANZG) (Australian and New Zealand Governments and Australian state and territory governments, 2018)
- Health Based Targets Manual (WSAA, 2015)
- Department of Water and Environmental Regulation (DWER) Water Quality Protection Notes
- By-Laws, international publications, and any other relevant publication for key contaminants of concern (e.g. turbidity, hydrocarbons and PFAS).

The ADWG provide the authoritative reference for use within Australia's administrative and legislative framework to ensure the accountability of drinking water suppliers (as managers) and of state and territory health authorities (as auditors of the safety of water supplies).

A risk assessment is one element of the ADWG which is a prerequisite for subsequent steps for prevention and control of hazards. The ADWG require identification of all potential hazards, their sources and hazardous events, and an assessment of the level of risk presented by each. The ADWG framework for risk assessment and preventative measures involves:



At the time of writing, the current revision of the ADWG is version 3.6, updated March 2021. This version does not contain guidance of source vulnerability assessment of drinking water catchments. Such guidance is available in a consultation draft section for the ADWG released as version 15 in August 2016, as section 5.7 Microbial health-based target for drinking water supplies (Australian Drinking Water Guidelines: Draft framework on microbial health based targets | NHMRC Public Consultations). This draft was largely based on guidance in the WSAA HBT Manual (2015), including source vulnerability assessment and how it is used to categorise source waters. The source vulnerability assessment performed in this DWRA is based on the WSAA HBT Manual; guidance.

3. Water supply system

This section presents information relating to the first step of the ADWG framework, including an assessment of the existing water supply system, catchment details, existing land uses and future water supply requirements.

3.1 Catchments

The water supply system examined here includes two large catchment areas, the Serpentine and South Dandalup Dam PDWSAs. Raw water from Serpentine Dam is transferred to Serpentine Pipehead Dam (hereafter referred to as Pipehead Dam), which also receives desalination transfers from the Integrated Water Supply Scheme (IWSS). These combined inputs are supplied to the Pipehead Dam water treatment plant (WTP), and following treatment the finished water is then directed to the IWSS. A conceptual diagram of supply and treatment is included as Figure 3.1.

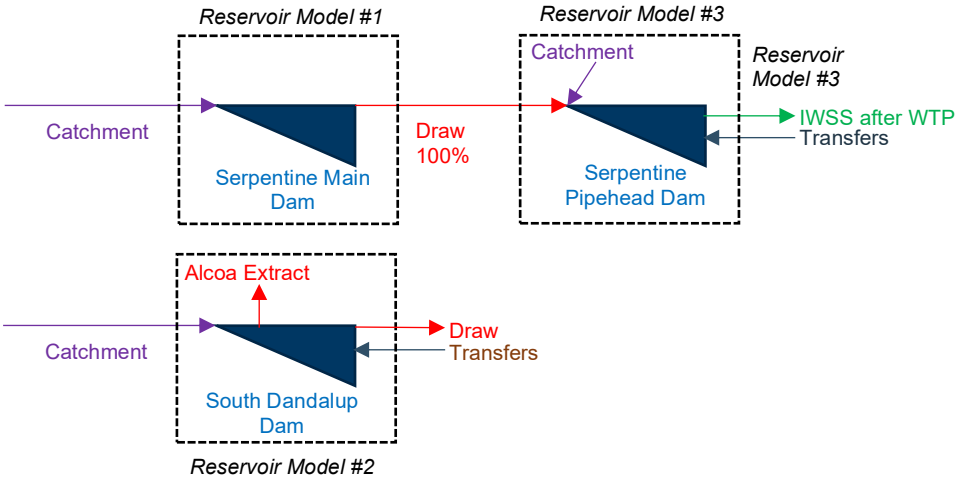


Figure 3.1 Conceptual diagram of supply to Serpentine Pipehead Dam

In the context of the WSAA HBT Manual (2015), the described combined catchment area constitutes a single "source water", culminating at the point of supply of raw water to the Pipehead Dam WTP. The source vulnerability assessment methodology in WSAA (2015) Table 1 differentiates inner and outer catchment areas, with the inner catchment described as typically 2-3 km from full supply level of a storage. However, this assumes that raw water abstraction for supply occurs from a single storage. In this case, multiple sources can be drawn on to supply the Pipehead Dam, which then supplies the WTP. To align with the WSAA (2015) approach for catchment vulnerability assessment, the Pipehead Dam and its immediate catchment area would be treated as the "inner catchment" of this source water, and the other surface water catchments (Serpentine Main Dam, South Dandalup Dam catchments) would be treated as "outer catchment" areas. This would be a slightly different but more accurate approach than treating the immediate surrounds of the upper lake storages (specifically the Reservoir Protection Zones) as inner catchments, which may be otherwise expected.

Summary details of the catchment areas have been drawn from the Drinking Water Source Protection Plans for the Serpentine Main Dam and Serpentine Pipehead Dam PDWSAs (DoW, 2007) and for the South Dandalup Dam PDWSA (DoW, 2005).

3.1.1 Serpentine Main Dam

The Serpentine Main Dam has a full supply capacity of 137.7 GL and collects water from a 664 km^2 catchment. The catchment is proclaimed under the *Metropolitan Water Supply,Sewerage and Drainage (MWSSD) Act (1909)*, and primarily classified as a Priority 1 PDWSA, with some private lands within the catchment classified as Priority

2. The reservoir is surrounded by a 2 km wide 'Reservoir Protection Zone' (RPZ) around its top water level, which includes the reservoir itself and does not extend outside the catchment area.

Approximately 12,500 ha of the Myara North mine region lies within the Serpentine Main Dam PDWSA, comprising approximately 19 per cent of the PDWSA, of which a portion will be disturbed by construction and mining. The existing Myara mine region of the Huntly Mine occupies a portion of the PDWSA.

3.1.2 South Dandalup Dam

The 208.2 GL capacity South Dandalup Dam is the largest reservoir supplying the IWSS. The catchment covers 311 km^2 and is proclaimed under the *MWSSD Act 1909*. Similar to Serpentine Main Dam, the catchment is predominantly classified as a priority 1 PDWSA, with a small area of private land managed as a priority 2 PDWSA. The South Dandalup Dam is also connected to the South Dandalup Pipehead Dam, which acts as a pumpback for South Dandalup Dam, adding to the available water for supply. Water from the South Dandalup Pipehead Dam is chlorinated before pump back to the South Dandalup Dam.

Approximately 6700 ha of the Holyoake mine region lies within the South Dandalup Dam PDWSA, comprising approximately 22 per cent of the PDWSA, of which a portion will be disturbed by construction and mining. The historical McCoy mine region of the Huntly Mine has formerly occupied a portion of the PDWSA.

3.1.3 Serpentine Pipehead Dam

The Serpentine Pipehead Dam is located directly downstream of the Serpentine Main Dam. It has a 2.6 GL full supply capacity, and in addition to inflows from Serpentine Main Dam, South Dandalup Dam and desalination inputs from the IWSS, is fed by a 28 km^2 catchment consisting entirely of State Forest and Serpentine National Park.

Approximately 200 ha of the Myara North mine region lies within the Pipehead Dam PDWSA, comprising approximately 7 per cent of the PDWSA, of which a portion may be disturbed by mining. The existing Myara mine region of the Huntly Mine occupies a portion of the PDWSA.

3.1.4 Upper Wungong Brook Catchment

The Upper Wungong Brook catchment comprises 128 km^2 and discharges into Wungong Dam, a drinking water supply reservoir with capacity of 60 GL. The catchment is proclaimed under the *Metropolitan Water Supply, Sewerage and Drainage (MWSSD) Act (1909)*, and primarily classified as a Priority 1 PDWSA, with a small area classified as Priority 2. The reservoir is surrounded by a 2 km wide RPZ around its top water level.

Approximately 2100 ha of the Myara North mine region lies within the Upper Wungong Brook PDWSA, comprising approximately 5 per cent of the PDWSA, of which a portion may be disturbed by construction and mining. The Myara North region lies in the upper reaches of the PDWSA and lies approximately 9 km upstream of the RPZ. The historical Jarrahdale Mine has formerly occupied a portion of the PDWSA.

3.1.5 Supply allocations

Water Corporation's current allocation licence for Serpentine Main Dam and Serpentine Pipehead Dam (licence 56737) totals 53.89 GL/annum and is issued for the purpose of providing water for public potable water supply and irrigation.

Water Corporation's current allocation licence for South Dandalup Dam (licence 56734) is 26.9 GL/annum. This licence is issued for the purpose of providing potable water for public water supply to the IWSS. Alcoa currently have two licences (No. 83356 and 153635) to abstract a total of 100 ML/annum from South Dandalup Dam, which is used to supply water (primarily for dust suppression) to the Huntly Mine.

Water Corporation's current allocation licence for Wungong Dam (licence 58767) is 20.6 GL/annum. This licence is issued for the purpose of providing potable water for public water supply.

3.1.6 Treatment and distribution

Source water arising from the Serpentine, South Dandalup and Pipehead PDWSAs is drawn from the Pipehead Dam and treated with chlorine. Finished water is transferred to the IWSS for distribution to downstream customers.

Source water arising from the Upper Wungong Brook PDWSA is drawn from the Wungong Dam and treated with chlorine before supply to the IWSS.

3.2 Climate

Western Australia's south west region has a 'Mediterranean' type climate characterised by typically high winter rainfalls and an intense summer drought. A summary of the nearest Bureau of Meteorology (BoM) to the Myara North and Holyoake mine regions is provided in Table 3.1.

Table 3.1 Summary of nearest BoM climate stations

BoM Station	Station number	Distance from Mine Development Envelope	Data range
Serpentine Main Dam Station	009115	Within Myara North mine region	1963 to 2016 Rainfall
Karnet Station	009111	4 km south of Myara North, 47 km north of Holyoake mine region	1963 to 2020 Rainfall, evaporation and solar radiation data
Dwellingup Station	009538	7 km from Holyoake mine region	1935 to 2020 Rainfall, evaporation and solar radiation data

Monthly statistics for the Karnet Station since its inception are shown in Figure 3.2, and SILO[1] point data was extracted and annual rainfall plotted in Figure 3.3. Average annual rainfall is within +/-3 per cent between stations.

The mean monthly maximum temperature ranges from 15.8°C in July to 30.9°C in January. Average annual evaporation (1520 mm) typically exceeds average annual rainfall (1153 mm), albeit rainfall exceeds evaporation during winter and shouldering months.

Western Australia's south west region has undergone a 15-20 per cent reduction in rainfall since the 1970s, as illustrated in Figure 3.3 (Petrone K. C., Hughes, Van Niel, & Silberstein, 2010). This trend has been forecast to continue with a further 2 to 14 per cent reduction predicted by 2030. Temperature increase and potential evapotranspiration are also forecast to increase by 0.7 °C and 2 to 3 per cent, respectively (CSIRO, 2009; DoW, 2015).

Rainfall is also known to decline with distance inland. The 1100 mm annual rainfall isohyet (High Rainfall Zone or HRZ) and the 900 to 1100 mm annual rainfall isohyet (Intermediate Rainfall Zone or IRZ) have been identified in research as defining features for differing hydrological effects across the Huntly Mine region.

[1] Rainfall, temperature, and evaporation data sourced from the SILO data downloaded from https://legacy.longpaddock.qld.gov.au/silo/ppd/ on 5 June 2020. Point data from the SILO climate database (Queensland Department of Science, 2015) provides a continuous daily climatic record for a given point with gaps infilled based on interpolation of records from nearby weather stations.

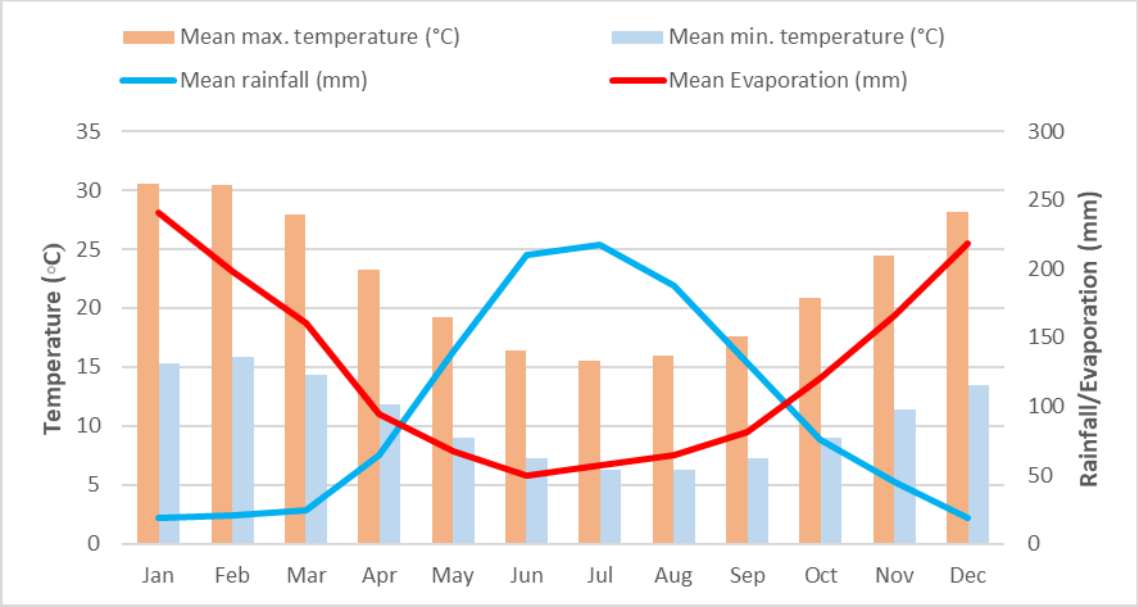


Figure 3.2 Monthly climate statistics at Karnet Station (Years 1965-2020)

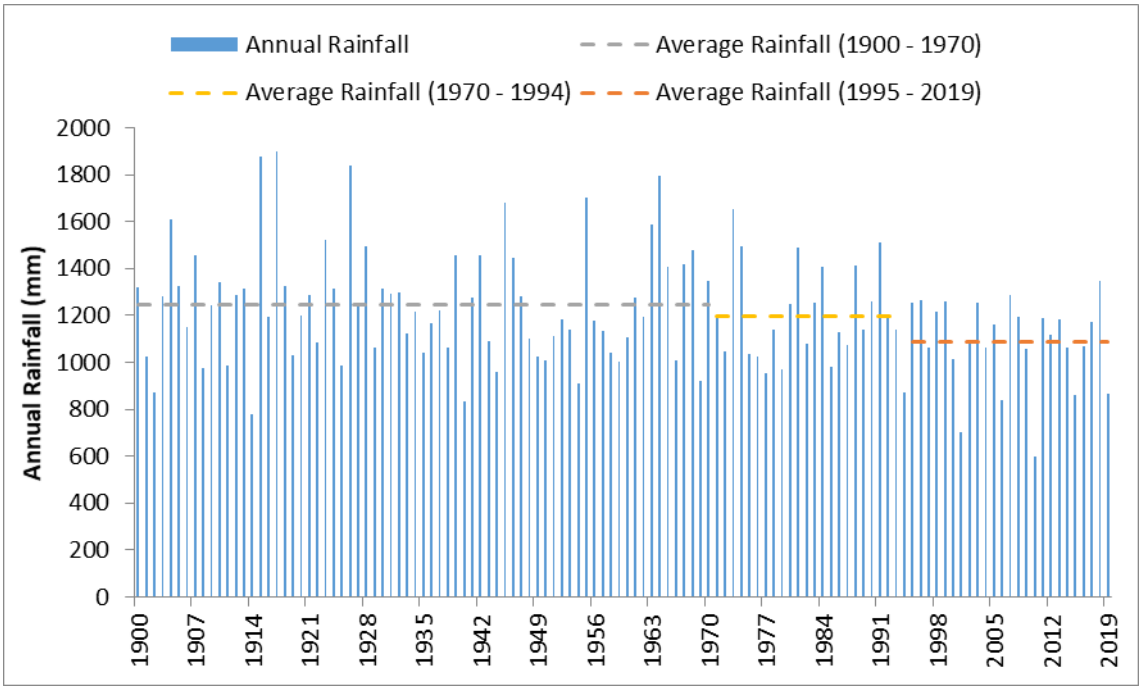


Figure 3.3 Annual rainfall at Karnet Station

3.3 Hydrogeology setting

3.3.1 Overview

The Serpentine Main Dam, South Dandalup Dam and Upper Wungong Brook catchments are located on the Darling Plateau, an undulating lateritic regolith over Archaean granite with dolerite intrusions. The groundwater host rocks predominantly comprise the weathered and fresh Archaean basement crystalline rocks. In addition, more recent sediments are incised into the basement rocks, coincident with existing drainage or palaeodrainage lines.

The generalised hydrogeology over the catchments comprise three main aquifer units:

– Shallow weathered zone aquifer: comprising lateritic caprock (duricrust) and shallow gravely to sandy sediments which represents a seasonal aquifer with significant storage, infiltration and flow capability.

– Deep weathered zone aquifer (lower saprolite) an aquifer of high storage potential, but limited bulk permeability (comprising clays).
– Fractured bedrock aquifer- permeability and yields are dependent on facture development and connectivity of the fractures.
– In addition to the above, where drainage lines are sufficiently developed, and have eroded the basement material, sediments, typically alluvial, have accumulated in the lower lying areas. The permeability of the sediments is variably distributed and related to lithology.

Broadly, groundwater levels within all aquifers appear to follow topography, such that groundwater level is highest in areas of highest topography and lowest in areas of lowest topography. Groundwater provides baseflow, following winter rains and aquifer recharge, to the major surface water bodies of the area.

3.3.2 Groundwater recharge, flow and discharge

Groundwater recharge into the subsurface occurs through rainfall infiltration into soils and downwards percolation of stored rainwater to the groundwater table. Root channels penetrating vertically via fissures and discontinuities in the cemented layer and deep into the clay zones are a consistent feature in the lateritic regolith. These channels form preferential flow paths and are understood to form significant vertical fluxes into groundwater systems (Turner & Johnston, 1987; McFarlane & Williamson, 2002;).

Stored rainwater is also subject to evapotranspiration (water loss) by the overlying vegetation (jarrah forest), so that a portion of infiltrated rainwater would reach and recharge the groundwater table. Where vegetation is cleared (e.g. timber harvesting or mining), evapotranspiration may be reduced which may increase recharge to the groundwater table.

Groundwater migrates from topographical highs towards the groundwater discharge boundaries in topographic flows, is expected to be towards the Serpentine Main Dam, South Dandalup Dam and Wungong Dam.

3.4 Hydrological setting

The Serpentine reservoir is fed by the Serpentine River, originating in the east of the catchment and then flowing north-west towards the reservoir. Big Brook is the main southern tributary, flowing from the south along the western edge towards the reservoir (Kitsios, Bari, & Charles, 2009). 39 Mile Brook collects runoff from the Jack Rocks catchment, draining to the north-east of the reservoir.

The South Dandalup reservoir is fed primarily by the South Dandalup River, generally draining from east to west. Barnett Brook is the only named tributary, draining a 17.6 km^2 catchment on the southern side of South Dandalup River. The 8.5 ha Banksiadale Dam, used for mining purposes, is located approximately 2 km north of the reservoir.

The catchments are in the Darling Plateau, which is characterized by sharply incised drainage lines forming dense drainage networks in the western, higher rainfall zone (HRZ), with these transitioning to open, flat-floored valleys in the eastern, lower rainfall zone (IRZ) (Churchward & Dimmock, 1989).

Seasonality in rainfall is reflected in streamflow seasonality. Some of the larger streams in the HRZ have previously exhibited perennial base flows. However, the drying climate discussed in Section 3.1 has caused a significant reduction in streamflow, leading to a shift from perennial to ephemeral streams and a decline in the runoff coefficient in recent decades. Runoff from Perth's drinking water catchments has declined up to 70 per cent in the last 40 years that is associated with a 15–20 per cent rainfall reduction (Bates, Hope, Ryan, Smith, & Charles, 2008). The Serpentine reservoir inflow dropped nearly one-half (58 to 32 mm) from 1989–2000 to 2001–2008 (Petrone K. C., Hughes, Van Niel, & Silberstein, 2010).

3.5 Existing land uses

3.5.1 Serpentine PDWSA

The Serpentine Main Dam and Pipehead Dam catchments include the following land uses:

– Land and forest management, including timber harvesting
– Commercial land uses such as mining and pine plantations
– Linear infrastructure including the Muja Northern Terminal Western Power transmission line, pipelines, roads (including Albany Highway), tracks, and telephone lines
– Recreation.

Detail of activities associated with existing land uses and their potential risks that may impact the water supply system can be found in the *Serpentine Dam Catchment Area and Serpentine Pipehead Dam Catchment Area Drinking Water Source Protection Plan* (DoW 2007).

The following aspects are noted with respect to the activities listed:

– **Timber harvesting** – timber harvesting is undertaken by Forest Products Commission (FPC) within the Jarrahdale and Dwellingup State Forests in accordance with the Forest Management Plan (FMP) and Regional Forest Agreement (RFA). Harvesting occurs as a mosaic of infrequent clearing nominally once every several decades. Department of Biodiversity, Conservation and Attractions (DBCA) timber harvesting data indicating that most of the PDWSAs were logged approximately two to three times since 1920. Harvesting is subject to DBCA Silvicultural Guidelines, including retention of older habitat trees and avoidance of old growth forest, fauna habitat zones and reserves. FPC no longer undertakes timber harvesting within the Serpentine National Park or Monadnocks Conservation Park. Future timber harvesting will exclude native forests from 2024, unless the harvesting improves forest health or is for clearing of approved mining operations (WA Government, 2021).
– **Firewood** – firewood is collected within Jarrahdale and Dwellingup State Forests for private use, which is managed via licences issued by DBCA.
– **Plantations** – PDWSAs include pockets of pine plantations, including a 105 ha pine plantation 5 km north of the Serpentine Main Dam reservoir.
– **Mining and rehabilitation** – Alcoa bauxite mining and rehabilitation is occurring within the Myara mine region, south of the Serpentine River and proposed Myara north region, including within the Serpentine Main Dam and Pipehead Dam RPZs. Alcoa previously undertook bauxite mining in the northern corner of the Serpentine Main Dam PDWSA as part of the former Jarrahdale Mine, with rehabilitation conducted in 1999 and 2000.
– **Apiaries** – bee keeping activities are undertaken at designated sites, nominally 3 km apart, within State Forest, under licence with DBCA.
– **Infrastructure** – includes Western Power transmission line, pipelines, roads, telephone lines and towers.
– **Feral animal control** – feral animal baiting occurs for the Western Shield Program, using 1080 bait (sodium monofluoroacetate), which is a naturally occurring chemical. . Studies in Australia and New Zealand have confirmed that there is no evidence of 1080 persisting in or contaminating soil or waterways. This is because sodium fluoroacetate is readily trapped by cellulose and humus material in soils and is degraded into harmless by-products by a number of species of micro-organisms (DoW, 2009). Shooting to control problem animals is undertaken by authorised personnel.
– **Prescribed burns and wildfires** – prescribed burns and fire response activities are undertaken by DBCA and DFES. Figure 3.4 and Figure 3.5 present the extent of prescribed burns and wildfires in the Serpentine Main Dam and Pipehead PDWSAs over the past five decades. Historically, fire response may have used per- and polyfluoroalkyl substances (PFAS) in firefighting foams, which are key contaminants of concern for drinking water. DFES has not used PFAS since 2003.
– **Recreation** – boating, swimming, fishing, and marroning are prohibited in the reservoir for health reasons. Camping, hiking, cycling, horse riding, picnicking, licensed vehicle access, and motor rally events are listed as activities in specific areas, and illegal hunting and unlicenced vehicle access may also occur.

According to the Serpentine Dam and Pipehead Drinking Water Source Protection Plan (DWSPP), motor rally events have not been held in the PDWSA catchment area since 2006, however a motor rally event was held in the Serpentine Main Dam PDWSA on 7 November 2020. Given the national significance of these events to the local area, the DWSPP indicates that the events are giving conditional approval to be hosted within the catchment.

Some public facilities are provided in relation to public access and use of the State Forest, including provision of a car park, fireplaces, picnic facilities and a composting toilet at the Balmoral Road Prisoner of War (POW) Camp Ruins site, east of Jarrahdale in the proposed Myara North mine region.

The PDWSA is intersected by the Munda Biddi Trail, a long distance off-road cycling track, and the Bibbulmum Track, a long distance hiking track. The Munda Biddi Trail does not have designated camping sites within the PDWSA with the closest site, the Wungong campsite, being located to the north within the Wungong Dam PDWSA. The Bibbulmun Track passes along the eastern portion of the Serpentine Main Dam PDWSA including the Monadnocks and White Horse Hill campsites with composting toilets.

Numerous gravel tracks and off-road tracks exist throughout the catchment that are accessed by members of the public.

This review has indicated no additional hazards within the catchment as already detailed in the DWSPP, other than legacy PFAS.

The Shire of Serpentine-Jarrahdale, Shire of Boddington, Shire of Murray and Shire of Wandering all intersect the catchment area. A review of the planning schemes for these shires indicate that land uses remain consistent with those identified in the Serpentine and Pipehead Dam DWSPP.

A review of DWER's contaminated sites database indicates there are no reported contaminated sites within the Serpentine or Pipehead Dam PDWSAs.

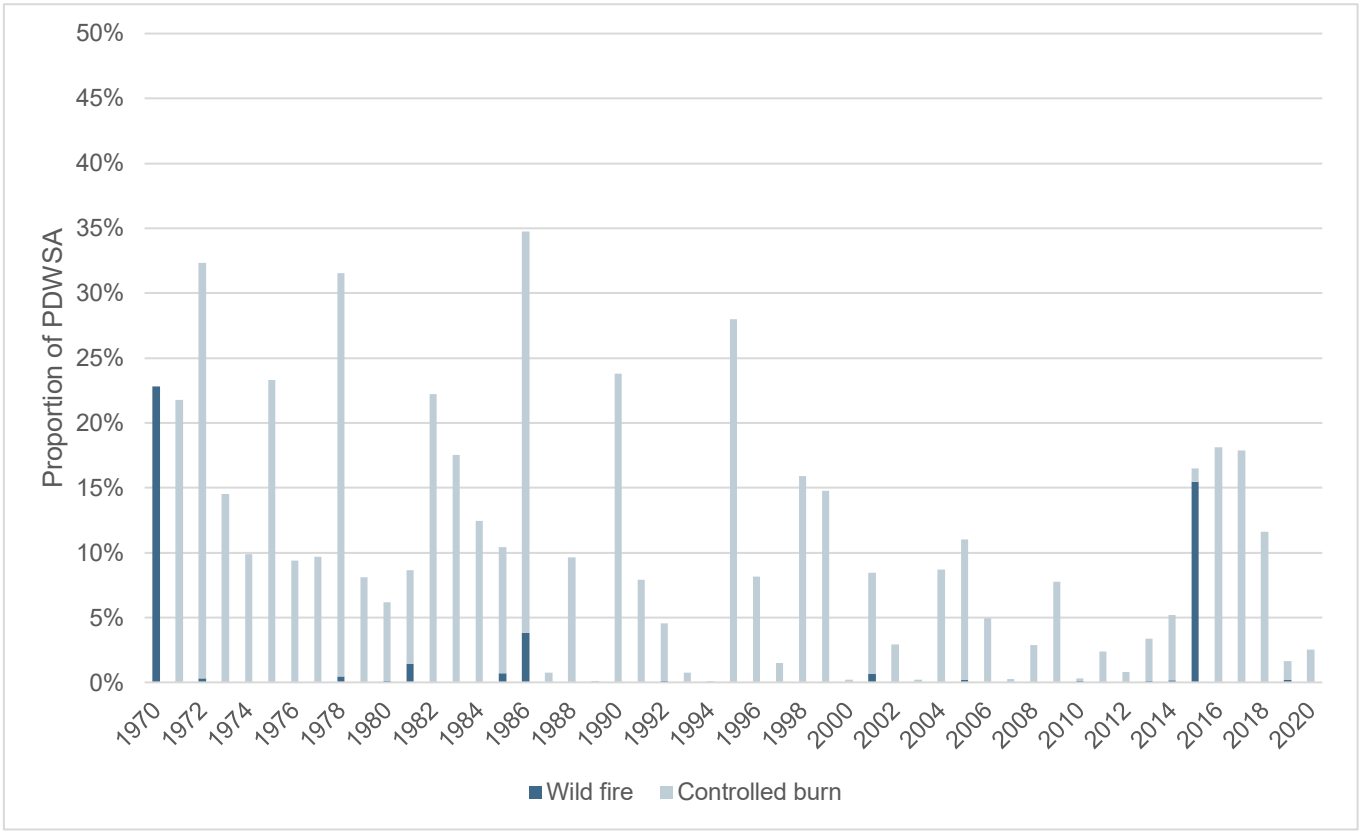


Figure 3.4 Serpentine PDWSA bushfire activity and rehabilitation

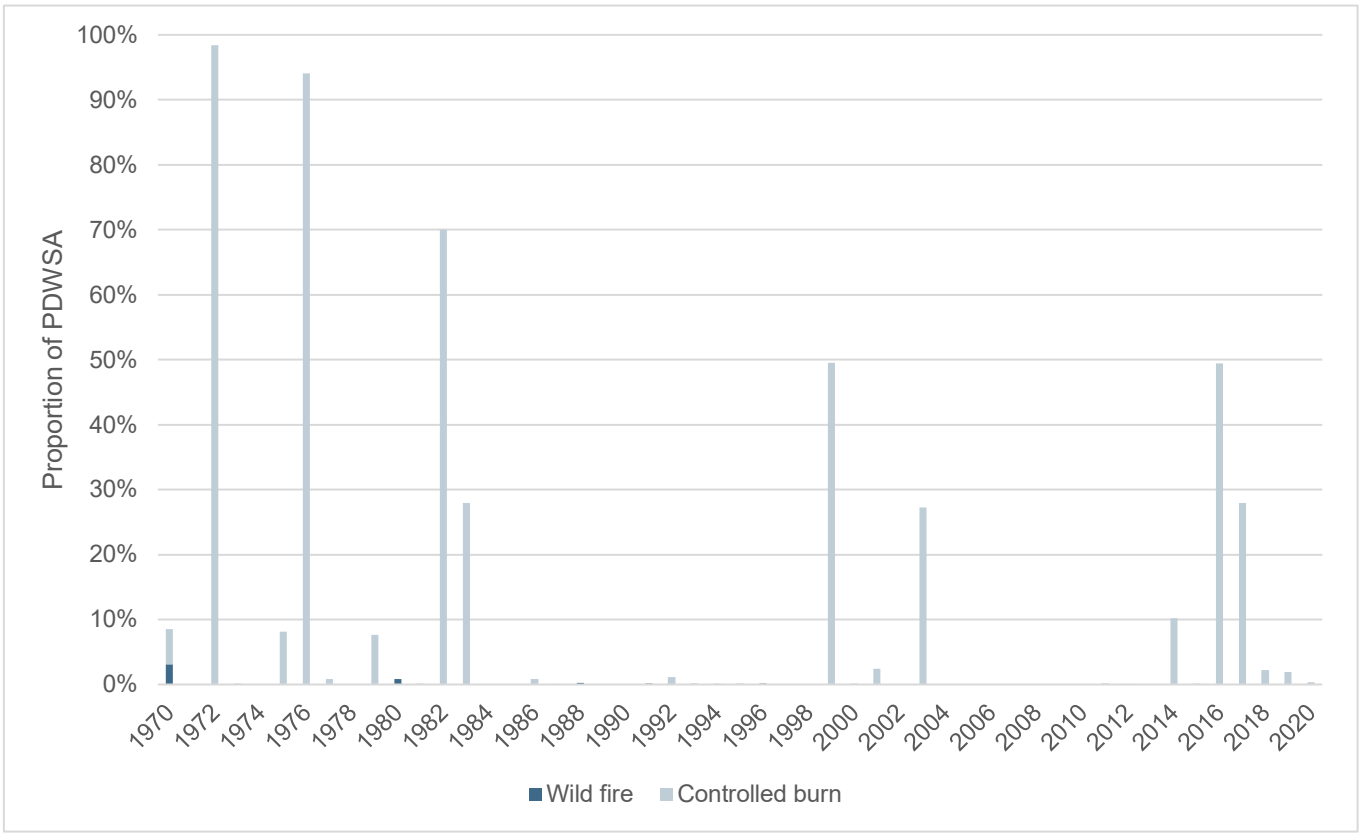


Figure 3.5 Serpentine Pipehead PDWSA bushfire activity and rehabilitation

3.5.2 South Dandalup Dam PDWSA

The South Dandalup Dam (SDD) catchment area includes the following land uses:

– Land and forest management, including timber harvesting;
– Mining and gravel extraction; and
– Recreation.

These land uses are generally the same as those identified for the Serpentine Main Dam catchment area, with the exception that a gold mining lease exists in the SDD catchment area. As such, the water quality hazards from these land-uses are similar to those from the Serpentine Main Dam catchment. Further detail of these activities and their risks can be found in the So*uth Dandalup Dam Drinking Water Source Protection Plan* (DoE, 2005).

The following aspects are noted with respect to the activities listed:

– **Timber harvesting** – FPC undertakes timber harvesting within the Dwellingup State Forest in accordance with the FMP and RFA. DBCA timber harvesting data indicating that most of the PDWSA was logged approximately two to three times since 1920. Harvesting is subject to DBCA Silvicultural Guidelines. Future timber harvesting will exclude native forests from 2024, unless the harvesting improves forest health or is for clearing of approved mining operations (WA Government, 2021).
– **Firewood** – firewood is collected within Dwellingup State Forest for private use, which is managed via licences issued by DBCA.
– **Mining and rehabilitation** – Alcoa bauxite mining was previously undertaken in the South Dandalup PDWSA as part of its Huntly Mine.
– **Recreation** - the only authorised activity is hiking and camping on the Bibbulmun Track, however unauthorised activities may include swimming, fishing, marroning, broader camping, cycling, horse riding, picnicking, illegal hunting, and vehicle access.

The Bibbulmun Track intersects the eastern side of the SDD catchment, including the associated Mt Wells campsite which has a composting toilet.

Numerous gravel tracks and off-road tracks exist throughout the catchment that are accessed by members of the public.

- **Apiaries** – bee keeping activities are undertaken at designated sites, nominally 3 km apart, within State Forest, under licence with DBCA.
- **Infrastructure** – includes Western Power transmission line, pipelines, roads, telephone lines and towers.
- **Feral animal control** – feral animal baiting occurs for DBCA's Western Shield Program, using 1080 bait. Shooting to control problem animals is undertaken by authorised personnel.
- **Prescribed burns and wildfires** – prescribed burns and fire response activities are undertaken by DBCA and DFES. Figure 3.6 and Figure 3.7 present the extent of prescribed burns and wildfires in the SDD and SDPD PDWSAs over the past five decades. Historically, fire response may have used PFAS in firefighting foams. DFES has not used PFAS since 2003.

About 400 ha, or 1.2 per cent, of the SDD catchment is private land. Two private properties owned by Bunnings Forest Products Pty Ltd (Bunnings) and Boddington Gold Mine joint venture (operating as Boddington Gold Mine) are located along the eastern boundary of the catchment. The area of private land within the catchment is primarily native vegetation.

A review of DWER's contaminated sites database indicates there are no reported contaminated sites within the SDD PDWSA.

The shires of Murray and Boddington intersect the catchment area. A review of the planning schemes for these shires indicate that land uses within the SDD catchment area are consistent with those identified in the SDD DWSPP (DoE, 2005).

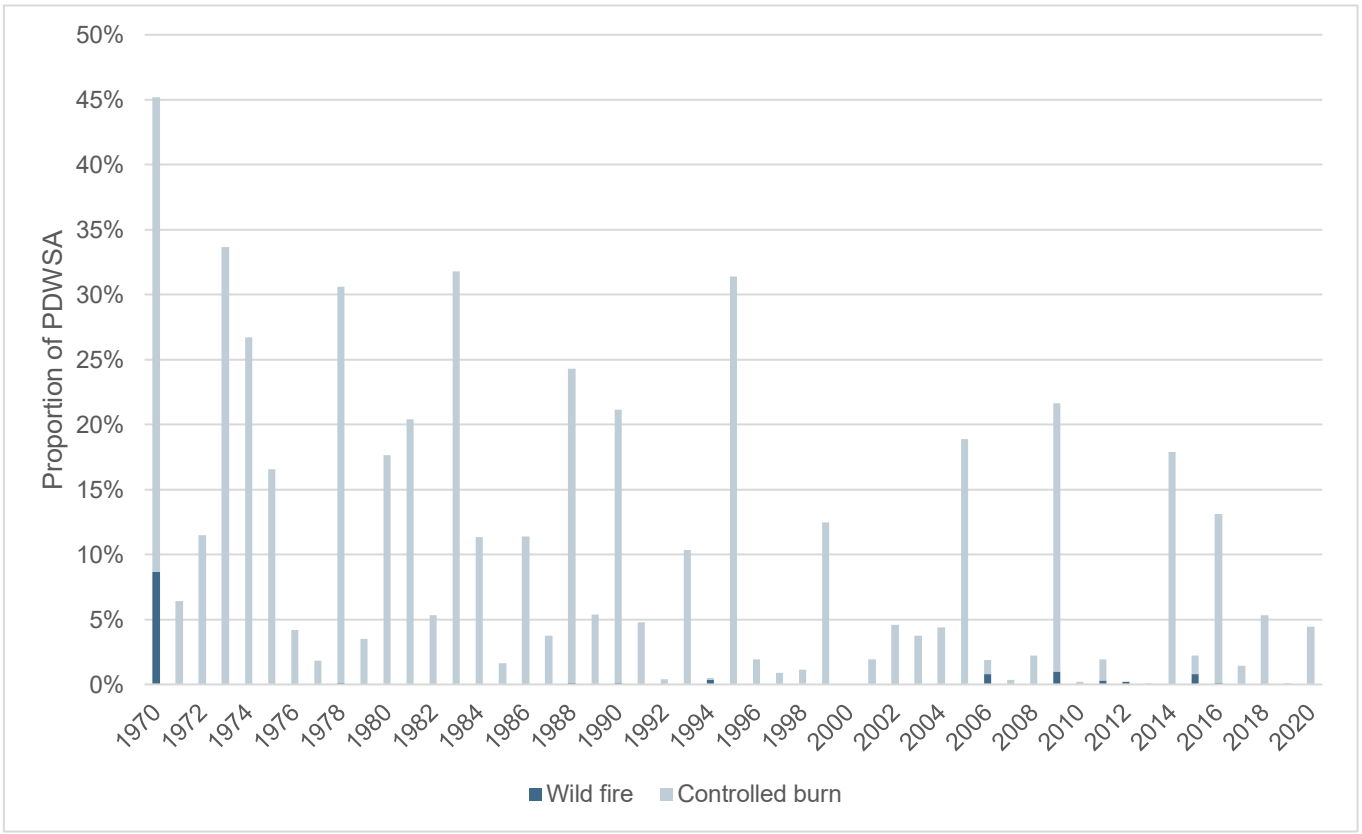


Figure 3.6 ***South Dandalup PDWSA bushfire activity and rehabilitation***

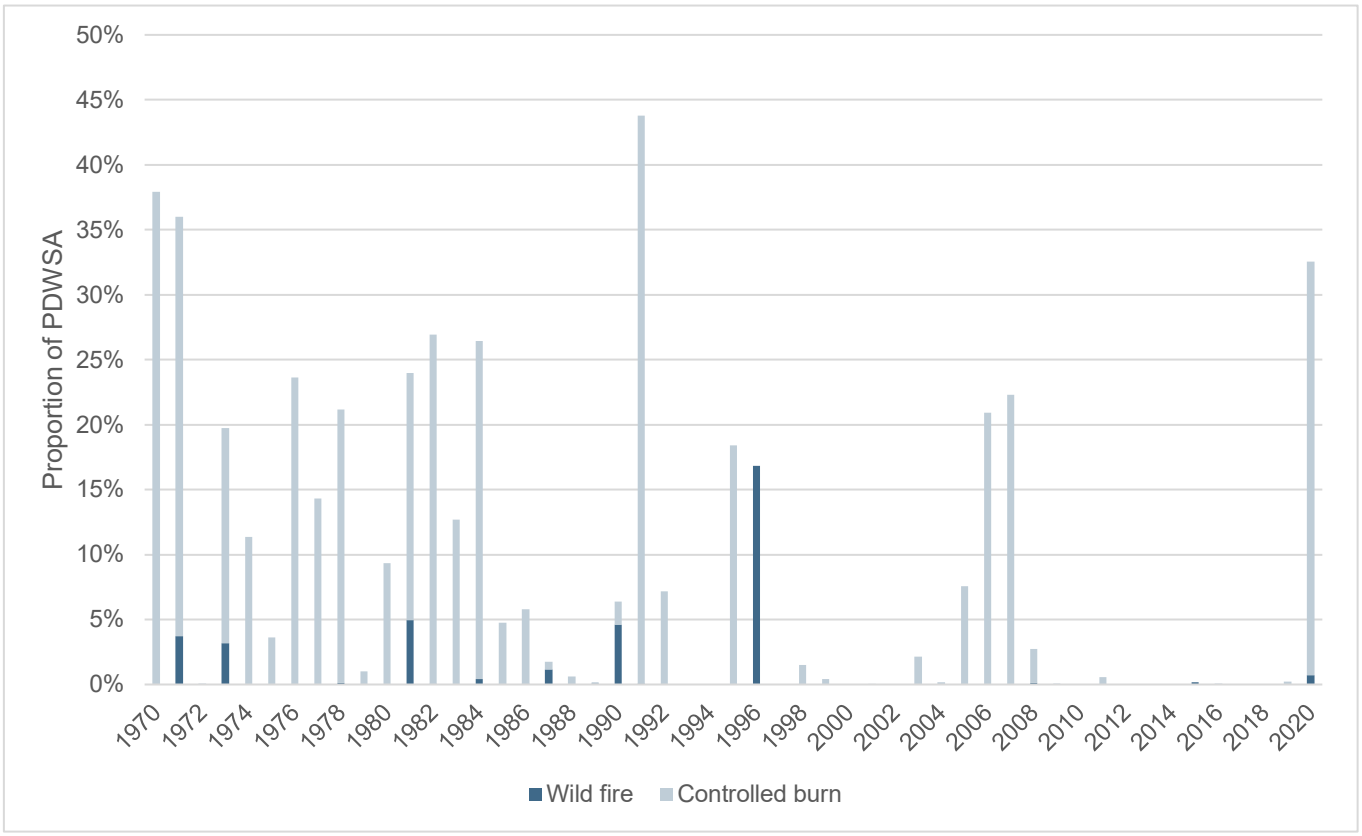


Figure 3.7 South Dandalup Pipehead PDWSA bushfire activity and rehabilitation

3.5.3 Upper Wungong Brook PDWSA

Upper Wungong Brook PDWSA primarily lies within Jarrahdale State Forest, with a small portion within Monadnocks Conservation Park and also private properties. Land uses include:

- Land and forest management, including timber harvesting and timber plantations
- Private land including general farming, horse stables and residences
- Apiaries and private resource harvesting
- Gravel pits
- Recreation
- Mine site rehabilitation associated with the former Jarrahdale Mine, now closed.

3.6 Potential water quality hazards from existing land uses

The potential hazards to source water quality related to the existing land uses in the Serpentine Main Dam and South Dandalup Dam PDWSAs are presented in the relevant DWSPPs for these catchments (respectively DoE 2005, DoW 2007). These hazards have been considered in relation to the Proposal in the hazard identification and conceptual site models (see Section 5).

3.7 Future water supply

The Serpentine Main Dam and SDD will continue to be key reservoirs for supply to the IWSS (Water Forever, Water Corporation 2009). However, future water supplies for the IWSS will increasingly come from desalination, groundwater replenishment and deeper groundwater aquifers rather than surface water supplies. Catchment yields

into the Serpentine Main Dam and SDD are expected to reduce over time due to the effects of climate change. (DoW 2009, CSIRO 2009). Accordingly, Serpentine Main Dam, SDD and Pipehead Dams may be subject to increasing storage of desalinated water in the future.

4. Historical water quality

This section presents information relating to the second step of the ADWG framework, comprising review of existing and historical water quality within the Serpentine Main Dam and SDD. The review was based on the following information:

– Microbial data collected by GHD in 2020 as part of baseline surveys for the Proposal.
– Water Corporation data provided for the period 01/01/2000 to 31/12/2020, for turbidity and colour. No historical data was available for microbes or toxicants.

4.1 Microbial data

As noted in WSAA (2015) section 3.1.4, routinely collected *E. coli* data on raw water immediately prior to treatment is used to define a microbial indicator assessment. This assessment would be used to confirm the vulnerability assessment to determine the source water category.

In this case, raw water immediately prior to treatment would include the source water for the Serpentine Pipehead Water Treatment Plant (WTP). This WTP has only chlorination for inactivation of microbes which is only applicable for a Category 1 source. As *E. coli* monitoring data for this point have not been made available, the maximum *E. coli* concentration at the monitoring point has been assumed to be <20 *E. coli* per 100 mL, aligning with a Category 1 source water designation.

Greater concentrations of *E. coli* can be expected in the water courses coming from surface water catchment areas, including inflows from Serpentine and South Dandalup. However, the transport of the surface waters through large storages will result in the reduction of those concentrations. This is due to the combined effects of microbial die-off from processes such as solar exposure and predation, removal processes such as sedimentation, and the dilution of surface water inflows to Serpentine Pipehead Dam with desalination inputs.

The available microbial data from sampling within the catchment have been summarised here, so as to indicate the current microbial status of those areas. The amount of available data is small, and so this summary is not intended to be comprehensive.

Figure 4.1 and Figure 4.2 provide a summary of available microbial data taken within the proposed Myara North and Holyoake regions within the Serpentine Main Dam and SDD PDWSAs. These data were collected by GHD in 2020 as part of baseline surveys for the Proposal. No microbial data were available from Water Corporation for the Serpentine Main Dam or SDD.

Data were collected over four sampling events in 2020 and are sourced from 17 locations within the Myara North region, and 15 locations within the Holyoake region. A total of 48 data points were available for the Serpentine Main Dam PDWSA and 24 for the SDD PDWSA, however each individual location has up to 4 data points total.

As shown in Figure 4.1 and Figure 4.2, the concentrations at the sampled locations included *E. coli* concentrations ranging between 0 and 200 organisms per 100 mL. As noted previously, indicator concentrations in catchment water courses can be expected to be more elevated than the maximum concentrations expected in a Category 1 source water, of <20 *E. coli* per 100 mL. The environmental effects from surface water transport through a large storage have not yet occurred at the sampling locations shown in these figures.

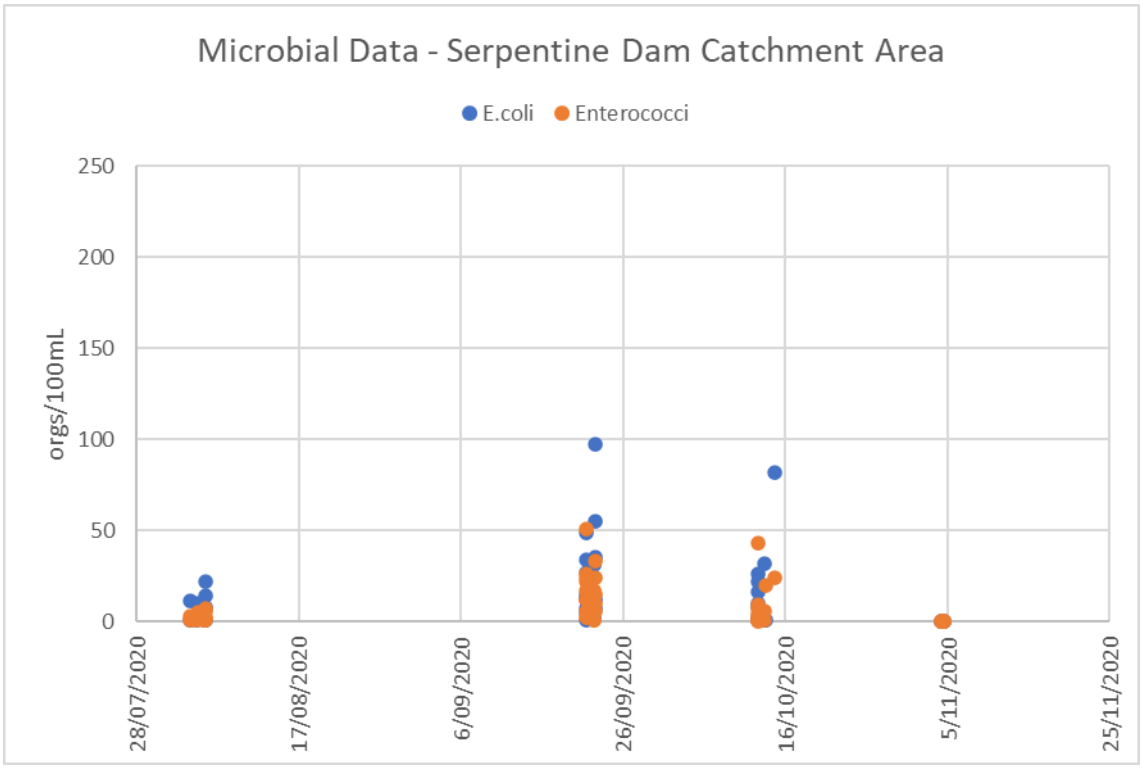


Figure 4.1 *Serpentine Main Dam catchment microbial data summary*

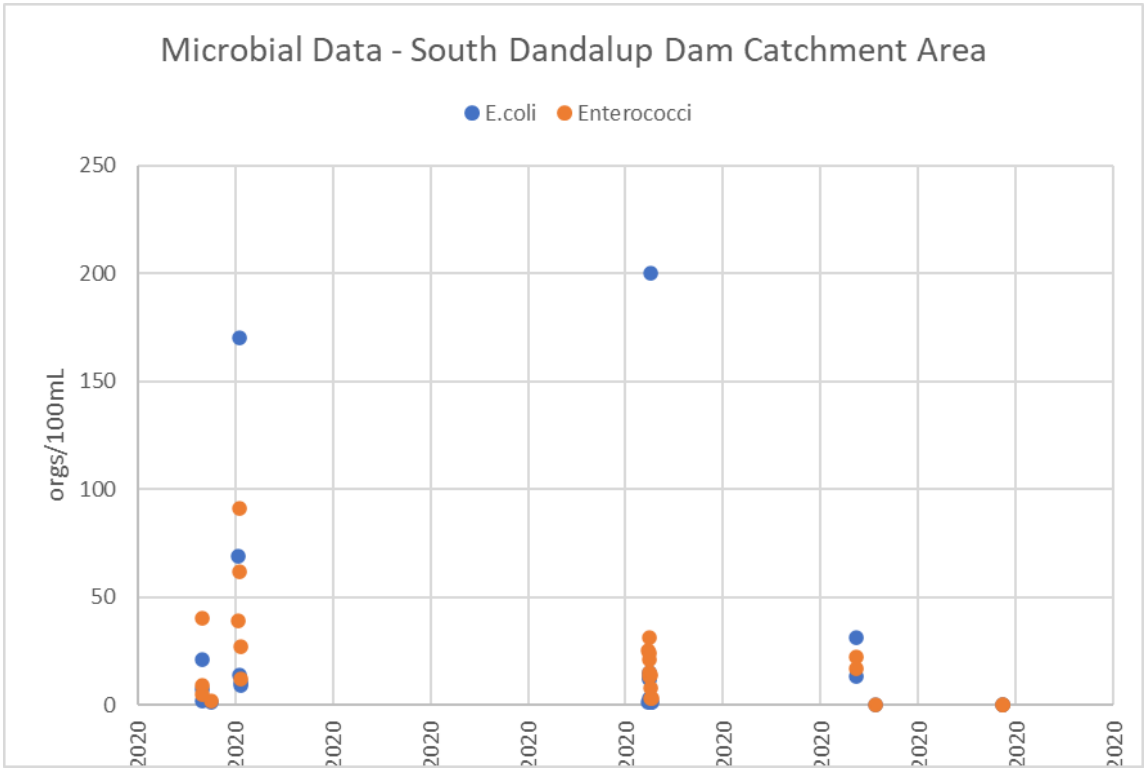


Figure 4.2 *South Dandalup Dam catchment microbial data summary*

4.2 Turbidity

Figure 4.3, Figure 4.4 and Figure 4.5 present historical (2000-2020) turbidity in Nephelometric Turbidity Units (NTU) and inflow data provided by Water Corporation for the Serpentine, Serpentine Pipehead and South Dandalup reservoirs. The monthly inflow data was based on water balance estimates. The turbidity data is reported for the offtake and was recorded at varying frequencies over the twenty-year period (see Table 4.1), at

the Serpentine and Pipehead Dams approximately weekly to fortnightly from 2002 to 2012 and approximately monthly from 2013 to 2020, and approximately fortnightly to monthly throughout for the South Dandalup Dam.

Table 4.1 Frequency of water quality records – no. records per year measured at the offtake

Year	Serpentine Main Dam	Serpentine Pipehead Dam	South Dandalup Dam
2000	13	5	9
2001	9	6	11
2002	90	92	47
2003	34	41	36
2004	36	36	12
2005	30	30	12
2006	36	36	15
2007	39	39	12
2008	39	39	12
2009	45	39	12
2010	30	33	30
2011	36	33	36
2012	41	39	30
2013	15	36	12
2014	12	39	12
2015	21	45	18
2016	12	42	21
2017	12	36	21
2018	15	42	16
2019	15	36	18
2020	15	27	14

To analyse the potential effects of mining and bushfires on turbidity, the figures also present the cumulative mining disturbance area (cleared or rehabilitated) within the RPZ and outside the RPZ, as well as the annual bushfire areas within and outside the RPZ. The mining disturbance areas within the RPZ are presented as a percentage of the RPZ area, and the mining disturbance and annual bushfire areas outside the RPZ are presented as a percentage of the PDWSA area outside the RPZ. Controlled burns represent all non-wildfire burns, e.g., prescribed burns and plantation burns.

The historical turbidity data indicates that offtake turbidity was generally less than 1 NTU throughout the twenty-year period, including during mining disturbance within the PDWSAs and RPZ. The data does not display any increasing trend with turbidity associated with cumulative mining disturbance or the effects of large bushfires within the PDWSAs or RPZ. The turbidity data was collected on an approximately monthly basis between 2013-2020 and there is some potential for turbidity spikes to have occurred within the monthly timestep, however this would be limited by the dispersion and mixing across the reservoir prior, which would tend to flatten turbidity spikes, therefore significant turbidity events should be noticeable in monthly records at the outlet.

Between February 2017 and September 2020, the Myara mine region experienced 128 drainage failures, of which 38 events generated turbid discharge exceeding 25 NTU for 1-hour or more and were located within the Serpentine RPZ or Pipehead catchment. These discharges were from mining areas, haul roads, or other infrastructure, discharging to land that eventually drains to the reservoir. Failure mechanisms are described in Appendix I. No anomalous readings were observed at the offtake following these events, suggesting that the reservoirs provide significant dilution and settlement services.

High turbidity levels in the Serpentine and South Dandalup reservoirs correspond to periods of low reservoir storage.

Wungong Reservoir turbidity readings ceased in 2003 and are therefore not plotted.

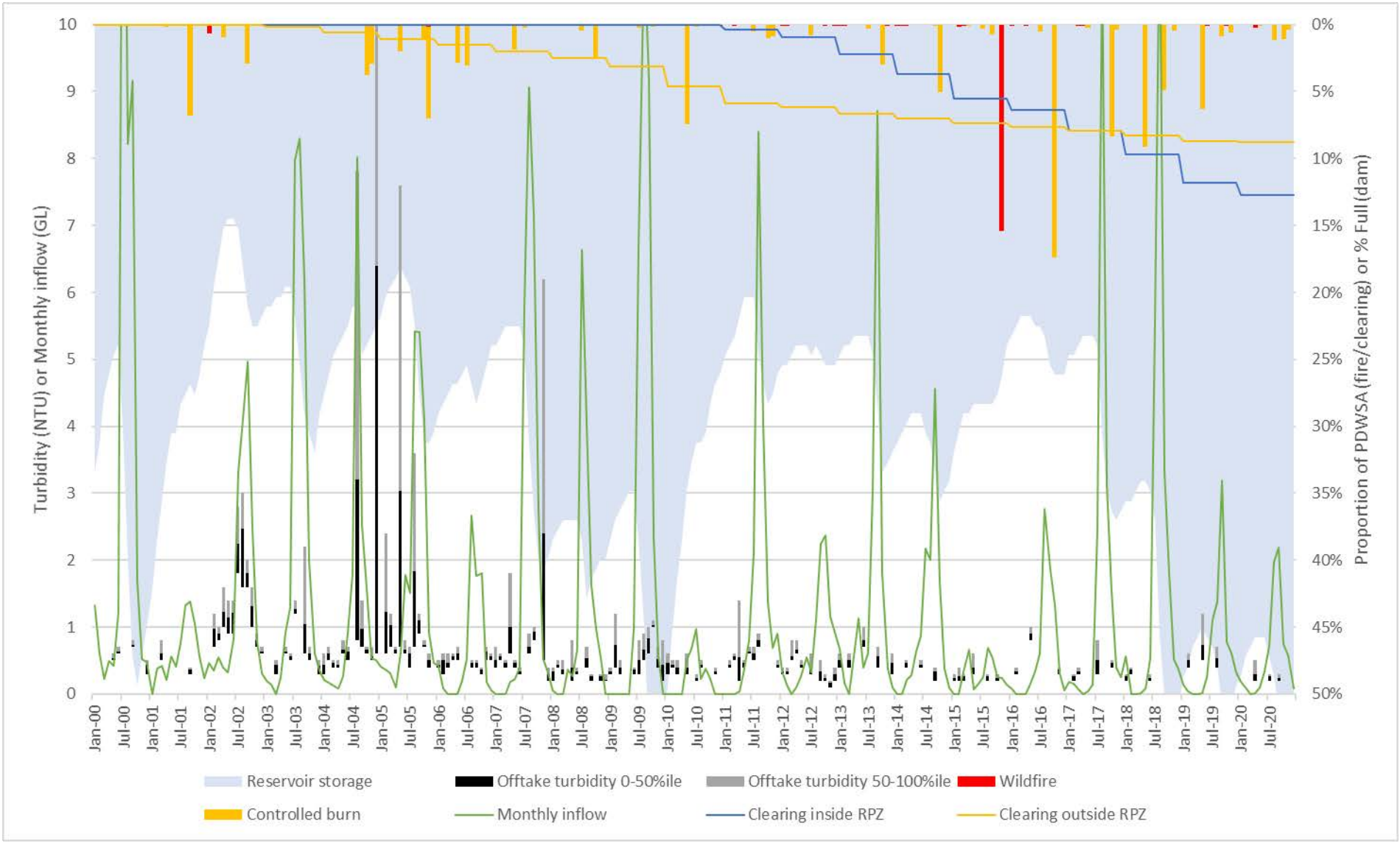


Figure 4.3 ***Serpentine Reservoir – offtake turbidity, reservoir storage, inflows, mining, and bushfires***

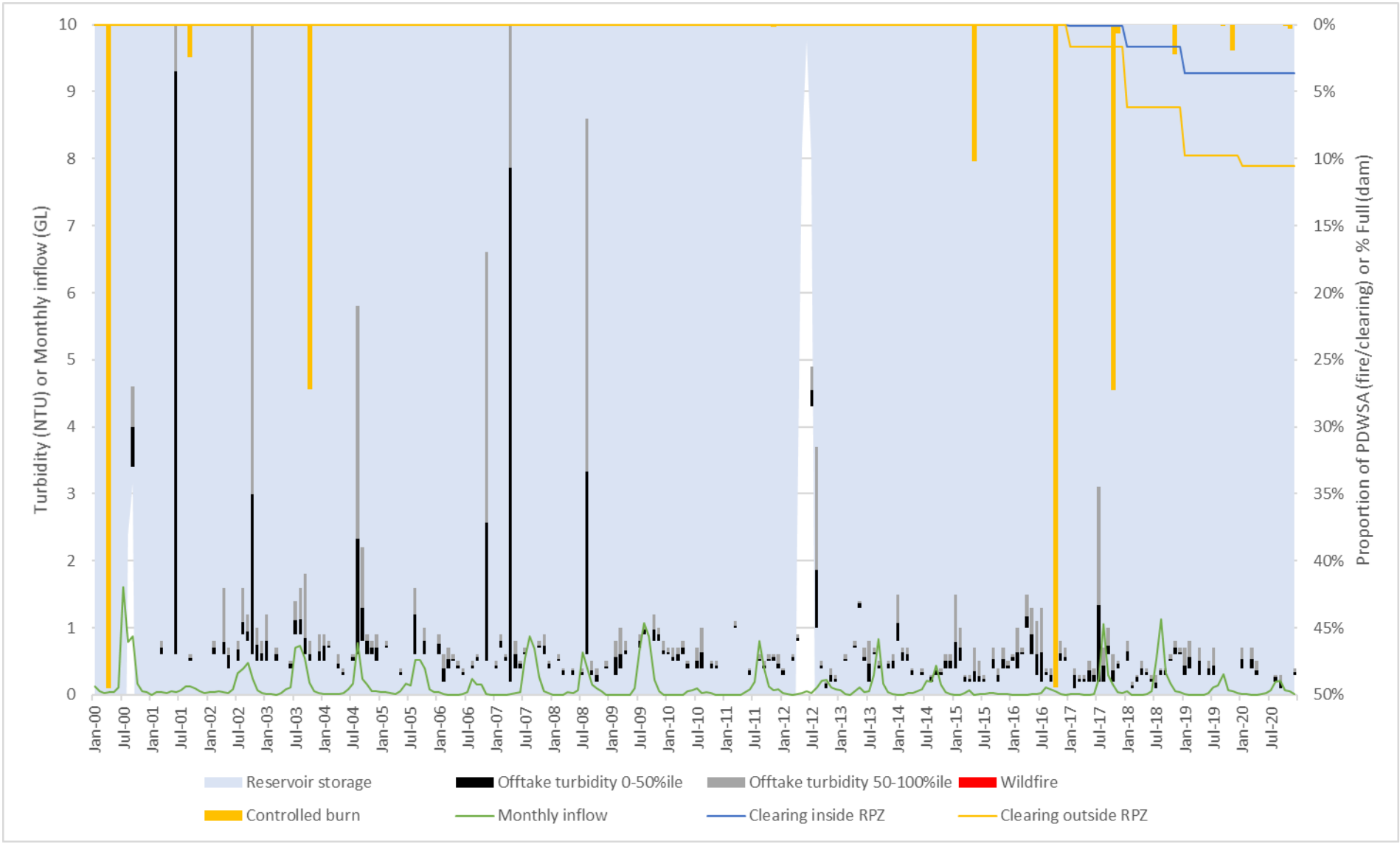


Figure 4.4 ***Serpentine Pipehead Reservoir – turbidity, storage, inflows, mining, and bushfires***

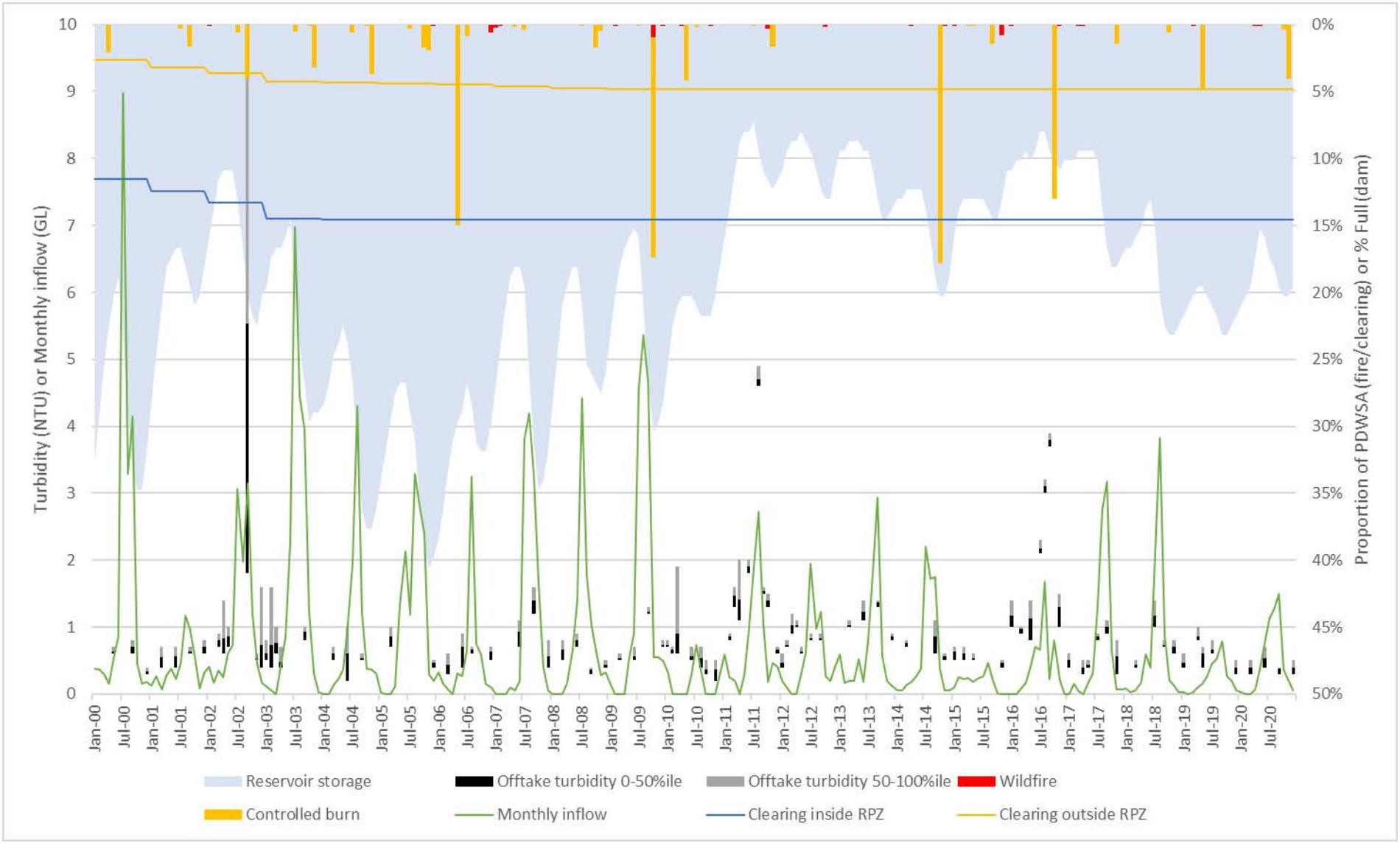


Figure 4.5 South Dandalup Reservoir – turbidity, storage, inflows, mining, and bushfires

4.3 Colour

Figure 4.6, Figure 4.7 and Figure 4.8 present historical data (2000-2020) for colour in True Colour Units (TCU), as an analogue of dissolved organic carbon (DOC), provided by Water Corporation for the Serpentine, Serpentine Pipehead and South Dandalup reservoirs. The colour data was recorded at varying frequency over the twenty-year period (see Table 4.1), on the same dates as turbidity.

To analyse the potential effects of mining and bushfires on DOC, the figures also present the cumulative mining disturbance area (cleared or rehabilitated) within the RPZ and outside the RPZ, as well as the annual bushfire areas within and outside the RPZ. The mining disturbance and annual bushfire areas within the RPZ are presented as a percentage of the RPZ area, and the mining disturbance and annual bushfire areas outside the RPZ are presented as a percentage of the PDWSA area outside the RPZ.

The historical colour data indicates that colour has varied between approximately 1-4 TCU over the twenty year period and does not display any increasing trend associated with mining disturbance or the effects of large bushfires within the PDWSAs. As with turbidity, any significant colour spikes associated with washout of DOC following bushfires or clearing should be evident in the colour records, due to dispersion and mixing in the reservoir prior to sampling at the offtake.

High colour levels in the Serpentine and South Dandalup reservoirs correspond to low reservoir storage volumes.

Wungong Reservoir turbidity readings ceased in 2003 and are therefore not plotted.

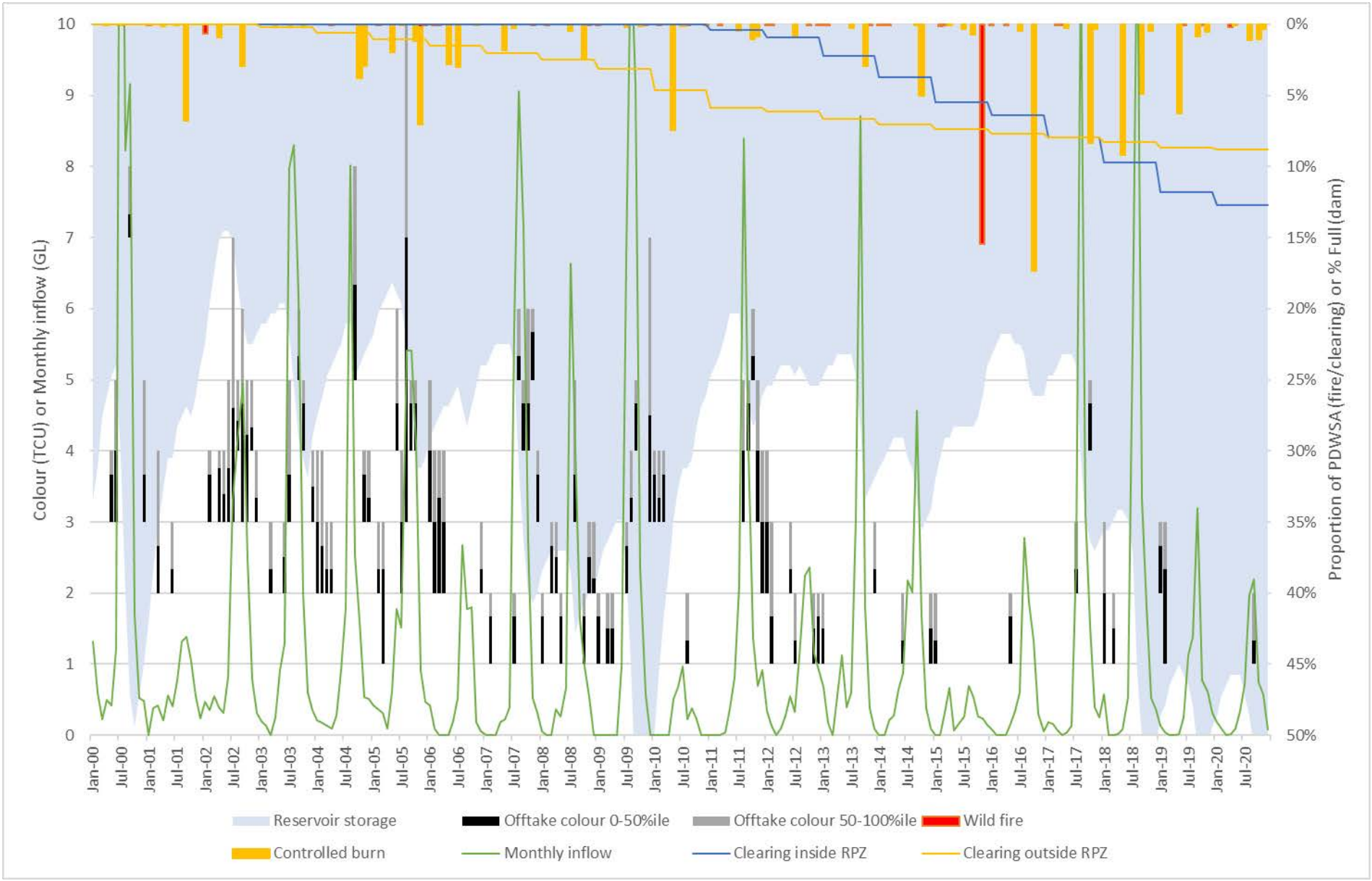


Figure 4.6 ***Serpentine Reservoir – offtake colour, reservoir storage, inflows, mining, and bushfires***

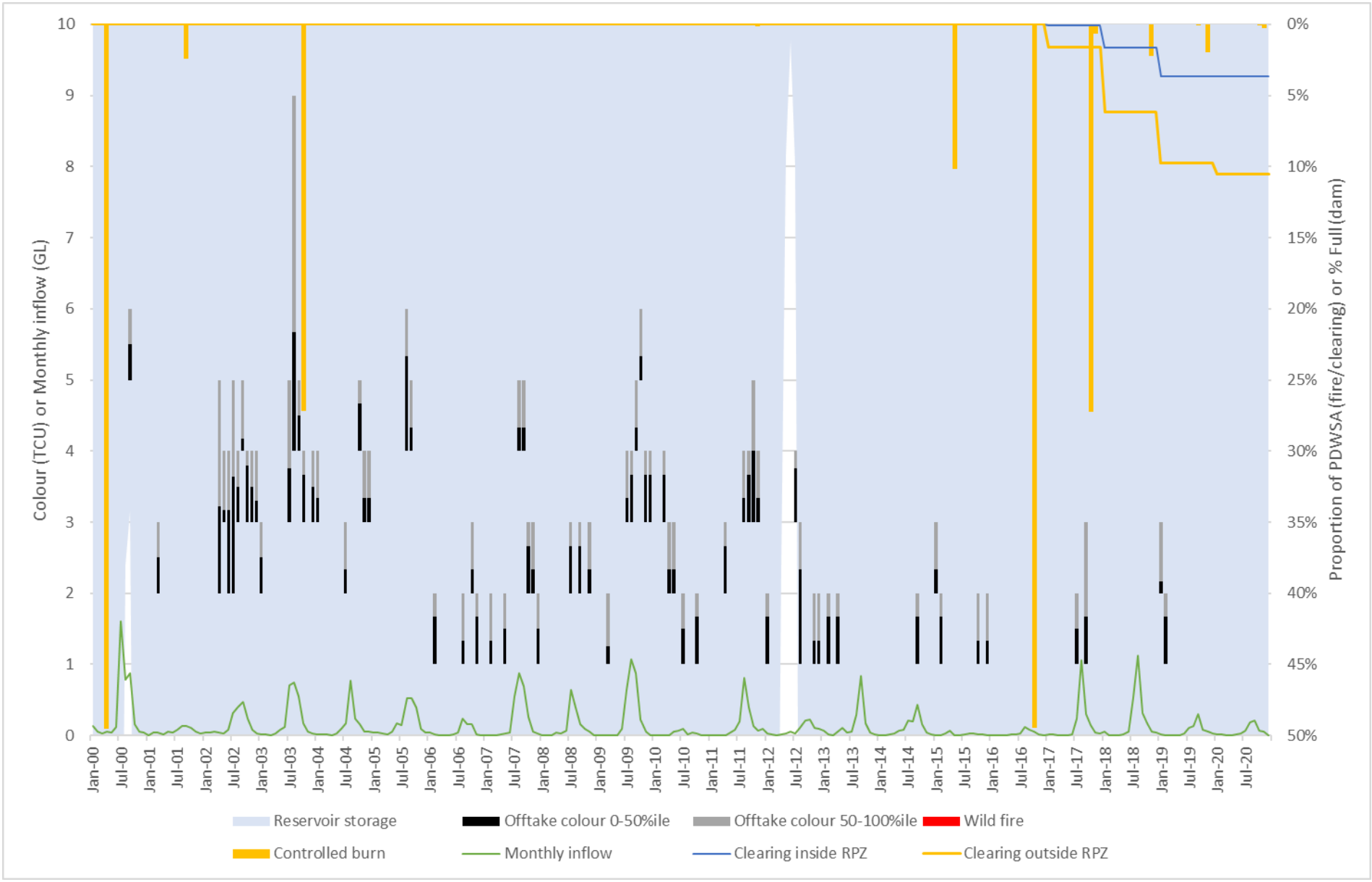


Figure 4.7 ***Serpentine Pipehead Reservoir – offtake colour, reservoir storage, inflows, mining, and bushfires***

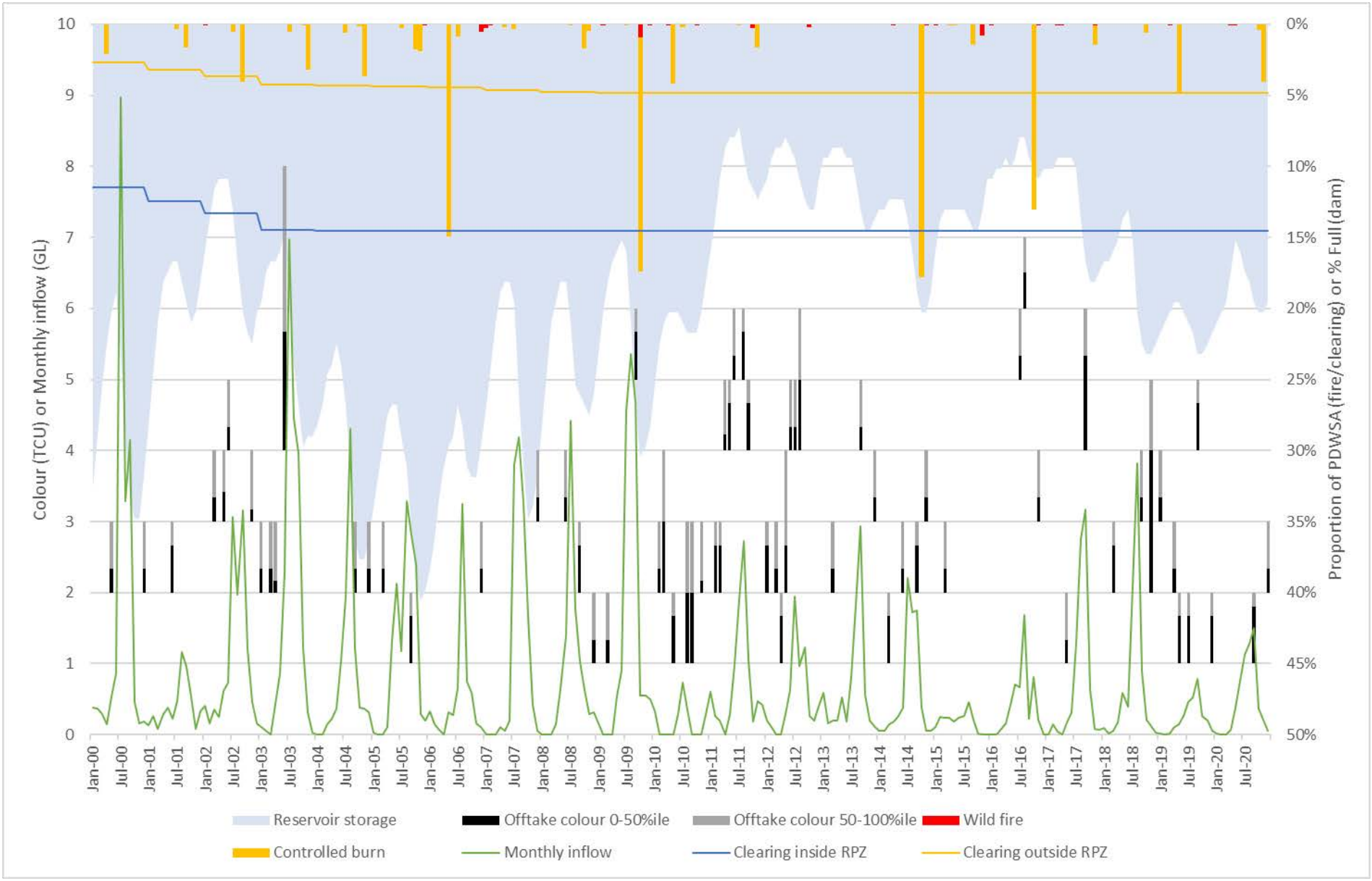


Figure 4.8 ***South Dandalup Reservoir – offtake colour, reservoir storage, inflows, mining, and bushfires***

4.4 Salinity

Figure 4.9, Figure 4.10, and Figure 4.11 present historical data (2000-2020) for salinity expressed as Electrical Conductivity (µS/cm), unadjusted for temperature, provided by Water Corporation for the Serpentine, Serpentine Pipehead and South Dandalup reservoirs. The salinity data was recorded in a temperature range typically between 12°C and 25°C, at varying frequency over the twenty-year period (see Table 4.1), on the same dates as turbidity and colour.

To analyse the potential effects of mining on salinity, the figures also present the cumulative mining disturbance area (cleared or rehabilitated) within the RPZ and outside the RPZ. The mining disturbance areas within the RPZ are presented as a percentage of the RPZ area, and the mining disturbance areas outside the RPZ are presented as a percentage of the PDWSA area outside the RPZ.

The historical salinity data indicates that salinity has varied between approximately 20-35 µS/cm over the twenty year period and does not display any increasing decreasing trend associated with mining disturbance within the PDWSAs.

Salinity levels in the Serpentine and South Dandalup reservoirs trend lower in response to increasing reservoir levels, and higher with falling reservoir levels.

Wungong Reservoir turbidity readings ceased in 2003 and are therefore not plotted.

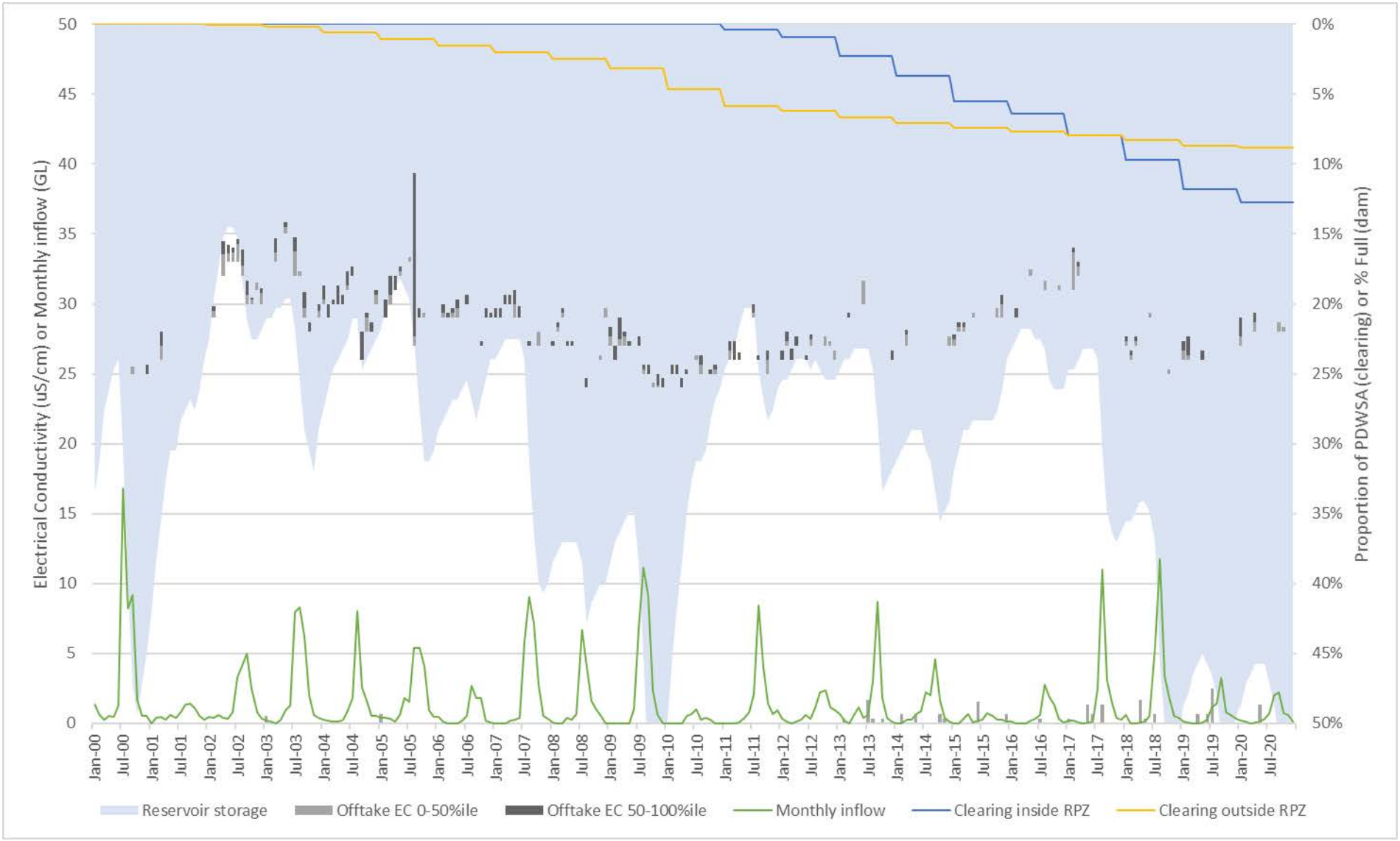


Figure 4.9 ***Serpentine Reservoir – offtake salinity, reservoir storage, inflows, and mining***

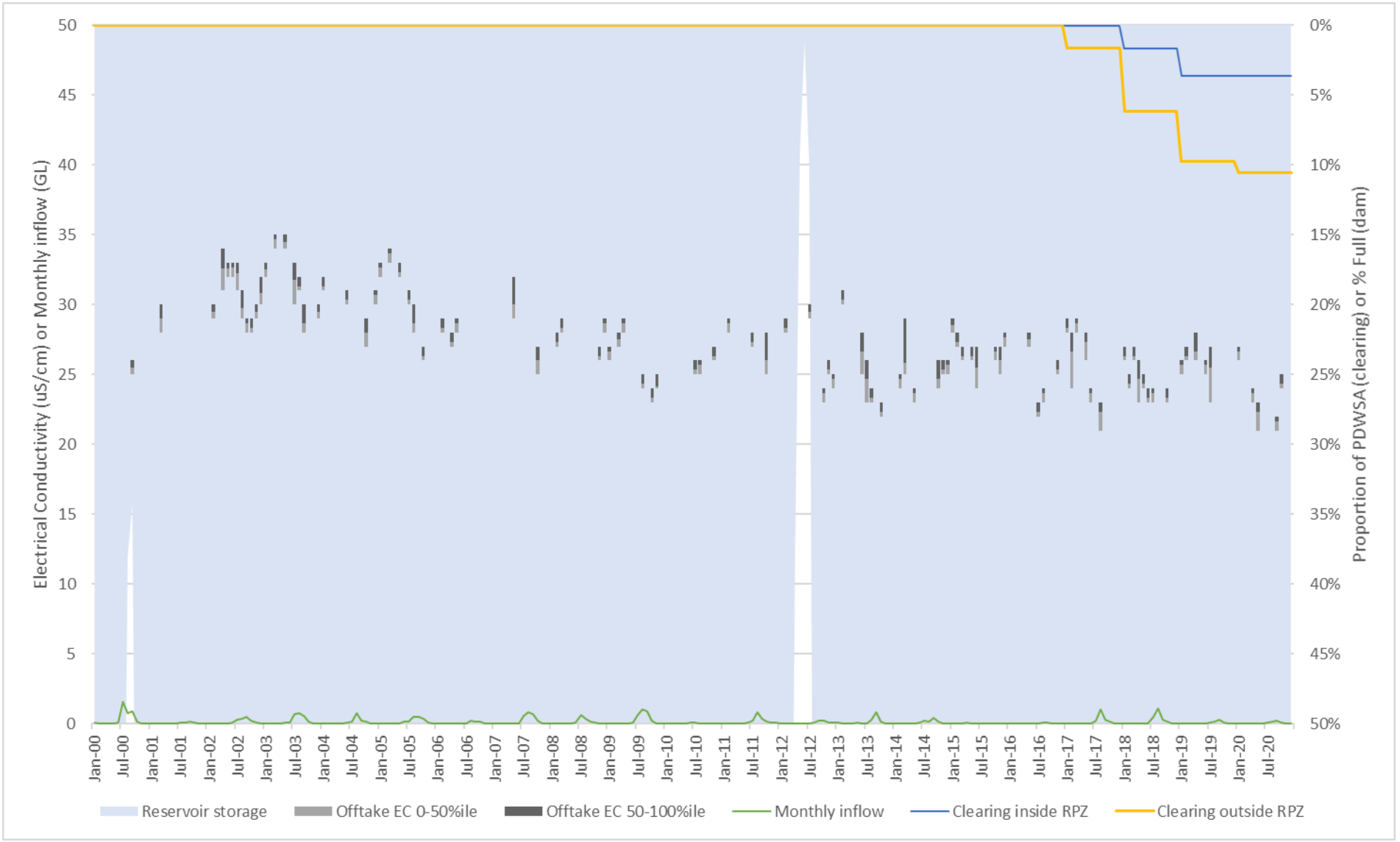


Figure 4.10 ***Serpentine Pipehead Reservoir – offtake salinity, reservoir storage, inflows, and mining***

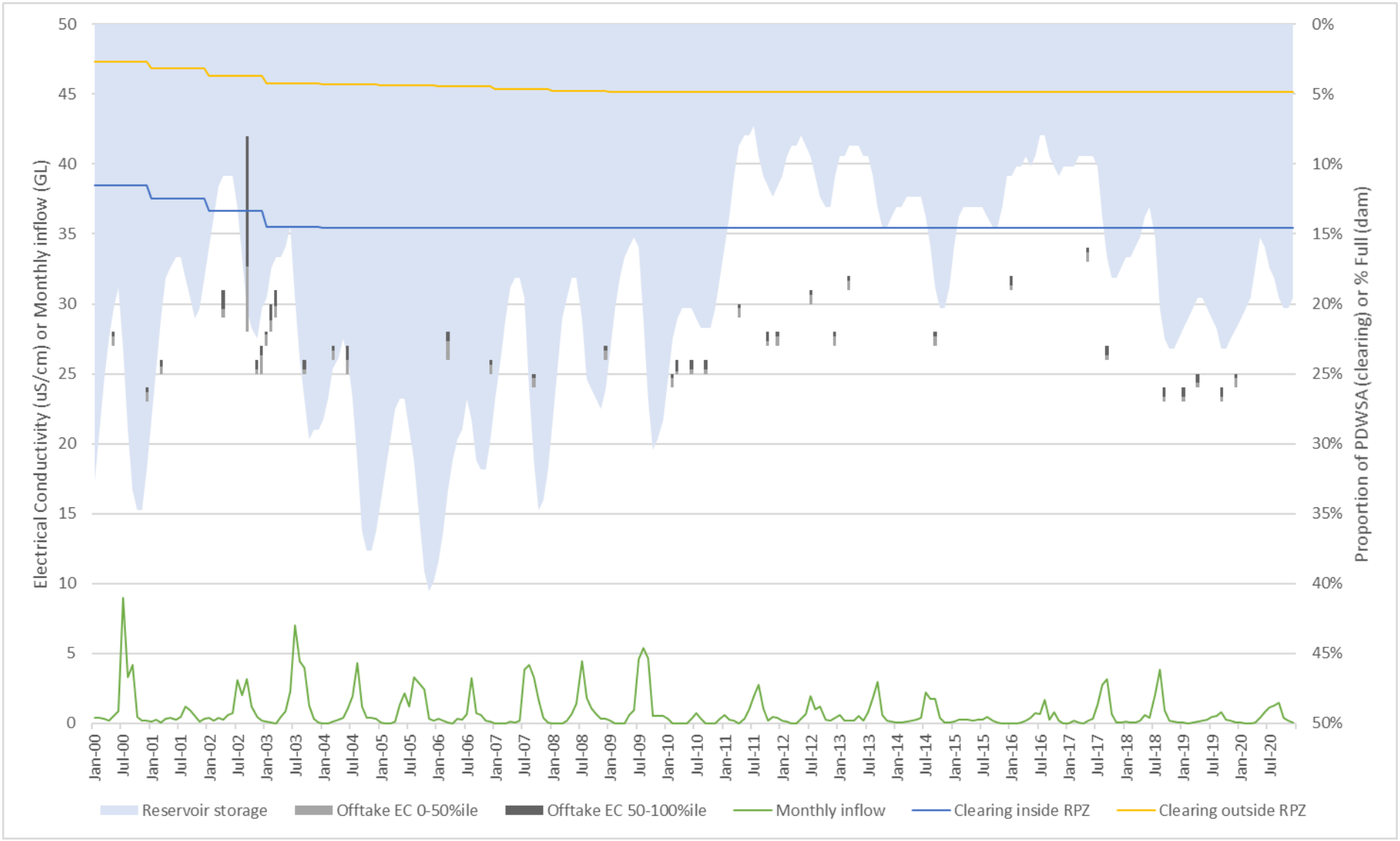


Figure 4.11 South Dandalup Reservoir – offtake salinity, reservoir storage, inflows, and mining

5. Hazard identification

This section presents information relating to the third step of the ADWG framework, comprising a hazard identification based on proposed land uses and conceptual site models, and a Tier 1 catchment vulnerability assessment in accordance with the Health Based Targets (HBT) Manual (WSAA, 2015).

The catchment vulnerability assessment is targeted to pathogens, which ADWG consider the greatest risk to consumers of drinking water, whereas the hazard identification is comprehensive, covering a range of contaminants including pathogens, turbidity and toxicants.

5.1 Proposed land uses

The Proposal comprises transition of the existing Myara operations of the Huntly mine that occur within the Serpentine and North Dandalup Dam PDWSAs into the Myara North and Holyoake mine regions.

The proposed Myara North and Holyoake regions are shown in Figure A-1 and Figure A-2 in Appendix A. These figures show the extent of land uses, along with the outline of proposed mining areas, and the locations of indicative mine pits and mine facilities.

The proposed Myara North mine region is located south-east of the town of Jarrahdale in the Shire of Serpentine Jarrahdale. Alcoa previously mined north of Jarrahdale from 1963 to 1998.

The proposed Holyoake mine region is located approximately 5 kilometres east of Dwellingup within the shires of Murray and Boddington.

The bauxite mining process involves:

– Harvesting of timber by FPC and wood waste by Simcoa.
– Vegetation clearing and, as a last resort, burning of residue that cannot be reused by third parties, with coarse woody debris retained for rehabilitation.
– Topsoil and overburden removal. Material is stockpiled or used directly for rehabilitation.
– Ripping or drilling and blasting of caprock, and excavation of bauxite. Bauxite is transported by haul roads to a central Run of Mine (ROM) pad and is then subject to blending and crushing prior to conveying to stockpiles at Pinjarra Alumina Refinery.
– Rehabilitation to jarrah forest by deep ripping to remove compaction of pit floors, re-contouring the surface, returning of topsoil and overburden, seeding, planting and fertilising.

The development of the Myara North and Holyoake regions will require new mine facilities, overland conveyors, haul roads, access roads, power generation and transmission infrastructure.

The new mine facilities will include ROM pads, crushers, vehicle refuelling bays, fuel storage laydown areas, offices and crib rooms, staff ablutions, light vehicle washdown and maintenance, and sewage and oily wastewater treatment. Power generation will involve diesel generators supplied by above ground diesel storage tanks, with a substation comprising transformers and switchgear. Water will be piped from existing facilities at Myara or McCoy and stored in lined water storage ponds. Heavy vehicle maintenance and washdowns will occur at existing facilities at McCoy, which are not part of the Proposal.

5.2 Preliminary conceptual site models

Preliminary conceptual site models (CSM) were developed to identify the potential contaminant sources and pathways from the Proposal to the Serpentine Main Dam, Serpentine Pipehead and South Dandalup reservoirs. The CSMs were developed based on a detailed review of the water supply system, catchment characteristics and proposed land uses associated with the Proposal and are presented in Appendix B. The CSMs include:

Figure B-1 Conceptual model overview

Figure B-2 Clearing and mining conceptual model

Figure B-3 Exploration and rehabilitation conceptual model

Figure B-4 Mine facilities conceptual model

Figure B-5 Bushfire and controls conceptual model

Figure B-6 Conveyor operation conceptual model

Figure B-7 Haul road operation conceptual model

Figure B-8 Linear infrastructure stream crossing conceptual model

Figure B-9 Climate change considerations conceptual model

Further detail into each source, pathway and receptor as identified from these models is captured in Appendix C.

5.3 Latency and long-term impacts

While proposed mining and rehabilitation has a limited time span of perhaps 20 years, the reservoirs and catchments are intended to remain as a permanent public drinking water supplies. Hazards may only become present long after mining is complete, and the likelihood and consequences of all hazards need to be considered in the context of their potential longer-term and cumulative impacts with respect to existing land uses and short and long-term environmental stressors.

Climate change is expected to result in rising temperatures and associated increased evapotranspiration, less frequent and more intense rainfall events and declining annual rainfalls. These changes have the potential to lead to:

– a decline in groundwater levels, streamflow and hence reservoir levels
– a decline in salt yields to surface water as groundwater levels decline
– increased fire intensity and frequency
– decline in forest density and health
– greater soil loss volumes as a result of reduced soil structure associated with vegetation loss and more intense rainfall events. Analysis of soil loss risk data for the catchments (Viscarra Rossel, et al., 2016) shows little east-west variation in soil loss risk despite the lower rainfall intensity in the eastern catchments.

The above impacts may ultimately result in reduced catchment yields and potentially a greater likelihood for increased concentrations of pollutants to enter the reservoirs. There is insufficient evidence on whether the decline in streamflow will counteract with increased pollutant concentrations to alter pollutant loads. The interactions between proposed mining and rehabilitation activities with those arising from climate change and existing land uses will need to be considered in the assessment of these hazards.

5.4 Site images

A number of site images have been included in Appendix D, to illustrate relevant aspects of mining works in the catchment. The images include:

Figure D-1 Erosion barriers (watershots, blasted drainage lines) or cleared hillside

Figure D-2 Erosion barriers (watershots, blasted drainage lines) or cleared hillside #2

Figure D-3 Temporary facilities, overhead view

Figure D-4 Temporary facilities, angle view

Figure D-5 Effluent discharge area, signage

Figure D-6 Effluent discharge area, metering

Figure D-7 Effluent discharge area, purple dripper pipe dispersing to leaf litter on ground surface

Figure D-8 Effluent discharge area, overland piping prior to discharge area

Figure D-9 20-year jarrah and marri rehabilitation at Banya

Figure D-10 0-year rehabilitation at Kisler

5.5 Summary of hazards

The key potential hazards to Serpentine Main Dam, Pipehead Dam and SDD from the Proposal include:

Generation and discharge of pathogenic microorganisms from increased human activity. Pathogen contamination of drinking water can have significant effects on human health, if pathogen risks are not mitigated.

Pathogen hazards are further examined in sections 6 and 7.

Increases in sediment, suspended solids, and turbidity from erosion during mining activities. Erosion results in the mobilisation of soil particles, which are released into the air and tributaries and increase the turbidity within the water body. Pathogens adsorb onto these soil particles and may be shielded from the effects of disinfection.

Turbidity hazards are further examined in section 8.

Increases in stream salinity as a result of mining-induced saline groundwater discharge. Saline water is not potable, and smaller increases in salinity can affect the aesthetic of the source water. Salinity can also have a wider ecosystem impact due to its effect on plant growth/health.

This potential hazard is described in the Hydrology and Water Quality Report (GHD, 2021b) and has not been further examined here.

Contamination from spills, leaks, and/or emissions from the storage, handling, and use of hazardous materials and waste. Pesticides are toxic and some are potentially carcinogenic. Nutrients from fertiliser are toxic to humans at high levels, with infants less than 3 months old being most susceptible. Hydrocarbons and other chemicals are potentially toxic and carcinogenic, and harmful by-products may be formed when they are combined with chlorine (i.e., during chlorine disinfection). The risks from some additional potential hazards have not been examined here, including metals, microplastics, and explosives. Assessments have instead focused on those hazards presenting a higher risk to the catchment as a source water.

It is noted that Alcoa will not use PFAS in firefighting foams in the Myara North and Holyoake regions, and that all water supplies to construction and operations in the Myara North and Holyoake regions will be sourced from public water sources, captured onsite stormwater or from licensed onsite water treatment facilities where approved for reuse, within the drinking water catchment. Further discussion about PFAS assessment is included in section 12.

Diesel spill hazards are further examined in section 11.

Table 5.1 provides a summary of the potential unique contaminant sources from the Proposal.

The unique pathways of contaminants from the Proposal include:

– Overland flow – surface flows during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir
– Infiltration and subsurface flow - infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir
– Seasonal flow path - transport along watercourse during winter / spring flow period, discharging into reservoir
– Direct inhalation (only applies to irrigation of treated wastewater, should this be via sprinklers, and dust suppression).

Table 5.1 Summary of contaminant sources from the Proposal

Source type	Source description	Contaminant
Exploration, construction and operational workforce	Use of bushland for toileting	Pathogens
Sewage	Treatment of workforce sewage	Pathogens, nutrients, suspended solids
	Irrigation of treated effluent over bushland near construction compound and mine facilities	
	Mobile ablutions facilities	
	Pump out and transport of raw sewage for off-site disposal	
	Raw sewage leaks during tanker collisions	
	WWTP process upsets / failure resulting in reduced treatment efficacy / higher contaminant loading	
Waste	Solid and liquid waste generation from construction and operational activities	Nutrients, hydrocarbons, metals, pathogens, surfactants, plastics, suspended solids
	On-site waste disposal	
Fire and controls	Bushfire due to machinery or electrical sparks	Suspended solids - soot/ash / bushfire induced soil erosion / specific ionic species, trihalomethanes, industrial hydrocarbons, pesticides, and herbicides
	Fires caused by leaks or spills during refuelling or vehicle collisions	
Rehabilitation	Use of fertiliser for vegetation	Nutrients, herbicide
	Use of herbicide for vegetation	
Clearing	Clearing of vegetation and removal of caprock	Salinity, hydrocarbons, PFAS (legacy), suspended solids
	Change in hydrological regime	
	Rising groundwater mobilising salts in soils and/or pre-mining contaminants	
Conveyor operation	Spilling ore and/or sediment from damaged equipment or dusting off the belt	Sediments, suspended solids, metals, plastics, hydrocarbons
	Abrasion of the belt discharging pollutants	
	Oil leaks from bearings on conveyor idlers	
	Fuel or oil leaks from accidents of maintenance/inspection vehicles along conveyor corridor	
Power plant	Construction and operations power supply	Hydrocarbons
	Diesel power plant fuel farm leak or spill	
	Substation transformer oil leak or spills	

Source type	Source description	Contaminant
Mine infrastructure	Hazardous materials / package chemical storage and use for vehicle and equipment maintenance	Suspended solids, hydrocarbons, surfactants, nutrients, metals, organic solvents, PFAS (legacy)
	Fuel storage and handling at mine facilities	
	Washbay washwater generation	
	Vehicle and equipment washdowns	
	Overflow of potentially contaminated water ponds	
Light and heavy vehicles	Fuel leaks during refuelling on-site	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
	Oil leaks during vehicle/equipment maintenance	
	Fuel or oil leaks whilst driving or during vehicle collisions	
	Tyre wear	
	Vehicle parking at mine facilities	
	Vehicle and equipment maintenance at mine facilities	
Linear infrastructure construction near waterways	Disturbance to bed and banks of waterways or reservoir leading to erosion	Suspended solids
	Temporary material stockpiling	
	Contaminated bulk construction material brought to site	Hydrocarbons, suspended solids, metals, other chemicals

6. Source vulnerability assessment

As required in the ESD Required Work item 50, a source vulnerability assessment of the Serpentine, Pipehead and South Dandalup Reservoirs is required, in accordance with the Australian Drinking Water Quality Standards and relevant contemporary guidance. This is constituted by the ADWG and other supporting documentation.

The ADWG is moving towards adoption of Health Based Targets (HBTs). These include risk assessment metrics for pathogen infection rates and disability adjusted life years (DALYs) to increasingly quantify pathogen risks to drinking water.

Historically, the approach to microbial safety of water supplies has been that pathogens should be absent from drinking water. This is primarily verified by *Escherichia coli* (*E. coli*) monitoring of supplied water in conjunction with qualitative 'catchment to tap' risk assessments as part of a drinking water quality management plan.

In contrast, HBTs require estimation of source water pathogen risk and the effectiveness of catchment management and treatment processes to reduce risks to acceptable levels. The WSAA HBT Manual outlines two tiers of source water assessment:

Tier 1 is recommended for all drinking water sources. Sanitary survey information together with source water microbial indicator data are used to categorise the source in terms of its vulnerability to pathogen contamination.

Tier 2 is optional and involves carrying out a quantitative microbial risk assessment (subject to ample source water pathogen data) to complement the Tier 1 assessment.

To that end, a sanitary survey (SS) and source vulnerability assessment were undertaken to better understand the **microbial risk** from the Proposal to the drinking water supply systems. This has been conducted in accordance with Chapter 5 of the ADWG, and the Draft ADWG Chapter 5.7 HBT (2016).

6.1 Methodology

This preliminary catchment assessment adopts a desktop-based SS of the Proposal, to characterise microbial risks from mining in the proposed Myara North and Holyoake regions.

The first step of a SS is to establish the area of influence and scope of the SS. In general, several $\log_{10}$ orders of pathogen inactivation occur over weeks to months following pathogens entering the natural environment, so reducing the SS boundary to inner catchment areas is worthwhile in some cases. However, for this vulnerability assessment the SS boundary has been kept to the entire catchment area for both PDWSAs as a conservative measure.

The microbial sources and pathways described as part of the catchment assessment in Section 5.2 is considered representative of a desktop SS.

The vulnerability assessment process as described in Figure 5 of the HBT Manual has been used to define the source category of the catchment with respect to the existing land uses and the Proposal. This has been based on the catchment details in section 3.1, and the hazard identification in sections 5.1 and 5.2. The CSM process diagrams shown in Section 5.2 include all of the potential pathogen sources and their pathways from mining and existing land uses. The use of this conceptual model representation is in line with the *Good Practice Guide*.

The SS provides key outputs relating to (WSAA 2015):

– pathogen sources arising from the presence of people and cattle
– intensity of these developments/activities
– proximity to feeder streams and water storage
– presence of in situ barriers such as riparian vegetation, fencing and detention in storage

The SS outputs are then aggregated into a vulnerability assessment, which assesses the relevant land use challenges to classify the water source into one of four vulnerability categories:

– Protected catchment

– Moderately protected catchment
– Poorly protected catchment
– Unprotected catchment

The four vulnerability categories are directly related to the required pathogen removal by treatment processes.

The vulnerability assessment and catchment categorisation has been semi-quantitatively validated based on the Baker et al (2016) standardised survey method, along with a review of likely pathogen travel times from mining areas. A review of available microbial monitoring data within the proposed mining catchment area has also been undertaken.

6.2 Source categorisation

The source categorisation in the HBT Manual (WSAA 2015) considers three land use challenges that are targeted to microbial risk: namely from permanent human, itinerant human, and stock animal sources. Table 6.1 presents a summary of how these three land use challenges are applicable to the PDWSAs.

Table 6.1 Land use challenges applicable to the PDWSAs

Land use challenge	Application to the Serpentine Main Dam and South Dandalup Dam PDWSAs
Permanent human	Serpentine Main Dam café caretaker's residence. No other human settlements existing or proposed within PDWSAs No living in accommodation (LIA) for mining, timber harvesting and other forest industries, all workforces are drive in-drive out
Itinerant human	Recreational public use of Serpentine Main Dam facilities, South Dandalup Dam facilities, Munda Biddi Trail, Bibbulmun Track, Balmoral Track, POW camp. Composting toilets at Serpentine Main Dam and South Dandalup Dam recreational areas, POW camp, Bibbulmun track campsites. Serpentine Main Dam café includes on-site sewage treatment plant (STP) and effluent disposal. Mine facilities include on-site STP and effluent disposal. Mobile mine ablutions block with septage pump out and tankering off-site. Mobile workforce for Proposal construction, mining, ore haulage and rehabilitation. Mobile workforce for timber harvesting, prescribed burns and fire response. Apiary operators at designated apiary sites.
Stock animals	No stock animals are expected to be kept within either PDWSA.

The vulnerability assessment comprises an assessment of the land use challenges with respect to their intensity, proximity to waterways and level of protection (preventative barriers). Table 6.2 and Table 6.3 present the vulnerability assessments for the Serpentine Main Dam and South Dandalup Dam, respectively, based on a review of the existing and proposed land uses described in Sections 3.5 and 5.1.

As noted in Section 2.2, the ADWG (2021) categorises drinking water sources as WSAA (2015), however does not include guidance around vulnerability assessment, and so the WSAA (2015) guidance is drawn on here for that aspect of assessment. As described in WSAA (2015) Table 1, the different vulnerability assessment categories for drinking water sources typically have particular challenges from land use. These challenges include impacts from permanent human habitation, itinerant human activities, and from stock animals. In this case, the existing challenges have been summarised as follows:

Existing challenges

– Negligible human settlements, limited to a caretaker's residence at Serpentine Main Dam
– Low level or negligible recreation in the outer catchment, including a café and facilities adjacent to Serpentine Main Dam
– No rural properties with stock animals, and active management of feral pig populations

These challenges align with either category 1 or category 2 source waters in WSAA (2015). Other characteristics typically associated with each of these categories include:

Category 1, typical characteristics:

– Human settlements and recreation excluded from the whole area of influence, typically the whole hydrological catchment and reservoir.
– Natural bushland
– Protection enforced by policed regulation
– Low intensity/low risk activities many be allowed in the outer catchment but active source protection (e.g. ranger patrols) is practiced to ensure negligible contamination risk
– Supply is from a large reservoir with long detention time for the water

Category 2, typical characteristics:

– Human settlements excluded from inner catchment
– Recreation excluded from inner catchment, and no recreation close to or on the main water body
– Farming excluded from inner catchment
– Bushland inner catchment, low density rural outer catchment
– Stock fully fenced out of main feeder streams behind vegetated buffer zones
– Protection enforced by policed regulation
– Low level and low intensity activities may be allowed within the outer catchment but active source protection (e.g., ranger patrols) is practiced minimising contamination risk

The existing human settlement and stock animal challenges align well with category 1 source waters. Some challenges presented from itinerant human activity could be regarded as within either category. However, with the consideration of other mitigating factors, including the dilution of surface water inputs within Serpentine Pipehead Dam from groundwater and desalination inputs, the source water could be classified as a category 1 source, given the present challenges to water quality. Raw water from this source is currently treated to a level applicable for a Category 1 source

The source vulnerability assessment indicates that the classification of the source water is unlikely to change with the Proposal. The Proposal involves a move of the Huntly Mine workforce and operations from the existing Myara region to the Myara North region, both of which are predominantly within the Serpentine Main Dam PDWSA. The Proposal will result in a re-introduction of the Huntly Mine workforce and operations to the South Dandalup Dam PDWSA, which previously occurred in that PDWSA in the 1990s and 2000s. The Proposal will act to restrict itinerant public access (authorised and un-authorised) within both PDWSAs.

6.3 Western Australian guidance

The categorisation is consistent in the context of Western Australian guidance. With respect to mining in P1 PDWSAs in Western Australia, the Strategic Policy (DoW 2016a) refers to WQPN no. 25: Land use compatibility tables for PDWSAs, which '*outlines appropriate land uses and activities within PDWSAs and their priority areas, and should be referred to when making decisions about land use*'.

WQPN 25 states that mining within a P1 PDWSA but outside protection zones is compatible, subject to conditions on:

– licensing to abstract surface or groundwater
– storage of fuels and chemicals, depth of excavation, and rehabilitation criteria.
– mining within the RPZ subject to demonstration that the risk of water contamination is effectively controlled under all circumstances

Mining within a P1 PDWSA and inside a protection zones is classified as incompatible, however applicants can apply for special consideration and will be required to:

– demonstrate that alternative locations for the land use have been considered
– site specific information about the land uses and activities is provided; and
– a risk assessment is undertaken in accordance with ADWG.

The DWSPPs for the three PDWSAs states that the acceptability of mining is subject to more specific conditions related to mining and rehabilitation, for example:

– “[Bauxite mining is] acceptable if operated in compliance with conditions imposed by [Mining Management Program Liaison Group] MMPLG.
– Ensure the conditions imposed by the MMPLG specifically pertaining to water quality protection are adhered to.
– Ensure Alcoa continues to manage water protection in accordance with their Environmental Management Manual (updated bi-annually).
– Ensure Alcoa operates according to the “Working Arrangements between Alcoa World Alumina – Australia, the Water and Rivers Commission and the Water Corporation Covering Alcoa’s Mining Operations in the Darling Range”.
– Ensure Alcoa’s monitoring program continues.”

The State Government policies indicate that mining in P1 PDWSAs is conditionally acceptable, with key conditions being demonstrated satisfactory management of impacts, and demonstrated effective control of risks within the RPZ ‘*under all circumstances*’.

Table 6.2 Source categorisation – Serpentine Main Dam

Land use challenge	Existing land use			Existing land use plus Proposal		
	Intensity	Proximity	Protection	Intensity	Proximity	Protection
Permanent human	Single residence – Serpentine Main Dam caretaker.	Caretaker residence within RPZ ~ 250 m from reservoir.	n/a	No change	No change.	No change.
	No living-in accommodation (LIA) for mining and forest industries workforce. All workforce drive in-drive out.	n/a	n/a	No change. No LIA proposed for Myara North construction or operations workforce.	n/a	n/a
	No other settlements within PDWSA.	n/a	PDWSA classification restricts urban and residential development.	No change.	n/a	n/a
Itinerant human	Myara mine facilities include STP and effluent disposal. Myara mine demountable ablutions block with septage pump out and tankering off-site, no on-site disposal. Myara mine mobile workforce for construction, mining, ore haulage and rehabilitation.	Myara mine facilities STP and mobile ablutions block located outside RPZ. Myara mine mobile workforce operate throughout PDWSA, including RPZ subject to Water Corporation Working Arrangements.	STP effluent disposal via above ground irrigation, located away from creekline. Demountable ablutions block serviced by bunded pump out tank, zero on-site discharge. Bushland inner and outer catchment. Large water supply reservoir (capacity > 1 GL and annual throughflow).	No change Mine workforce will remain similar size to existing, moving from Myara region to Myara North region. Myara North mine facilities STP will accept similar loading as existing Myara facilities STP. Myara North demountable ablutions block will accept similar loading to existing Myara mobile ablutions block.	No change Myara North mine facilities STP and mobile ablutions block will be located outside RPZ.	No change.
	Recreational public use of Serpentine Main Dam facilities, Munda Biddi Trail, Bibbulmun Track, Balmoral Track, POW camp. Composting toilets at Serpentine Main Dam recreational area,	Munda Biddi Trail, Bibbulmun Track, Balmoral Track, POW camp outside of RPZ. Serpentine Main Dam facilities within RPZ of	Public access restricted within RPZ, apart from Serpentine Main Dam facilities and café. Camping not permitted within RPZ.	No change	Public access excluded from Myara North region during construction, operations and rehabilitation, including RPZ.	Public access restricted within Myara North region, via locked gates on current access points from public roads. Surveillance from mine workforce

Land use challenge	Existing land use			Existing land use plus Proposal		
	Intensity	Proximity	Protection	Intensity	Proximity	Protection
	POW camp, Bibbulmun track campsites. Serpentine Main Dam café includes on-site sewage treatment plant (STP) and effluent disposal. DBCA and FPC mobile workforce for timber harvesting, prescribed burns and fire response. Apiary operators at designated apiary sites. Un-authorised public access for recreation.	Serpentine Main Dam or Pipehead Dam. Serpentine Main Dam café STP within RPZ of Serpentine Main Dam or Pipehead Dam. DBCA and FPC operations through PDWSA including within RPZ subject to Water Corporation approval. Un-authorised public access may occur throughout PDWSA.	Signage, locked gates and ranger patrols within RPZ. Water Corporation undertakes surveillance throughout PDWSA and particularly RPZ. Bushland inner and outer catchment. Large water supply reservoir (capacity > 1 GL and annual throughflow).			operating in Myara North region. Reduced authorised and un-authorised recreational activity in Myara North portion of PDWSA.
Stock animals	No stock animals within PDWSA. Feral pigs occur within PDWSA and pose a risk of pathogen spread.	n/a	Water Corporation rangers and licensed hunters undertake hunting and trapping of feral pigs.	No change	n/a	n/a

Table 6.3 Source categorisation – South Dandalup Dam

Land use challenge	Existing land use			Existing land use plus Proposal		
	Intensity	Proximity	Protection	Intensity	Proximity	Protection
Permanent human	No living-in accommodation (LIA) for forest industries workforce. All workforce drive in-drive out.	n/a	n/a	No change. No LIA proposed for Holyoake construction or operations workforce.	n/a	n/a
	No settlements within PDWSA.	n/a	PDWSA classification restricts urban and residential development.	No change.	n/a	n/a
Itinerant human	No current mine facilities or mining workforce within PDWSA. Holyoake region mobile workforce for exploration. Past Huntly region (1990s) and White region (2000s) mobile workforce for construction, mining, ore haulage and rehabilitation.	n/a	n/a	Holyoake mine facilities will include STP and effluent disposal. Holyoake mine demountable ablutions block with septage pump out and tankering off-site, no on-site disposal. Holyoake mine mobile workforce for construction, mining, ore haulage and rehabilitation.	Holyoake mine facilities STP and mobile ablutions block will be located outside RPZ. Holyoake mine mobile workforce will operate in PDWSA outside of RPZ.	STP effluent disposal will be via above ground irrigation, located away from creekline. Demountable ablutions block will be serviced by bunded pump out tank, zero on-site discharge. Bushland inner and outer catchment. Large water supply reservoir (capacity > 1 GL and annual throughflow).
	Recreational public use of South Dandalup Dam facilities, Bibbulmun Track. Composting toilets at Bibbulmun track campsites. DBCA and FPC mobile workforce for timber harvesting, prescribed burns and fire response. Apiary operators at designated apiary sites. Un-authorised public access for recreation.	Bibbulmun Track and campsite outside of RPZ. South Dandalup Dam facilities within RPZ, toilets located outside of PDWSA. DBCA and FPC operations within RPZ subject to Water Corporation approval.	Recreation restricted within PDWSA, apart from Bibbulmun Track and South Dandalup Dam facilities. Signage, locked gates and ranger patrols within RPZ. Water Corporation undertakes surveillance throughout PDWSA and particularly RPZ.	No change	Public access excluded from Holyoake region during construction, operations and rehabilitation.	Public access restricted within Holyoake region, via locked gates on current access points from public roads. Surveillance from mine workforce operating in Holyoake region. Reduced authorised and un-authorised recreational activity in

Land use challenge	Existing land use			Existing land use plus Proposal		
	Intensity	Proximity	Protection	Intensity	Proximity	Protection
		Un-authorised public access may occur throughout PDWSA.	Bushland inner and outer catchment. Large water supply reservoir (capacity > 1 GL and annual throughflow).			Holyoake portion of PDWSA.
Stock animals	No stock animals within PDWSA. Feral pigs occur within PDWSA and pose a risk of pathogen spread.	n/a	Water Corporation rangers and licensed hunters undertake hunting and trapping of feral pigs.	No change	n/a	n/a

6.4 Source vulnerability assessment verification

A verification of the source vulnerability assessment was undertaken, based on the Baker et al. (2016) standardised survey method, along with a review of likely pathogen travel times from mining areas. This method is in essence a sanitary survey, with a greater level of detail than is described in high-level methods such as described in WSAA (2015). As a sanitary survey is an integral part of a source vulnerability assessment, this is a supplement to and verification of the high-level survey described in section 6.1, and supports the source vulnerability assessment required in the ESD work item 50.

Baker et al (2016) describes a systematic methodology to identify microbial risk sources in catchment areas, and to assign risk scores to those sites, based on the likelihood of the site affecting catchment water quality and of the potential consequences. *Escherichia coli* (*E coli)* and protozoan pathogens are included in the assessment as indices of chlorine sensitive and chlorine resistant microorganisms, respectively. The likelihood of faecal contamination entering the waterway at a given location is determined (usually from collected field data, but in this case from the catchment assessment) by evaluating the generation of contaminants and the potential connectivity with catchment waterways and mitigated by the factors which can moderate or prevent contamination from entering the waterways. The method then adopts consequence scores, which are approximately equivalent to the logarithmic$_{10}$ load of the organism generated per day based on literature values. The methodology has been used extensively in Queensland and Victorian water sources, to identify the relative risks of contamination sources within catchment areas, and to allow the prioritisation of management actions to locations presenting the greatest risks to water quality.

This methodology has been applied here so as to assess the relative risks of contamination sources associated with mining activities. Mining involves two distinct microbial risk areas, these being:

– Sewage treatment systems and treated effluent irrigation within the mine facilities area; and
– Mobile work teams in construction, mining and rehabilitation

Worst-case and normal conditions for each of these microbial risk areas have been reviewed with respect to the Baker et al. (2016) methodology, and the likelihood, consequence and risk rating from each system is provided in Table 6.4.

6.4.1 Sewage treatment systems and irrigation

The proposed mine facilities are located at the centroid of the Myara North and Holyoake regions, outside the RPZ of the Serpentine Main Dam and SDD PDWSAs, and it is assumed that the treated effluent irrigation area will be located at a high point within the facilities areas, and located at a minimum 500 m away from the nearest watercourse. The average slope from this high point to each of the nearest watercourses is 1-6 per cent. It is further assumed that the wastewater treatment system will include secondary treatment, chlorination, and UV disinfection; and designed to be compatible with:

– Water quality protection note 22 Irrigation with nutrient-rich wastewater (DoW, 2010)
– Water quality protection note 33 Nutrient and irrigation management plans (DoW, 2016)
– *Government sewerage policy* (DPLH, 2019)

The Huntly mine operations have a total workforce of approximately 230, comprising 135 during the day shift and 95 during the night shift, with a total equivalent persons of approximately 50-100 (depending on whether showers are used). Assuming that the mine facilities Sewage Treatment Plant (STP) treats sewage from the entire workforce, the STP would be considered a “decentralised system” under the Baker et al. (2016) definitions of on-site systems. The worst-case condition for this treatment system is a hydraulic failure (i.e. overflow of treated wastewater).

There will also be a demountable ablution block for workers located closer to mining areas, but still outside the RPZ. This will have an on-site system with no effluent irrigation, whereby effluent is pumped out and removed from the catchment. This treatment facility is assumed to be an “on-site system” (10 EP or less) for the purpose of this assessment. The location of this system is unknown at this stage, so the slope from the system is conservatively assumed to be steep, and located at least >100 m away from the nearest water course.

Based on the above information and assumptions, residual risks relating to normal operations of the sewage systems were determined to be low. The worst-case hydraulic failure scenario without downstream mitigation in place resulted in a moderate[2] microbial risk rating.

6.4.2 Mobile work teams

At a worst case, the mobile mining and rehabilitation workforce may comprise up to 20 staff in a subcatchment area at any one time (J. White, Alcoa, pers. comm.). These workers have been treated as “passive recreators” (i.e. no water contact) under the Baker et al. (2016) designations of likelihood. The “medium recreator numbers (100 individuals)” designation has been adopted to assign a consequence rating for these workers. Workers within these areas will have access to toilet facilities which will be located at a demountable ablution block and at the mine facilities, and will also be educated on the significance of the PDWSA and their responsibilities in this regard. Nonetheless, it is conservatively assumed that workers in these areas will not have access to toilet facilities.

The residual microbial risk rating from workers on-site is low.

A cumulative risk rating has not been undertaken at this stage, as a field-based sanitary survey of the entire catchment would be required to inform such an assessment.

6.4.3 Summary

Given the worst-case outcomes from this assessment produced either medium or low results, -this assessment is considered in line with the outcomes of the vulnerability assessment and source categorisation in Section 6.2.

While it is acknowledged that downstream treatment should not be relied upon to ensure high quality drinking water, the expected log reduction values of chlorine disinfection are shown in Table 6.5 to highlight that chlorine disinfection at the dam water treatment plants can remove some bacteria and viruses, but does not remove any protozoa. Therefore, the need to control pathogenic risks at the source (i.e. at the proposed STP and irrigation systems) through multiple barriers is critical to protecting water source quality.

[2] It is noted that as the Baker et al 2016 methodology is typically based on field surveys, the likelihood classifications are based on actual site conditions, such that the likelihood adopted for the worst-case scenario would be the likelihood of microbial contaminants reaching the waterway **after** a hydraulic failure has occurred, without accounting for the likelihood of the hydraulic failure occurring in the first place. This is considered inappropriate for this assessment as the actual likelihood of a failure occurring needs to be considered. As such, the ADWG likelihood classifications have been referred for this scenario, as discussed in Table 6.4.

Table 6.4 Microbial risk assessment (Baker, Ferguson, Chier, Warnecke, & Watkinson, 2016)

Primary hazard	Scenario	Secondary hazard	Likelihood	Consequence			Attenuation			Attenuated score		Risk rating
				Source	E coli score	Protozoa score	Measure(s)	E coli score	Protozoa score	E coli	Protozoa	
Treated effluent irrigation	Worst-case hydraulic failure, no on-site treatment (no mitigation)	Hydraulic failure* Moderate slope** Watercourse >100m	Unlikely***	Decentralised system (~100 EP)	9	5	Buffer zone of 50m or more in land irrigation area	-1	-1	8	4	Medium***
	Normal operations	Normal function Moderate slope** Watercourse >100m	Unlikely		9	5	Buffer zone of 50m or more in land irrigation area Land irrigation of effluent by surface irrigation Secondary treatment Chlorinated UV disinfection	-9	-4	0	1	Low
On-site system	Worst-case hydraulic failure (no mitigation)	Hydraulic failure* Steep slope** Watercourse >100m	Unlikely***	On-site system (10 EP or less)	8	4	None (treatment failure)	0	0	8	4	Medium***
	Normal operation	Normal function Steep slope** Watercourse >100m	Rare		8	4	No discharge (composting toilet, pump-out system, portaloo)*	-8	-5	0	-1	Low
Workers	Worst-case (no mitigation)	Passive recreation (no water contact), toilet facilities absent	Possible	Medium recreator numbers (100 individuals)	2	2	Work sites do not allow small children recreating in water	-1	-1	1	1	Low
Notes	As defined by Baker et al. 2016: *Hydraulic failure = overflow of effluent **Steep slope = greater than 10 per cent slope. A moderate slope is regarded as 5 – 10 per cent slope. ***The likelihood adopted by Baker et al. (2016) is the likelihood of microbial contaminants reaching the waterways **after** a hydraulic failure has occurred, and would therefore be "Possible" in this instance. However this measure of likelihood does not account for the likelihood of a hydraulic failure actually occurring. As such, the assessment has deferred to the ADWG classifications of likelihood in this case, in which case the likelihood of a hydraulic failure occurring is considered to be "Not impossible, but more likely not to occur than to occur", i.e. "unlikely".										

Table 6.5 Assumed Log Removal Values (LRVs) for Serpentine and South Dandalup Dam Water Treatment Plants

Process	Log reduction value (score)			Process control limits
	Protozoa	Bacteria	Virus	
Chlorine disinfection	0	4	4	Ct>15 mg/L.min with pH <8.5 (based on ADWG default). Feed water turbidity <1.0 NTU

6.4.4 Pathogen travel times

In order to further verify the low-risk outcome regarding workers within the catchment, worst-case pathogen transport times from the edge of the proposed mining pits to the nearest streams have been estimated. As streamflow generation is dominated by groundwater discharge, with direct surface run-off a lesser fraction of total flow (as discussed in Section 3.4), travel times via groundwater flow have been estimated. Only the indicative Myara North mine layout has been assessed as no equivalent indicative mine plan exists for Holyoake at this stage.

Figure 6.1 illustrates a histogram of the shortest distance from mine pits to the nearest stream as well as a histogram of the associated average slope over that distance. The majority of mine pits are more than 100 m away from the nearest stream, and have an average slope below 9 per cent. Of the 1100 pits, 10 per cent have both a distance of <200 m to the nearest stream and an average slope of >8 per cent.

The estimated travel time for water to travel via subsurface flow from the mine pit edge to the nearest water course is shown in Figure 6.2. These travel times have been calculated from Darcy's Law, under the conservative assumptions outlined in Table 6.6. Application of Darcy's Law in this instance is simplistic and conservative in that it assumes the travel pathway is a direct lateral subsurface flow (i.e. interflow) from mine pit edge to the stream, of which recent studies have indicated is likely only relevant within valley floors and immediate surrounds (beyond mine pit areas) (Grigg, 2017; Jackson, Bitew, & Du, 2014).

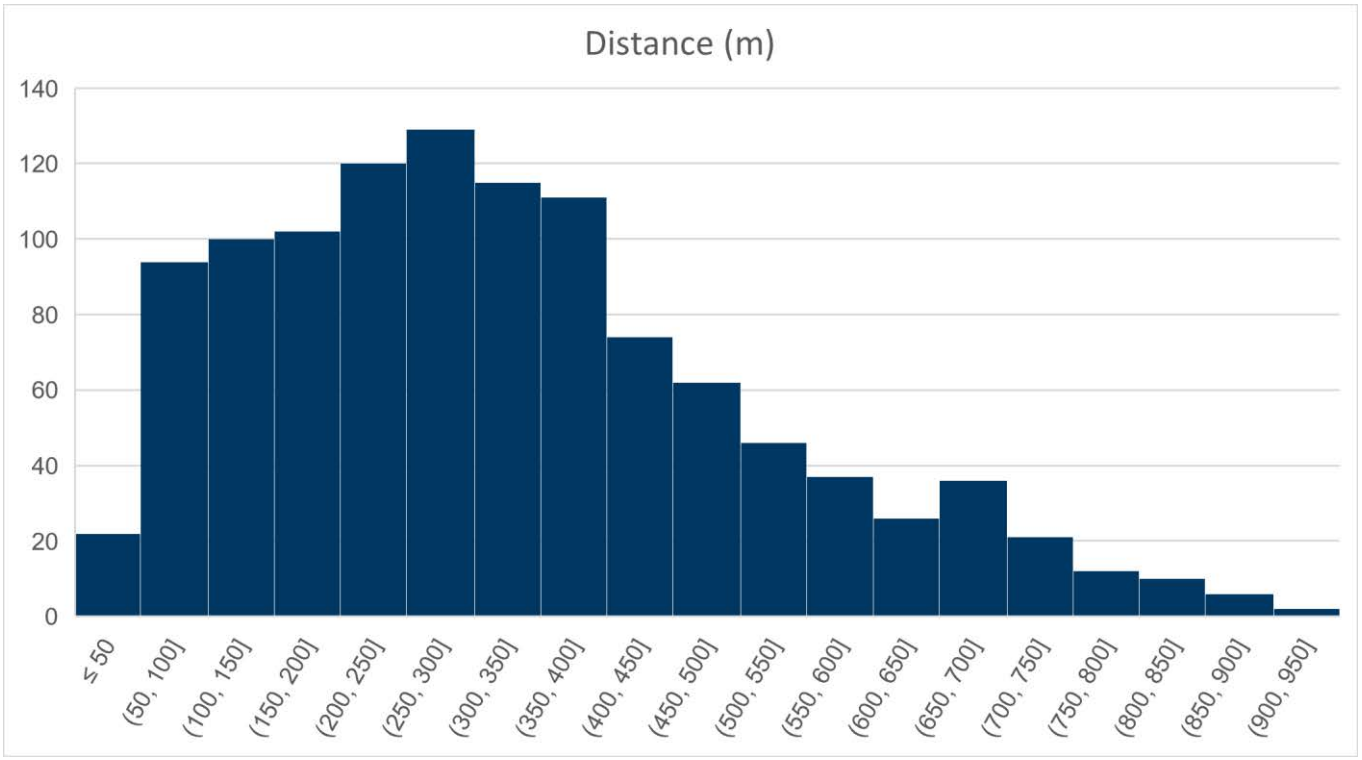
Table 6.6 Adopted hydrogeological parameters

	Maximum travel time	Likely average travel time	Description
Hydraulic conductivity (m/d)	2 (maximum)	0.3 (average)	Maximum and average as measured from slug testing of 14 bores within the Myara North area.
Porosity	0.1	0.1	Conservative representation of saprock, which is typically constrained to 0.1 to 0.3

The worst case and likely average travel time based on these assumptions is 12 days and 78 days from mine pit boundary to reservoir. The time required for a given level of pathogen reduction varies according to pathogen type and key process variables such as temperature, UV intensity and substrate. However, in general, several log10 orders of pathogen inactivation occur over weeks to months following pathogens entering the natural environment. The estimated travel time for subsurface flow from the pits to the nearest water course is within 60 days for around 110 pits (i.e. 10per cent of the total). This aligns with the number of pits that are both a distance of <200 m to the nearest watercourse and have an average slope of >8 per cent.

Accordingly, the likelihood of pathogens entering a waterway and subsequently entering the reservoir from subsurface flow is considered rare for the majority of mine pits, however there are over a hundred proposed pits that would require strict hygiene management to appropriately mitigate the risk of pathogens entering a nearby water course.

This review has not assessed the location of specific pits with respect to the reservoir itself, nor whether the nearest watercourses to the pits actually produce flow during normal rainfall events. Regardless, while groundwater discharge is the dominant source for streamflow, there remains the greater risk that a major rainfall event would result in overland flow and direct discharge into the reservoir and/or watercourse.



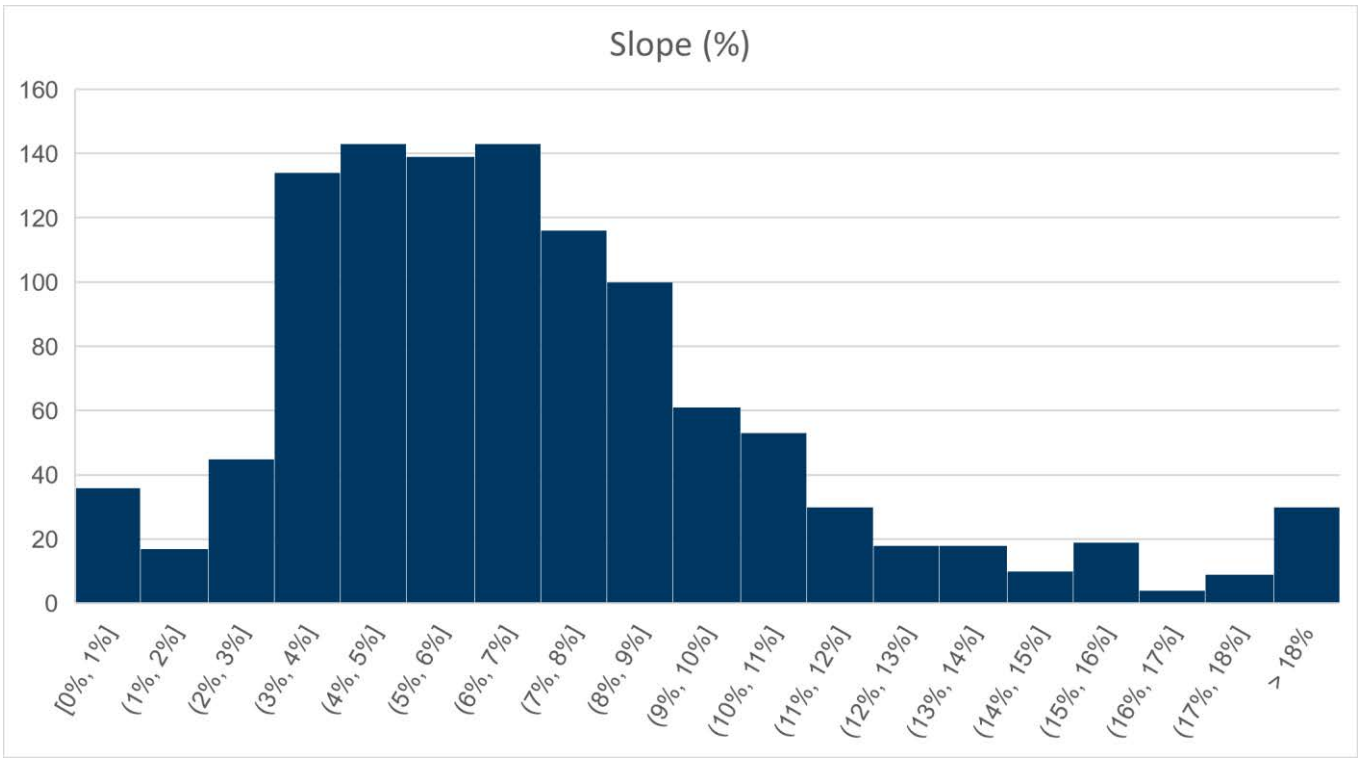


Figure 6.1 Histogram of mine pit distance and average slope from edge of pit to nearest stream

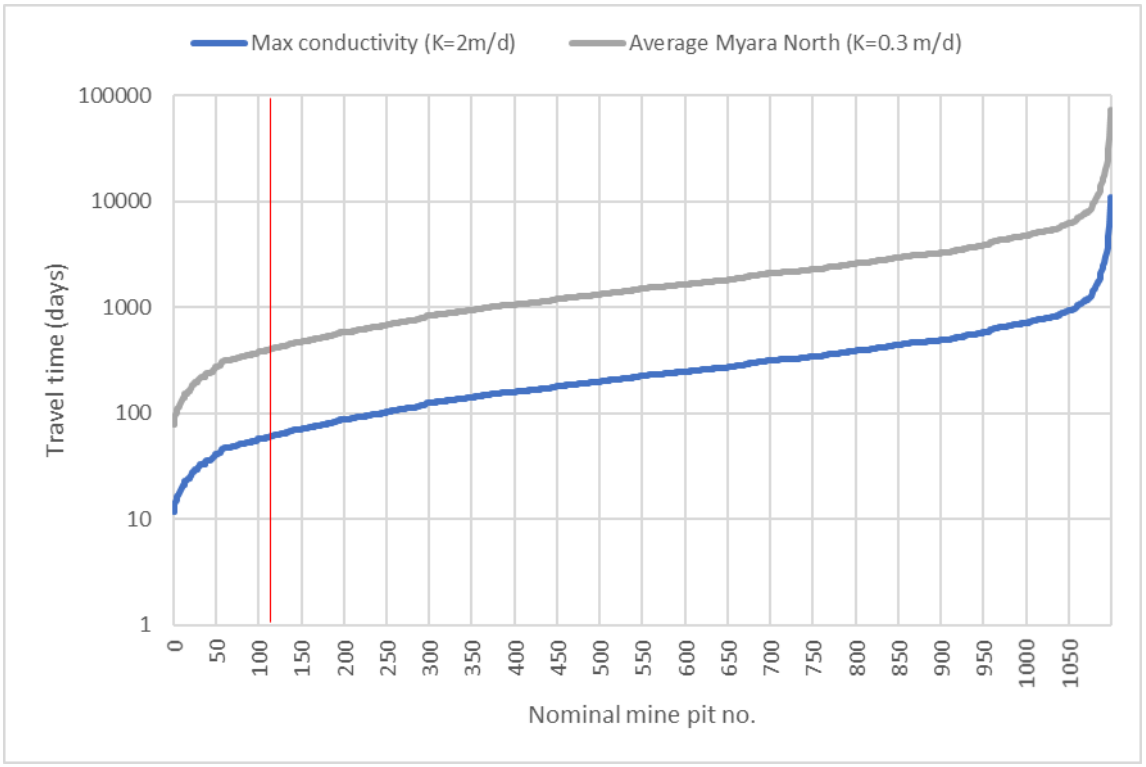


Figure 6.2 Distribution of travel time of groundwater from mine pit edge to nearest water course

7. Quantitative microbial risk assessment

This section describes a quantitative microbial risk assessment (QMRA), which has been conducted to estimate the impacts of pathogen inputs in the described drinking water catchment areas that potentially become entrained in the source waters for drinking water supply, The QMRA examines the concentration of a reference pathogen (*Cryptosporidium*) through to potential exposure to the local population.

Due to the number of variables involved in the calculation of a QMRA, the preferred approach has been to define simple upper limit scenarios and use these to estimate the approximate health risks for those scenarios. This is consistent with other characterisations of catchment risks using a QMRA approach, such as used by Billington et al (2011). The examined scenarios are outlined in section 7.1. These include potential events able to introduce pathogens to the catchment, and estimation of the subsequent dilution and removal by environmental effects of those pathogens, which are described in much greater detail in the hydrological modelling of the reservoirs in GHD (2021). This modelling has been performed with AEM3D, a 3D numerical model that includes hydrodynamic, thermodynamic and biogeochemical modules to simulate the temporal behaviour of stratified water bodies from environmental forcing. It was configured in this study to simulate the spatial and temporal variations of TSS, *Cryptosporidium* and hydrocarbons under various scenarios.

The general format for the QMRA is that described in the AGWR (2006) and WSAA (2015). This format allows clarity with the assumptions used, the transparent calculation of pathogen risks and of concentrations of pathogens through the exposure pathways examined, and the ready update of calculations in the event that the assumptions are subsequently updated. Where applicable, quantitative values for assumptions have been drawn from AGWR (2020).

The following considerations have been made in this QMRA:

– *Cryptosporidium* is the standard reference pathogen in the WSAA (2015) guidance for Tier 2 assessment of source waters. This reference describes the use of monitoring data for this pathogen, however in the absence of such data, literature-based assumptions have been made as to the concentration of viable and human-infective *Cryptosporidium* in contamination events. Other reference pathogens could be simultaneously examined, to represent other pathogen groups including viruses and bacteria. However, *Cryptosporidium* is resistant to chlorination, the mode of water treatment employed for this source, making it the worst-case pathogen in this situation.
– The exposure pathway by which human populations could potentially be exposed to pathogens is limited to the consumption of treated drinking water. Other pathways such as recreation in catchment waters are not considered to be likely, due to restrictions on such activities and the other practical barriers that prevent them from occurring.
– The risk of illness for exposed populations have been estimated and expressed as Disability Adjusted Life Years (DALYs). Dose response information for the reference pathogens has been drawn from AGWR (2021).

The various inputs to the QMRA are summarised in section 7.2. These inputs are drawn from literature sources, and from the reservoir modelling performed for this catchment area in GHD (2021).

The QMRA outputs are summarised in section 7.3. The outputs of the QMRA include the estimated risk of illness from exposure to *Cryptosporidium* via drinking water for the various scenarios, expressed in DALYs. As a comparative risk expressed in DALYs, the health based target for drinking water favoured by WSAA is a risk of 10^{-6} DALYs per person per annum. The scenarios have been examined by calculating the unmitigated or raw risks, and then applying applicable factors to calculate mitigated risks. The estimated mitigated risks are also summarised as QMRA outputs.

7.1 Scenarios

Four pathogen discharge hazardous events have been examined as scenarios, as expanded on in section 7.1.1. These are calculated using two different sets of assumptions, as follows:

– Direct deposition. This is the worst case, and assumes that no pathogens are removed via surface (overland) transport to the reservoir. This is effectively the same as if the contamination was directly deposited into the reservoir. The pathogen inputs by scenario are summarised in Table 7.1.
– Some removal via surface (overland) flow. This case assumes that some pathogen removal occurs during overland flow. The extent of this removal is based on specific conditions (slope, rainfall, vegetation coverage, etc), an assumed value for removal has been applied based on available overland transport literature (section 7.2.2). The pathogen inputs by scenario are summarised in Table 7.2.

Numerous citations have been made in the scenario descriptions. Further discussion about the cited literature has been included in section 7.2.

In particular, assumptions have been made about the amount of pathogen removal during surface (overland) and sub-surface transport, and from additional mitigation measures. The literature on which these assumptions have been based is very briefly described in the footnotes of Table 7.1 and Table 7.2. The amount of removal that can be expected in practice will vary depending on local conditions, such as terrain slope, rainfall intensity and duration, vegetation cover, the presence of gullies and other channels, and distance between the hazard and the reservoir. Consequently, the assumed removals are general, and may need to be changed when examining specific situations.

The transport assumptions are removed in the worst case (direct deposition) scenario set, so as to allow the effect of the transport assumptions to be clearly identified. Some attenuation via transport will occur with all of the described hazards, and should be included in the assessment of those hazards.

Where specific considerations have been made in the modelling (GHD, 2021), these are summarised in section 7.1.2. These include sub-catchment locations where the hazard is introduced.

7.1.1 Scenario descriptions

Hazard 1

A raw sewage overflow event located within a STP within the catchment area, during wet catchment conditions with heavy rainfall. An overflow could result from an undersized effluent storage, inadequate maintenance of the storage, blockage within the system, infiltration of rainwater flows into the storage, leakage of the storage, and/or other circumstances resulting in storage failure. As a worst case event, the overflow has been assumed to have a small distance of surface (overland) transport before being transported via steep gullies or ephemeral waterways into the reservoir or its tributaries. A conservative attenuation of 2 logs of pathogen load has been assumed for the worst case scenario. This assumes a 10 per cent mobilization rate, (i.e. transported via flow from rainfall) as estimated for manure in connected source areas (Billington, 2010), with an additional 1 log removal from overland transport across bare soil from the overflow to the gully (a minimal removal estimate from overland transport studies - Tate et al 2000; Atwill et al 2002; Davies et al 2003; Trask et al 2004; Ferguson et al 2007).

Hazard 2

Treated effluent accumulates at the surface of a designated irrigation area, and is subsequently washed out by heavy rainfall. Accumulation of effluent could result from improper irrigation practices, irrigation equipment breakages, blockages or other maintenance failure, poor siting of irrigation areas, and/or other circumstances resulting in irrigation area failure. As per Hazard 1, a worst case event assumes only a small distance of surface (overland) transport prior to flow into a steep gully and then into a creek or reservoir. Also as with Hazard 1, the worst case assumes 2 logs of attenuation from mobilization and minimal removal from bare soil prior to unimpeded flow.

Hazard 3

Treated effluent leaches into a subsurface perched aquifer during a period when rainfall exceeds evapotranspiration, flows to a steep creek or a downstream seepage face over tens of metres, and then in the reservoir or a creek. Subsurface flows to a waterway could result from poor siting or under sizing of irrigation areas, irrigation area failures, flow volumes elevated by rainfall beyond the receiving capacity of an irrigation area, and/or other circumstances of greatly increased input flows. A greater degree of attenuation (4 logs) has been assumed than with Hazards 1 and 2, due to the greater potential for removal during surface (overland) flow and from subsurface flows over greater distances than assumed for Hazards 1 and 2, and is similarly based on the

literature values for expected *Cryptosporidium* removal during those processes (as cited for Hazards 1 and 2, as well as Atwill et al (2002), where the effects of overland and shallow sub-surface flows on Cryptosporidium transport are described).

Hazard 4

An asymptomatic staff member with cryptosporidiosis defecates in bushland in the catchment area, shortly before a heavy rainfall event. This could result from uncontrolled access by staff to sensitive catchment areas (particularly near gully lines and riparian zones), where staff are unaware of the potential consequences of such actions, where ablution block access is difficult for field staff, where contingencies for staff toilet access needs have not been otherwise made, and/or other circumstances enabling this hazard to occur are present. As a worst case event, the faecal material is deposited in a gully or a riparian zone and is highly mobilized during the rainfall event, and 10 per cent of the material is transported into the reservoir or a creek, as a minimal attenuation value drawn from the surface (overland) transport literature previously cited for Hazard 1. This 10 per cent attenuation value is drawn from the manure mobilization estimate used by Billington (2011).

Additional scenario notes

Hazards 2 and 3 have potential to occur on a seasonal basis and will be modelled to occur concurrently, and also in combination with either Hazard 1 or Hazard 4. As a conservative assumption, pathogen concentrations have been modelled during a 1 EY storm scenario, which is more frequent and provides less dilution.

Table 7.1 Pathogen discharge, unmitigated hazards, no removal via overland flow

Hazard	Source	Pathway	Receptor	Duration
1: STP raw sewage overflow	Raw sewage overflow at some point in STP 18 m^3/day sewage @ 2,000 oocysts/L[3] = 36 million oocysts/day	Overflow occurs during wet catchment conditions and heavy rainfall No attenuation via overland flow i.e. direct deposition into reservoir assumed	36,000,000 oocysts/day discharge into creek Direct deposition into reservoir	Two days overflow[4]
2: STP effluent irrigation area washout	Treated effluent accumulates at surface of irrigation area during wet catchment conditions 18m^3/day treated sewage @ 200 oocysts/L[5] = 3.6 million oocysts/day Sustained heavy rainfall causes wash out of accumulated oocysts ~ ten times daily deposition = 36 million oocysts/day	Washout occurs during wet catchment conditions and heavy rainfall No attenuation via overland flow i.e. direct deposition into reservoir assumed	36,000,000 oocysts/day discharge into creek Direct deposition into reservoir	Two days heavy rainfall
3. STP effluent irrigation area subsurface flow	Treated effluent leaches into subsurface during winter/spring when rainfall exceeds evapotranspiration 18m^3/day treated sewage @ 200 oocysts/L = 3.6 million oocysts/day	Oocysts in leachate transported by shallow perched aquifer. No attenuation via overland or subsurface flow i.e. direct deposition into reservoir assumed	3,600,000 oocysts/day discharge into creek Direct deposition into reservoir	Three months shallow seepage per year
4. Defecation in the field	Asymptomatic infected staff member defecates in the field in gully or riparian zone, in bushland adjacent to mine pit or rehabilitation area 150 g stool @ 1 million oocysts/g = 150 million oocysts[6]	Stool present/remaining in riparian zone or gully near reservoir, wet catchment conditions during heavy rainfall event Assumed 100 per cent is washed into reservoir, no attenuation i.e. direct deposition into reservoir assumed.	150,000,000 oocysts discharge into creek Creek flowing into reservoir	Two days heavy rainfall

[3] Pathogen concentrations in faecal material can vary over a wide range. Analysis from two Australian sewerage schemes have been used to form default values in determining sewage treatment performance targets (AGWR 2006 and 2020, using unpublished data from SA Department of Health and Melbourne Water), which are consistent with international data. The default concentration of 2000 *Cryptosporidium* oocysts per litre is the 95th percentile concentration from these data, and has been used here as the pathogen concentration estimate for sewage inputs in this QMRA.

[4] Two days is a reasonable period for a 24 hr/day manned site to notice a continuous noxious discharge and arrange for emergency tinkering.

[5] AGWR (2006) cites an indicative removal of 0.5-1.0 logs of Cryptosporidium from secondary treatment. A 1-log removal applied to the default concentration results in an estimated concentration of 200 oocysts/L.

[6] Chappell et al, as reported in WHO 2006, describe humans at the peak of infection as shedding up to 10^{5-7} oocysts per gram of faeces. The higher shedding rates can be expected to be associated with symptomatic infection; the mid-range concentration of 10^6 oocysts/g has been used as a conservative estimate for shedding from an asymptomatic case. Feachem et al (1983) reported that the rate of excretion of faeces is 100-200 g/day. The mid-point of this range (150 g/day) has been applied to the QMRA as an assumed rate.

Table 7.2 Pathogen discharge, unmitigated hazards, some removal via overland flow

Hazard	Source	Pathway [7]	Receptor	Duration
1: STP raw sewage overflow	Raw sewage overflow at some point in STP 18 m^3/day sewage @ 2,000 oocysts/L[8] = 36 million oocysts/day	Overflow occurs during wet catchment conditions and heavy rainfall Transport via overland flow and shallow channel flow ~ several hundred metres of gullies with ephemeral storm flow, in Jarrah forest @ 5-10 per cent slope Attenuation ~2 log_{10}	360,000 oocysts/day discharge into creek Creek flowing into reservoir	Two days overflow[9]
2: STP effluent irrigation area washout	Treated effluent accumulates at surface of irrigation area during wet catchment conditions 18m^3/day treated sewage @ 200 oocysts/L[10] = 3.6 million oocysts/day Sustained heavy rainfall causes wash out of accumulated oocysts ~ ten times daily deposition = 36 million oocysts/day	Washout occurs during wet catchment conditions and heavy rainfall Transport via overland flow and shallow channel flow ~ several hundred metres of gullies with ephemeral storm flow, in Jarrah forest @ 5-10 per cent slope Attenuation ~2 log_{10}	360,000 oocysts/day discharge into creek Creek flowing into reservoir	Two days heavy rainfall
3. STP effluent irrigation area subsurface flow	Treated effluent leaches into subsurface during winter/spring when rainfall exceeds evapotranspiration 18m^3/day treated sewage @ 200 oocysts/L = 3.6 million oocysts/day	Oocysts in leachate transported by shallow perched aquifer ~ several tens of metres to creek or downslope seepage face Attenuation ~ 4 log_{10}	360 oocysts/day discharge into creek Creek flowing into reservoir	Three months shallow seepage per year
4. Defecation in the field	Asymptomatic infected staff member defecates in the field in gully or riparian zone, in bushland adjacent to mine pit or rehabilitation area 150 g stool @ 1 million oocysts/g = 150 million oocysts[11]	Stool present/remaining in riparian zone or gully near reservoir, wet catchment conditions during heavy rainfall event Approximately 10 per cent is washed out and transported via overland flow and shallow channel flow ~ minimal distance over Jarrah forest @ 5-10 per cent slope	15,000,000 oocysts discharge into creek Creek flowing into reservoir	Two days heavy rainfall

[7] Water Futures (2011), Table 3-4, baseline manure mobilization rates. 10 per cent assumption for manure deposited within connected source areas. 1 per cent assumption of mobilization from land in the absence of riparian fencing and vegetation cover. Additional removal (to 4-log) assumed from subsurface transport of leachate

[8] Pathogen concentrations in faecal material can vary over a wide range. Analysis from two Australian sewerage schemes have been used to form default values in determining sewage treatment performance targets (AGWR 2006 and 2020, using unpublished data from SA Department of Health and Melbourne Water), which are consistent with international data. The default concentration of 2000 *Cryptosporidium* oocysts per litre is the 95th percentile concentration from these data, and has been used here as the pathogen concentration estimate for sewage inputs in this QMRA.

[9] Two days is a reasonable period for a 24 hr/day manned site to notice a continuous noxious discharge and arrange for emergency tinkering.

[10] AGWR (2006) cites an indicative removal of 0.5-1.0 logs of Cryptosporidium from secondary treatment. A 1-log removal applied to the default concentration results in an estimated concentration of 200 oocysts/L.

[11] Chappell et al, as reported in WHO 2006, describe humans at the peak of infection as shedding up to 10^{5-7} oocysts per gram of faeces. The higher shedding rates can be expected to be associated with symptomatic infection; the mid-range concentration of 10^6 oocysts/g has been used as a conservative estimate for shedding from an asymptomatic case. Feachem et al (1983) reported that the rate of excretion of faeces is 100-200 g/day. The mid-point of this range (150 g/day) has been applied to the QMRA as an assumed rate.

7.1.2 Catchment-specific considerations in the modelling

Serpentine Main Dam

The modelling (GHD, 2021) has been performed assuming that the described hazard is presented in particular catchment areas. These are tabulated in Table 7.3 (reproduced from Table 8: Pathogen hazard locations, in GHD 2021). The noted catchment areas are the worst case locations for contamination to occur within the overall larger catchment, being the closest to the off-take points, and are further described in GHD (2021).

Table 7.3 Pathogen hazard locations

Hazard	Serpentine Main Dam, Existing Location	Serpentine Main Dam, Proposed Locations
1: STP raw sewage overflow	Catchment 13	Catchment 5
2: STP effluent irrigation area washout	Catchment 13	Catchment 5
3. STP effluent irrigation area subsurface flow	Catchment 13	Catchment 5
4. Defecation in the field	Catchments 16 (4A), 10 (4B), 9 (4C) Reference: Catchment 1 (4D, Dam recreation area)	Catchments 3 (4A), 5 (4B), 7 (4C) Reference: Catchment 1 (4D, Dam recreation area)
Hazard	**South Dandalup, Proposed Locations**	**Serpentine Pipehead Dam, Proposed Location(s)**
1: STP raw sewage overflow	Catchment 35	N/A
2: STP effluent irrigation area washout	Catchment 35	N/A
3. STP effluent irrigation area subsurface flow	Catchment 35	N/A
4. Defecation in the field	Catchments 35 (4A), 34 (4B), 33 (4C) Reference: Catchment 30 (4D, Dam recreation area)	Catchments 23 (4A), 24 (4B) Reference: Catchment 20 (4D, not a mining area)

Notes:

The “Existing locations” are the locations of existing activities which could lead to the described hazards.

The “Proposed location(s) are where the proposed activities could lead to the described hazards.

Hazard 4 has been examined as 4 variants of the same scenario (i.e. Hazards 4A, 4B, 4C and 4D), based on the effect should the hazard be presented in different parts of the catchment. Hazard 4D has been modelled as a hazard from dam recreation areas, as it is not sourced from proposed or existing mining activities it has not been examined further in this QMRA.

Frequency of hazards: Hazard 1 has been assumed as occurring once within a two year period (i.e. 0.5 events per year). The other hazards have all been assumed as occurring twice per year (i.e. 2 events per year).

7.2 QMRA inputs

7.2.1 Pathogen sources

The sources of pathogens examined here include leakage of raw or partially-treated sewage from sewerage infrastructure, and from human faeces deposited in the catchment area during itinerant human activity.

Pathogen concentrations in faecal material can vary over a wide range. Analysis from two Australian sewerage schemes have been used to form default values in determining sewage treatment performance targets (AGWR 2006 and 2020, using unpublished data from SA Department of Health and Melbourne Water), which are consistent with international data. The default concentration of 2000 *Cryptosporidium* oocysts per litre is the 95th

percentile concentration from these data, and has been used here as the pathogen concentration estimate for sewage inputs in this QMRA.

The AGWR (2006) cites an indicative removal of 0.5-1.0 logs of *Cryptosporidium* from secondary treatment. A 1-log removal applied to the default concentration results in an estimated concentration of 200 oocysts/L, for pathogen sources where secondary treatment of sewage has occurred.

Cryptosporidium oocysts can be found in high numbers in the faeces of a host. Chappell et al, as reported in WHO 2006, describe humans at the peak of infection as shedding up to 10^{5-7} oocysts per gram of faeces. The higher shedding rates can be expected to be associated with symptomatic infection; the mid-range concentration of 10^6 oocysts/g has been used as a conservative estimate for shedding from an asymptomatic case. Feachem et al (1983) reported that the rate of excretion of faeces is 100-200 g/day. The mid-point of this range (150 g/day) has been applied to the QMRA as an assumed rate.

7.2.2 Overland and subsurface transport

The surface (overland) transport of *Cryptosporidium* oocysts sourced from cattle faeces has examined at some length in the literature. No literature containing experimental data examined the overland transport rates of *Cryptosporidium* from sewage or human faeces has been identified, so the available cattle data has been utilised here.

Billington et al (2011) reviewed catchment factors that affect the transport of *Cryptosporidium* oocysts to waterways, such as vegetation cover, slope type and depth, antecedent rainfall, rainfall intensity and location, and transport distance. These authors cited Ferguson (2005) in forming an estimate of *Cryptosporidium* mobilisation and overland transport under two sets of conditions, as follows:

– *Cryptosporidium* mobilisation of 1 per cent, from land in the absence of riparian fencing and vegetation cover.
– *Cryptosporidium* mobilisation of 0.002 per cent, from land with riparian fencing with >5 m setback and good vegetation cover.

Ferguson et al (2007) seeded artificial bovine pats with *Cryptosporidium* and other reference organisms, placed them on soil plots, and subjected them to artificial rainfall events of 55 mm/h for 30 minutes. The plots were divided into bare soil and natural vegetation, and the pats were tested as “fresh” pats and one-week “aged” pats. Transportation efficiency increased with decreasing size of the organism studied, so *Cryptosporidium* as the largest of the reference pathogens was the least transportable. Rainfall events mobilised 0.5-0.9 per cent of the seeded oocysts from the fresh pats, and transported them a distance of 10 m across the bare soil plots. Subsequent rainfall events applied to aged pats mobilised 0.01-0.06 per cent of the seeded oocysts. On the vegetated test plots, *Cryptosporidium* concentrations were less than half the concentrations of the bare soil plots, indicating a slower initial release of oocysts. On both bare and vegetated plots, *Cryptosporidium* showed significant reductions in mean concentrations with increasing distance transported.

Tate et al (2000), as reported in Ferguson et al (2007), simulated the release of oocysts from calf pats under storm conditions. Model pats containing 1.5×10^8 oocysts/kg were placed on a soil plot, and subjected to intense artificial rainfall of 7.62 cm/h for 90 minutes. The overflow flow from the plot was captured and examined for *Cryptosporidium*. Approximately 1.2 per cent of the total oocysts were detected in the flow, the majority in the first 30 minutes.

Similarly, Davies et al (2003) seeded artificial pats with approximately 10^7 oocysts, placed the pats on soil plots, subjected the plots to rainfall treatments, collected the runoff, and examined the runoff for *Cryptosporidium*. Experimental variables included differing vegetation (plots that were either devoid of vegetation or with natural vegetation cover), differing degrees of slope (5° and 10°), and differing rainfall events (rainfall of either 55 mm/h for 30 minutes, or 25 mm/h for 180 minutes). Surface runoff transported from $10^{0.2}$ oocysts from vegetated loam soil (25-mm/h, 180-min event on 10° slope) to up to $10^{4.5}$ oocysts from unvegetated soil (55-mm/h, 30-min event on 10° slope) over a 1-m distance. In the worst described case, approximately 0.3 per cent of oocysts were transported overland for a one metre distance.

Atwill et al (2002) examined the efficacy of vegetated buffer strips at *Cryptosporidium* removal from surface and shallow sub-surface flows, during simulated rainfall rates of 15 or 40 mm/h for 4 h. Log reductions of spiked *Cryptosporidium* oocysts ranged from 1.0 to 3.1 per metre of vegetated buffer, with slope, amount of vegetation cover and soil texture and density examined as different treatments. The authors concluded that a vegetated

buffer strip of a length of at least 3 m, at a slope of <20 per cent, should remove at least 3 logs of oocysts from agricultural runoff generated during events involving mild to moderate precipitation.

Trask et al (2004) examined the effects of slope, vegetation and rainfall intensities on oocyst transport in a tilting soil chamber. Slopes of up to 4.5 per cent, vegetation of bare ground or brome vegetation, and simulated rainfall intensities of 25.4 mm/h and 63.5 mm/h for 44 min were examined. Total recoveries of seeded oocysts in the overland flow (i.e. the proportion transported across the chamber) varied between 0.6 and 59 per cent.

7.2.3 Waterborne transport

The hydrology of the Serpentine Main Dam, Serpentine Pipehead Dam and South Dandalup reservoirs has been modelled in GHD (2021). The calculation of the *Cryptosporidium* dilution during waterborne transport through these reservoirs was the key objective of this modelling, and was expressed as the pathogen concentration (oocysts/L) in outflows from each reservoir, as an annual average so as to allow the calculation of annualised risks. This estimate includes losses due to sedimentation during retention within the reservoir bodies. It also includes losses from pathogen die-off, which are discussed in section 7.2.4. The calculated average pathogen concentrations in the reservoir output waters, based on the hazard inputs, are tabulated in Table 7.4. The calculated concentrations are at the output waters of the noted catchments (Serpentine Main Dam, South Dandalup Dam or Serpentine Pipehead Dam), it is noted that waters from Serpentine Main Dam are subsequently transported through and diluted within Serpentine Pipehead Dam prior to transfer to the IWSS.

Table 7.4 Reservoir outflow pathogen annual average concentrations (oocysts/L), by hazard

Hazard	Serpentine Main Dam, existing	Serpentine Main Dam, proposed	South Dandalup Dam, existing	South Dandalup Dam, proposed	Pipehead Dam, proposed
1	$1.94x10^{-8}$	$3.16x10^{-8}$	N/A	$1.86x10^{-8}$	N/A
2	$2.90x10^{-8}$	$6.93x10^{-8}$	N/A	$3.74x10^{-8}$	N/A
3	$1.21x10^{-9}$	$2.96x10^{-9}$	N/A	$2.86x10^{-9}$	N/A
4A	$2.28x10^{-6}$	$2.35x10^{-6}$	N/A	$7.79x10^{-7}$	$1.01x10^{-7}$
4B	$1.89x10^{-6}$	$1.44x10^{-6}$	N/A	$4.02x10^{-7}$	$1.52x10^{-5}$
4C	$1.26x10^{-6}$	$1.46x10^{-6}$	N/A	$8.53x10^{-7}$	N/A

Note: The South Dandalup *Cryptosporidium* concentrations are marked as Not Applicable (N/A) as there is no mining access occurring presently, with all mining being historical and considered ‘fully rehabilitated’. Similarly, the Pipehead Dam scenarios do not include mining infrastructure in that catchment.

Further dilution of flows from Serpentine Main Dam occurs in Serpentine Pipehead Dam, due to desalination inputs that are introduced in this storage. This has been applied as a mitigation factor of 1 LRV, applied to the calculated unmitigated risks from the tested scenarios. This estimate of mitigation is conservative, with a greater amount of mitigation for flows into Pipehead Dam estimated in GHD (2021)

7.2.4 Pathogen die-off

Cryptosporidium survival in surface waters under environmental conditions was reviewed by Murphy (2017), who examined two studies under dark conditions at various temperatures. Pathogen survival was expressed as the number of days required for a 1-log or 2-log reduction in numbers, and was summarised as follows:

– At 5 °C, the time taken for a 2-log reduction was >200 days (Ives et al, 2007)
– At 20-25 °C, the time taken for a 1-log reduction was 38-86 days (Sidhu & Toze, 2012; Sidhu et al, 2015, Ives et al, 2007), and for a 2-log reduction was 30-45 days (Ives et al, 2007)
– At 30 °C, the time taken for a 2-log reduction was 10-11 days (Ives et al, 2007)

As noted by Murphy (2017), the environmental survival of this organism seems to be very temperature sensitive. No studies were found on *Cryptosporidium* survival when exposed to sunlight, however as this organism can be inactivated by UV disinfection, a more rapid die-off is expected under such conditions. This author concluded that more data are needed about the survival of *Cryptosporidium* under a variety of environmental conditions.

Microbial die-off can also be expressed as a mortality or decay rate per day (K_d). The time for 1-log and 2-log reductions summarised in Murphy (2017) when converted to a decay rate are as follows:

– At 5 °C, a 2-log reduction over >200 days converts to a rate of <0.015/day
– At 20-25 °C, a 1-log reduction over 38-86 days converts to a rate of ~0.025-0.07/day, and a 2-log reduction over 30-45 days converts to a rate of ~0.1-0.14/day
– At 30 °C, a 2-log reduction over 10-11 days converts to a rate of ~0.35-0.4/day

Hipsey et al (2008) describe a *Cryptosporidium* decay rate in freshwater at 20 °C of 0.03-0.08/day, citing Walker and Stedinger (1999). The average of this rate – 0.055/day – has been used to model *Cryptosporidium* die-off in this QMRA. This rate is relatively conservative when compared with the other literature values, due to the consideration of higher temperature rates (i.e. 25 °C and 30 °C conditions) in the other cited literature. Given the uncertainty and variability associated with die-off due to environmental influences, this conservatism is regarded as prudent.

The 0.055/day rate of pathogen die-off has been incorporated into the hydrodynamic modelling (GHD, 2021), and is included in the amount of dilution resulting from waterborne transport (as noted in section 7.2.3).

7.2.5 Water treatment

Existing water treatment is chlorination only. Whilst chlorination can be highly effective at inactivating bacterial and viral pathogens, it is not effective at the inactivation of protozoa such as *Cryptosporidium*. No removal of this pathogen by chlorination has been assumed in this QMRA.

7.2.6 Exposure events

As exposure is via drinking water, 365 exposure events per year have been assumed, with 1 L of drinking water consumed per day. These default values have been drawn from WSAA (2015).

7.2.7 Pathogen dose response estimates

The dose response characteristics of *Cryptosporidium* have been drawn from WSAA (2015), Table A2.3, and from ADWG (2018), Tables A.5 and A.7. Different values for DALYs per case are presented in these references ($2.46x10^{-3}$ in WSAA (2015) Table A2.3, and $1.7x10^{-3}$ in ADWG (2018) Table A.7); the ADWG value is based on more recent and complete literature, and has been applied here. These are literature values that describe the probability of infection, probability of illness, the disease burden, and the proportion of the population susceptible to illness. The relevant values for this assessment have been summarised in Table 7.5.

Table 7.5 Cryptosporidium dose response characteristics

Dose response parameter	*Cryptosporidium*
Probability of infection/organism	0.2
Probability of illness/infection	0.7
DALYs per case	$1.7x10^{-3}$

For the proportion of population susceptible to illness, a value of 1 has been used for *Cryptosporidium* (WHO, 2011).

7.3 Results of QMRA

The calculations of the QMRA for Serpentine Main Dam as a source are presented in Table 7.6, and for South Dandalup and Serpentine Pipehead Dams in Table 7.7. The key outputs from the calculations are the (unmitigated) risk in DALYS/person/year from use of each dam as a source water (line l in the tables), and the additional LRVs that are required through mitigation to reduce the risk to the acceptable threshold of 10^{-6} DALYS/person/year.

The risks calculated in Table 7.6 and Table 7.7 are unmitigated. There are a number of applicable mitigation factors that require consideration in determination of risk from Serpentine Pipehead Dam, which is the source water used for supply. These factors are described below.

Dilution in SPD

As noted in section 3, there are substantial inputs of desalinated water to SPD, and these inputs are expected to make up an increasing proportion of total supply in the future. These inputs dilute the flows received from Serpentine Main Dam. Transit through SPD can be expected to result in some further pathogen removal, through microbial die-off and sedimentation, although these factors are relatively minor compared to the effects of dilution. A key factor in risk management is also selectivity about when water is transferred from the large storages to SPD, it is assumed that transfers would not occur during or immediately following flood events, when pathogen concentrations and turbidity could be expected to be at their most elevated. A conservative LRV of 1 has been assumed as an applicable risk mitigation factor to the calculated pathogen risks from Serpentine Main Dam flows.

Siting of infrastructure to minimize pathogen hazards

As noted in section 7.1.1, the unmitigated risks from sewerage infrastructure (hazards 1, 2 and 3) assume that the hazards are sited where overflows and leachate can be transported relatively unimpeded to surface waters through steep gullies or ephemeral waterways. Mitigation measures that impede ready transport can be applied to reduce the pathogen risks from such infrastructure, and include approaches such as the inclusion of vegetated buffer strips and porous infiltration trenches on drainage paths from the infrastructure.

The amount of removal expected from such measures will be dependent upon local circumstances. The available literature discussing *Cryptosporidium* removal during overland and sub-surface transport has been briefly summarised in section 7.2.2.

Restriction of personnel access to minimize pathogen hazards

As noted in section 7.1.1, the unmitigated risks from defecation by an infected but asymptomatic staff member (hazard 4) assumes access to and defecation in areas where flows are relatively unimpeded to surface waters through steep gullies or ephemeral waterways. Mitigation measures to restrict ready access to such areas can be applied to reduce the pathogen risks from such access, such as restricting access with fencing, ranger patrols, strict controls on personnel movements near water courses, and a policy of not accessing the catchment if gastrointestinal symptoms are suspected by staff.

As above, the amount of removal expected from such measures will depend upon local circumstances, and indicative estimates are available in the available literature.

Multiple hazards

The risk associated with multiple hazards can be calculated for the source water. In such scenarios, the calculated risks are additive, and the resulting pathogen risk can be compared with the acceptable risk threshold. The probabilities of multiple hazards occurring in combination becomes increasingly unlikely, however they become more likely in a situation where there are no or few oversight measures on activities in the catchment.

Table 7.6 Serpentine Main Dam, calculated risks from described scenarios (based on unmitigated risks with some removal from overland flow)

		Serpentine Main Dam												
Line	HBT Calculation Parameter	Hazard 1 Existing	Hazard 2 Existing	Hazard 3 Existing	Hazard 4A Existing	Hazard 4B Existing	Hazard 4C Existing	Hazard 1 Proposed	Hazard 2 Proposed	Hazard 3 Proposed	Hazard 4A Proposed	Hazard 4B Proposed	Hazard 4C Proposed	Calculation Notes/References
a	oocysts/L in source water	2.23E-07	3.34E-07	1.39E-08	2.62E-05	2.18E-05	1.45E-05	3.63E-07	7.97E-07	3.41E-08	2.71E-05	1.66E-05	1.68E-05	Average of simulation (GHD, 2021)
b	exposure per event (L)	1	1	1	1	1	1	1	1	1	1	1	1	1L of drinking water/person/day
c	Dose per event (orgs)	2.23E-07	3.34E-07	1.39E-08	2.62E-05	2.18E-05	1.45E-05	3.63E-07	7.97E-07	3.41E-08	2.71E-05	1.66E-05	1.68E-05	a x b
d	Number of events per year	365	365	365	365	365	365	365	365	365	365	365	365	
e	Dose per year	8.15E-05	1.22E-04	5.07E-06	9.57E-03	7.95E-03	5.28E-03	1.33E-04	2.91E-04	1.25E-05	9.89E-03	6.06E-03	6.14E-03	c x d
f	Probability of infection/organism	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	ADWG (2018), based on WHO (2016)
g	Probability of infection/year	1.63E-05	2.43E-05	1.01E-06	1.91E-03	1.59E-03	1.06E-03	2.65E-05	5.82E-05	2.49E-06	1.98E-03	1.21E-03	1.23E-03	e x f
h	Proportion of infection leading to illness	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	ADWG (2018), based on WHO (2016)
i	Probability of illness per year	1.14E-05	1.70E-05	7.10E-07	1.34E-03	1.11E-03	7.39E-04	1.86E-05	4.07E-05	1.74E-06	1.38E-03	8.48E-04	8.60E-04	g x h
j	DALYs per case	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	ADWG (2018), based on WHO (2016)
k	Proportion of population susceptible to illness	1	1	1	1	1	1	1	1	1	1	1	1	Assume 100% of population is susceptible to illness
l	Source water DALYs per person per year	1.94E-08	2.90E-08	1.21E-09	2.28E-06	1.89E-06	1.26E-06	3.16E-08	6.93E-08	2.96E-09	2.35E-06	1.44E-06	1.46E-06	i x j x k

Table 7.7 South Dandalup Dam and Serpentine Pipehead Dam, calculated risks from described scenarios (based on unmitigated risks with some removal from overland flow)

		South Dandalup, proposed						Pipehead, proposed		
Line	HBT Calculation Parameter	Hazard 1 Proposed	Hazard 2 Proposed	Hazard 3 Proposed	Hazard 4A Proposed	Hazard 4B Proposed	Hazard 4C Proposed	Hazard 4A Proposed	Hazard 4B Proposed	Calculation Notes/References
a	oocysts/L in source water	2.14E-07	4.31E-07	3.30E-08	8.97E-06	4.62E-06	9.82E-06	1.17E-06	1.75E-04	Average of simulation (GHD, 2021)
b	exposure per event (L)	1	1	1	1	1	1	1	1	1L of drinking water/person/day
c	Dose per event (orgs)	2.14E-07	4.31E-07	3.30E-08	8.97E-06	4.62E-06	9.82E-06	1.17E-06	1.75E-04	a x b
d	Number of events per year	365	365	365	365	365	365	365	365	
e	Dose per year	7.81E-05	1.57E-04	1.20E-05	3.27E-03	1.69E-03	3.59E-03	4.26E-04	6.40E-02	c x d
f	Probability of infection/organism	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	ADWG (2018), based on WHO (2016)
g	Probability of infection/year	1.56E-05	3.15E-05	2.41E-06	6.55E-04	3.37E-04	7.17E-04	8.52E-05	1.28E-02	e x f
h	Proportion of infection leading to illness	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	ADWG (2018), based on WHO (2016)
i	Probability of illness per year	1.09E-05	2.20E-05	1.69E-06	4.58E-04	2.36E-04	5.02E-04	5.96E-05	8.96E-03	g x h
j	DALYs per case	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	0.0017	ADWG (2018), based on WHO (2016)
k	Proportion of population susceptible to illness	1	1	1	1	1	1	1	1	Assume 100% of population is susceptible to illness
l	Source water DALYs per person per year	1.86E-08	3.74E-08	2.86E-09	7.79E-07	4.02E-07	8.53E-07	1.01E-07	1.52E-05	i x j x k

Table 7.8 Summary of risk estimates from tested hazards

	Serpentine (existing) risk inputs						Serpentine (proposed) risk inputs					
Hazard	1	2	3	4A	4B	4C	1	2	3	4A	4B	4C
Unmitigated risk, direct deposition (DALYs/person/year)	1.94E-06	2.90E-06	1.21E-05	2.28E-05	1.89E-05	1.26E-05	3.16E-06	6.93E-06	2.96E-05	2.35E-05	1.44E-05	1.46E-05
Dilution in SPD (factor)	1-log	1-log	1-log	1-log	1-log	1-log	1-log	1-log	1-log	1-log	1-log	1-log
Residual risk after dilution (DALYs/person/year)	1.94E-07	2.90E-07	1.21E-06	2.28E-06	1.89E-06	1.26E-06	3.16E-07	6.93E-07	2.96E-06	2.35E-06	1.44E-06	1.46E-06
Indicative removal, overland transport (factor)	2-log	2-log	4-log	1-log	1-log	1-log	2-log	2-log	4-log	1-log	1-log	1-log
Unmitigated risk, with overland transport (DALYs/person/year)	1.94E-09	2.90E-09	1.21E-10	2.28E-07	1.89E-07	1.26E-07	3.16E-09	6.93E-09	2.96E-10	2.35E-07	1.44E-07	1.46E-07

	South Dandalup (proposed) risk inputs						Serpentine Pipehead Dam risk inputs	
Hazard	1	2	3	4A	4B	4C	4A	4B
Unmitigated risk, direct deposition (DALYs/person/year)	1.86E-06	3.74E-06	2.86E-05	7.79E-06	4.02E-06	8.53E-06	1.01E-06	1.52E-04
Dilution in SPD (factor)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Residual risk after dilution (DALYs/person/year)	1.86E-06	3.74E-06	2.86E-05	7.79E-06	4.02E-06	8.53E-06	1.01E-06	1.52E-04
Indicative removal, overland transport (factor)	2-log	2-log	4-log	1-log	1-log	1-log	1-log	1-log
Unmitigated risk, with overland transport (DALYs/person/year)	1.86E-08	3.74E-08	2.86E-09	7.79E-07	4.02E-07	8.53E-07	1.01E-07	1.52E-05

Notes: Orange shading indicates calculated risk of >10^{-6} DALYs/person/year. Blue shading indicates a calculated risk of <10^{-6} DALYs/person/year.

7.4 Discussion of QMRA results

7.4.1 Mitigation factors

As noted in section 7.3, some of the risks calculated for unmitigated hazards, and combinations of unmitigated hazards, are greater than the HBT acceptable risk threshold of 10^{-6} DALYs/person/year. Further mitigation of risks could be used to control the actual risks presented through the use of multiple barriers. The following observations are made about potential mitigation factors:

– Under the current supply arrangements to the source water of SPD, the surface water supplies make up a relatively small proportion of the overall source volume. This proportion is expected to decrease further into the future. Consequently, the 1 LRV mitigation factor for Serpentine Main Dam flow dilution in SPD should be applied for any realistic estimate of risk from this source water.
– The inclusion of mitigation factors for sewerage infrastructure is regarded as a prudent minimum requirement for any construction or operations in a drinking water catchment area. This would include measures able to prevent unimpeded flows from overflows or leachate into waterways, and the removal of hazards where practicable.
– The restriction of personnel movement in a drinking water catchment is also regarded as a sensible minimum requirement. The aim of such restrictions would be to prevent access to vulnerable locations such as riparian areas, gullies and ephemeral waterways.

7.4.2 Identified elevated risks *(unmitigated)*

As identified in Table 19, the assessed unmitigated risk for Hazard 4B in the Serpentine Pipehead Dam was elevated above the 10^{-6} DALYs/person/year threshold of acceptable risk. As an elevated risk, this hazard requires attention during detailed design, so as to define how to reduce the risk to an acceptable level.

Further to the annualized risk estimation, exposure to elevated concentrations of *Cryptosporidium* for shorter periods of time presents a risk of infection. The ADWG does not set a guideline concentration for *Cryptosporidium* in drinking water, so there is no formalized threshold of acceptability of this risk. The ADWG does note that if such a guideline were established, it would be well below one oocyst/L, and involve the testing of impractically large volumes of water.

In addition to the averaged annual concentration of Cryptosporidium resulting from the examined hazards, GHD (2021) predicted the peak concentrations of this organism resulting the hazards. For the highest risk hazards presented in the Serpentine Pipehead Dam catchment, these included concentrations of ~0.00001 oocysts/L (Hazard 4A in catchment 23), and ~0.01 oocysts/L (Hazard 4B in catchment 24). From these calculated concentrations, the latter hazard presents an unacceptable short-term high risk (unmitigated) of cryptosporidiosis, in addition to the annualized risk. This observation supports the conclusion that the mitigation of this hazard to a level of acceptable risk requires attention during detailed design.

7.4.3 Combined risks

There are many contamination hazards which have been described in section 7.1. Whilst highly conservative and unrealistic due to a very low likelihood, a combined risk can be considered of all of the mitigated Serpentine, South Dandalup and Serpentine Pipehead Dam hazards occurring simultaneously (i.e Hazards 1, 2, 3, 4A, 4B, and 4C). This can be considered for the existing hazards, which include only the Serpentine inputs due to the current absence of mining activities in South Dandalup; and compared with the proposed inputs. These risks include the assumed dilution within Serpentine Pipehead Dam of flows from Serpentine Main Dam.

– Serpentine Main Dam (existing risks) = 5.48×10^{-7} DALYs/person/year
– Serpentine Main Dam (proposed risks) = 5.36×10^{-7} DALYs/person/year
– South Dandalup Dam (proposed risks) = 2.09×10^{-6} DALYs/person/year
– Serpentine Pipehead Dam (proposed risks) = 1.53×10^{-5} DALYs/person/year
– All dams (proposed risks) = 1.80×10^{-5} DALYs/person/year

The risks from the proposed South Dandalup and Serpentine Pipehead Dam combined hazards do not meet the $1x10^{-6}$ DALYs/person/year threshold. The assumptions for this risk assessment are conservative but are reasonable given the water is used downstream for drinking water supply to Perth.

It is emphasized that this conclusion is reached when no mitigation factors have been applied. The calculated values for the individual hazards are summarised in Table 7.8.

8. Turbidity assessment

8.1 Background

Turbidity is a key water quality concern for the described catchment. While not hazardous in itself, turbidity is able to reduce the efficacy of treatment processes able to inactivate or remove pathogens. The existing water treatment for water supplied from the catchment is limited to chlorination, and does not include a mechanism to reduce turbidity concentration in the raw water supplied to the WTP.

The ADWG notes that high turbidity has been shown to shield microorganisms from the action of disinfectants. If the turbidity of a water supply exceeds 1 NTU, adequate disinfection may be more difficult to maintain, but may still be achievable. Where the water has not been previously filtered, it is desirable that turbidity be <1 NTU at the time of disinfection, dependant upon the disinfection processes being used. For chlorine-only treatment, the effectiveness of disinfection may be affected at turbidities greater than 1 NTU. Generally, the lower the turbidity of the water at the time of chlorination the more effective chlorination will be, and validation work should be undertaken to demonstrate that disinfection of water under higher turbidity conditions is effective (ADWG turbidity fact sheet, 2018).

In addition to current disinfection efficacy, there are other relevant considerations about elevated turbidity in the catchment waters:

– Should additional further treatment at the WTP be introduced in the future for risk management purposes, the most cost effective measures (UV disinfection) require consistently low turbidity in source waters for assured disinfection efficacy.
– Maintaining the turbidity of water at customer taps of <5 NTU, as per ADWG guidelines.
– The potential impacts of turbidity within the catchment areas.

8.2 Turbidity and disinfection

The regulatory requirement for source waters turbidities to be <1 NTU may have originated with US regulations dating from the 1960s. Hoff (1979) questioned the utility of turbidity as an indicator of disinfectability in US regulations, due to the lack of specificity in determining the nature of the particles in generating turbidity. This was drawn from experimental work showing that clay and aluminium phosphate-based turbidity resulted in negligible or relatively minor interference with disinfection efficiency. Alternative parameters for the measurement of interference with disinfection were recommended for future consideration, including total organic carbon or nitrogen assays to determine whether solids were of organic or inorganic origin, and the determination of chlorine demand in source waters.

Other studies where the impacts from turbidity have been examined have also described other parameters that are of greater accuracy in predicting loss of efficiency. For example, turbidity effects on coliform detection and chlorination were examined by LeChevallier et al (1981). These authors found that disinfection was negatively correlated with turbidity, and was linked to the total organic carbon that was associated with the turbidity creating a chlorine demand. The effect of reduced disinfection was measured via the masking of membrane filtered coliform counts, concluding that the magnitude of masking increased from <1 coliform/100 mL in waters of <5 NTU, compared to >1 coliform/100 mL in waters of >5 NTU.

Keegan et al (2012) have reviewed the effects of turbidity and particulates on the disinfection of different pathogen groups. Particles may be organic or inorganic, with some particles being colloids. Colloidal particles comprise a large proportion of turbidity-causing substances in water. The size, type and concentration of particles can profoundly affect turbidity. Larger particles such as clays scatter light efficiently and yield higher turbidities than equivalent concentrations of substances such as humic acids. The presence of turbidity and particles is assumed to have an effect on disinfection, although it has been demonstrated that compounds such as clays, humic acids and fulvic acids have no effect on disinfection. Particulate matter may interfere with disinfection resulting in a tailing effect on an inactivation curve, whether by acting chemically to create a disinfectant demand, or by

physically shielding an organism from the disinfectant. It is also thought that smaller organisms such as viruses may gain greater protection than larger organisms at lower turbidity conditions and from smaller particles.

Experimentation by Keegan et al (2012) on disinfecting the highly chlorine-resistant virus CB5 in recycled waters with chlorine and chloramine examined waters with adjusted turbidities, through the addition of turbidity isolated from wastewater. These authors found that small increases in turbidity (0.2 to 5 NTU) demonstrated only slightly increased Ct values for virus disinfection. However, high turbidity (20 NTU) waters resulted in an increase of >2-fold to Ct. This study demonstrated that higher turbidity waters can be effectively disinfected for viruses with chlorine, but require higher chlorine Cts to factor in the chlorine demand from wastewater particulates. A Ct value is the product of the concentration of a disinfectant and the contact time with the water being disinfected. The particles causing turbidity were predominantly 3 µm in size and organic in origin. Lower turbidities, including 0.2 and 2 NTU, showed no significant difference in Cts. Viruses were still able to be disinfected in higher turbidity waters, examined up to 20 NTU, when longer contact times were used.

Where source waters are outside of the tested range for disinfection parameters such as turbidity, a challenge test can be undertaken to determine a specific log inactivation for the tested conditions. As an example of disinfection validation, a range of chlorination conditions were able to be defined by Canning et al (2015) in order to tailor and optimise virus disinfection in southeast Queensland source waters, using the Keegan et al (2012) values for the highly chlorine-resistant CB5 virus.

8.3 Turbidity modelling

An examination of turbidity in the catchment waters has been performed in GHD (2021) (Appendix F), using hydrologic and turbidity inputs presented in Appendix E. This has included the modelling of suspended solids inputs to the reservoirs, in the form of 1 µm diameter inorganic particles (clay) and 5 µm diameter inorganic particles (silt). The proportion of these particles in the modelled inputs was allocated to simulate natural waterways for un-mined catchment areas, and to simulate mining sumps for inputs from mined catchment areas.

The introduction of particles was modelled as a range of scenarios using combinations of the following variables:

– Catchment clearing associated with the baseline (pre-mining), existing mining, and proposed mining;
– Summer and Winter reservoir conditions;
– Storm intensity (1 Exceedance per Year (EY), 1 per cent Annual Exceedance Probability (AEP), and 10 per cent AEP);
– Drainage failure rates (5 per cent, 30 per cent and 75 per cent corresponding to 1 EY, 10 per cent and 1 per cent AEP storms)
– SS runoff concentrations of both mined (12.6 and 15.8 mg/L of SS_{Clay} and SS_{Silt}, respectively) and unmined (25.2 mg/L and 31.5 mg/L of SS_{Clay} and SS_{Silt}, respectively) catchments.

All turbidity scenarios are described in Appendix G. Whilst turbidity risk at the drinking water catchment scale is of primary concern to this report, turbidity risk at other scales has been assessed, and is presented in Appendix H.

8.4 Scenario results

The 1 EY events consistently had no impact on offtake SS concentrations. The predicted effects of large inflow events and associated drainage failures on the SS in the reservoirs and withdrawals include:

– Increases to SS_{silt} in all reservoirs and for all scenarios were short duration due to the relatively rapid settling as described beforehand for the verification simulations. Most SS variations were due to SS_{Clay}.
– For SMD with moderate drainage failure SS levels, minimal changes were predicted in the SS at the dam and withdrawals between the baseline, existing and proposed scenarios for either the winter or summer 10 per cent AEP inflow events. SS increases of up to ~0.5 mg/L and ~0.2-0.3 mg/L were simulated with the moderate drainage failure SS levels for the summer and winter 1 per cent AEP inflow events, respectively. With high drainage failure SS levels, minimal variations were again predicted for the 10 per cent AEP winter and summer events. SS increases of up to ~1 mg/L and ~0.3-0.4 mg/L were simulated with the high sump failure SS levels for the summer and winter 1 per cent AEP events, respectively.

– For SDD, material differences in SS at the dam wall and withdrawals were not predicted for the 1 per cent and 10 per cent AEP summer and winter inflow events between the baseline and proposed scenarios (note no existing mining scenario for SDD) for both moderate and high drainage failure SS levels. The relatively small proportion of the SDD catchment that is proposed to undergo mining activity does not generate sufficient additional SS loads over the baseline (no mining) scenario to cause a substantive increase.
– As with SDD, material differences in the 1 per cent and 10 per cent AEP summer and winter inflow events between the baseline and proposed SPD scenarios (note no existing mining scenario for SDD) for moderate and high drainage failure SS levels are not predicted. The hydrodynamic barrier effect induced by the SPD primary inflow and outflow in proximity to the dam wall increases the duration of particle settling in the up-reservoir volume prior to transport to the dam wall. Further, the high external transfers with low SS concentrations also dilutes the elevated catchment-derived SS_{clay} levels as they are transported to the dam wall after inflow loading events.

In summary;

– Serpentine Main Dam turbidity concentrations are sensitive to changes in sump failure suspended solids concentrations, as mining comprises a sufficient proportion of the catchment landscape to do so.
– In contrast, South Dandalup Dam is not sensitive to sump failure suspended solids concentrations, as the future mining area is a small proportion of the overall catchment area. There are no ‘existing mining’ scenarios for South Dandalup, as there is no current mining in the catchment, and areas mined in previous decades are assumed to be fully rehabilitated.

9. Fire risk assessment

9.1 Bushfire impacts to reservoir water quality

The impact of bushfires on reservoir water quality has been reviewed by several Australian authors (Smith et al 2011a, Smith et al 2011b, Canning et al 2020, Kahn 2020), with key findings as follows:

– bushfire intensity is a key determinant of water quality impacts
– high intensity fires lead to deposited inorganic ash, nutrients and metals
– high intensity fires can result in loss of riparian vegetation and stream bank stability, leading to gullies and mass erosion
– low intensity fires lead to increased leaf litter, organic ash and dissolved organic carbon (DOC)
– major water quality impacts from wildfires typically occur during subsequent heavy rainfall events, with runoff carrying large quantities of sediment, ash and nutrients in particulate and soluble form
– suspended sediments from burnt catchments form composite particles (flocs or aggregates) with higher potential for bound contaminants but significantly higher settling velocities, attributed to the effects of soil heating
– ash layers from a severe fire may be 2-10 cm thick and low in density, being readily eroded with rainfall and entrained with overland flow
– elevated DOC and/or nitrogen in reservoir water quality following a fire has potential to result in generation of disinfection by-products, such as trihalomethanes, haloacetic acids, haloacetonitriles and halonitromethanes.

Smith et al (2011a) summarised reported contaminant loads from catchments in the first year following fire, as follows:

– suspended sediment loads from 0.017 to 50 t/ha/yr, representing an increase of one to three orders of magnitude from un-burnt catchments
– suspended sediment concentrations from 11 mg/L to about 500,000 mg/L, the highest being during flash floods in a semi-arid ephemeral stream
– total nitrogen loads from 1.1-27 kg/ha/yr and total phosphorus loads from 0.03-3.2 kg/ha/yr, representing an increase of one to two orders of magnitude from un-burnt catchments

The sediment loads reported by Smith et al (2011a) correlate with estimates by Blake et al (2020) for the Northern Jarrah Forest impacted by the 2016 Waroona-Yarloop wildfire. Blake et al (2020) used the Revised Universal Soil Loss Equation (RUSLE) to estimate erosion risk, which indicated an approximate ten-fold increase in erosion risk from in the order of 0.01-0.1 t/ha/yr before the fire to in the order of 0.1-1 t/ha/yr following the fire. Erosion risk was estimated to increase by two orders of magnitude over localised areas, to in the order of 1-10 t/ha/yr, with hot spots identified in forested headwaters associated with steep terrain and high fire intensity.

Khan (2020) reported that during the 2019/2020 bushfires in NSW, most significant water quality impacts were avoided due to a combination of:

– very large reservoirs, providing time for sedimentation prior to water reaching offtakes
– in some cases, use of floating silt curtains to contain stratified water layers, providing additional opportunity for sedimentation
– adjustment of offtakes to target the best water quality and avoid the worst water quality
– some systems were able to draw on multiple sources to select those that were un-impacted
– use of off-river storages where available, drawing from rivers when quality is satisfactory.

Khan (2020) notes that not all water supply systems have these attributes and thus the capacity to manage water quality impacts from bushfire impacted catchments. An example was Brogo Dam in Bega Valley, which has a capacity of 9 GL and catchment of approximately 400 km^2. The catchment was substantially burnt in January 2020 then received 150 mm of rainfall, which resulted in turbidity at the offtake peaking at 600 NTU then remaining above 20 NTU for a number of weeks. Consequently, the Bega Valley Shire Council was required to truck water to

towns and the Australian Defence Force set up a mobile water treatment plant to filter some of the water from the dam.

9.2 Bushfire impacts to reservoirs in the Northern Jarrah forest

The water quality impacts to reservoirs has been demonstrated through two recent fires in the Northern Jarrah Forest, both of which were wildfires that affected large areas catchment:

– 2005 Perth Hills bushfire
– 2016 Waroona-Yarloop bushfire

The 2005 Perth Hills bushfire burnt approximately 27,000 ha of drinking water catchments, predominantly that of Mundaring Weir. The bushfire covering approximately 19 per cent of the catchment of Mundaring Weir, which had a water volume of approximately 27 GL at the time. Turbidity in the catchment streams increased with ranges from 5 NTU to more than 1000 NTU. A turbid plume was observed within the upper end of Mundaring reservoir (Battini and Barrett 2007), with turbidity peaks of up to 37 NTU, attenuating towards the dam wall (Battin and Barrett 2007, WSAA 2020). Water Corporation undertook flocculant dosing in the Darkin River over June to October 2005 to reduce turbidity levels. The flocculant dosing reduced turbidity in the reservoir, enabling Mundaring Weir to be kept online, however there was an increase in soluble aluminium which indicated limitations to ongoing dosing. Large volumes of floating ash were deposited in the reservoir and accumulated at the dam wall under certain wind conditions, requiring removal on three occasions during 2005 (WSAA 2020).

The 2016 Waroona-Yarloop bushfire burnt over 69,000 ha of land, including more than 90 per cent of the catchment of Samson Brook Dam and Samson Brook Pipehead Dam (DWER 2019). The Samson Brook Dam had a water level of less than 1 GL at the time. The fire resulted in elevated levels of turbidity, pathogens and other contaminants, resulting in the Water Corporation keeping the dams offline for over a year (DWER 2019).

The evidence reviewed by Australian authors and the impact of 2005 Perth Hills and 2016 Waroona-Yarloop fires suggest that the Serpentine Main Dam, South Dandalup Dam and Wungong Dam reservoirs may be susceptible to water quality impacts from bushfires. Such an event may include a high intensity wildfire that covers a large proportion of a catchment, occurs over steep terrain and in the year prior to heavy rainfall events.

In the event of a major wildfire and heavy rainfall sequence within a catchment, there is potential for substantial ash deposition, runoff and soil erosion that would occur outside of and/or bypass mine sediment barriers, which would be limited to the portion of catchment subject to mining. Major wildfires can occur over tens of thousands of hectares in a single event, an area which is an order of magnitude greater than the area of mine pits open at any time or under early rehabilitation establishment. Accordingly, major wildfires may impact a much larger extent of land and not be subject to sediment barriers compared to mining and rehabilitation. Soil erosion from wildfire impacted areas under heavy rainfall is expected to be highest in areas of high slope. Steep landforms occur in portions of the Serpentine Main Dam and Pipehead Dam PDWSAs associated with incised valleys of the Serpentine River and hills in the vicinity of Mount Solus. Steep landforms also occur to a lesser extent within the South Dandalup Dam and Wungong Brook PDWSAs associated with valleys of the South Dandalup River and Upper Wungong Brook.

A major wildfire and heavy rainfall sequence may therefore result in widespread ash deposition, runoff and erosion that generate substantial discharges of ash and sediment into the catchment's reservoir. Depending on the severity and location of fire and rainfall, there is potential for the scale of discharges to exceed the attenuating capacity of the reservoir and cause elevated contaminant levels at the offtake that exceed drinking water quality criteria.

9.3 Potential for future wildfires within the Northern Jarrah forest

There remains the potential for major wildfire events to occur throughout the Northern Jarrah Forest, irrespective of the Proposal. Previously, such events have included the 2003 Mount Cooke, 2005 Perth Hills and 2015 Boddington (Lower Hotham) fires which occurred away from bauxite mining and rehabilitation. The increased

prevalence of wildfires over the past two decades is expected to have been in part due to a reduction in prescribed burning since the 1990s. The reduction in prescribed burning was due to a variety of reasons independent of bauxite mining and rehabilitation, including (CALM 1994, Burrows et al 2015):

– climate variability (e.g. increasing frequency of high fire risk days in which burning cannot be scheduled)
– land use changes and population growth (e.g. urban and rural air quality constraints, landowner objections)
– resource constraints.

Climate change is expected to extend the period at which vegetation is flammable, increasing the frequency and scale of forest fires in the Jarrah Forest, though drying may also reduce the rate of fuel accumulation (Burrows and Wardell-Johnson 2003). Analysis undertaken for south-east Australia, which is predicted to undergo similar drying and warming as is forecast for the South-West region, suggests a potential for increased cumulative forest fire danger index and increased number of high and very high fire risk days (Maher et al 2010). Accordingly, there is potential for the frequency of wildfires to increase in the future.

9.4 Potential for mining and rehabilitation to increase frequency or severity of wildfires

Alcoa engagement with the Water Corporation and DWER raised a number of concerns regarding the potential for mining and/or rehabilitation to affect the fire regime of the Northern Jarrah Forest and increase the risk to drinking water quality. The concerns included the following:

– fire behaviour interactions are by their nature complex and need to be investigated further to better establish risk profiles and nature and extent of uncertainty
  - established stream zone buffers may act as fire 'wicks' given they are largely not subject to fire controls and may over time become high fire fuel load areas
  - increased leaf area index (LAI) associated with rehabilitation on steep slopes may result in significant changes to fire behaviour
  - removal of the upper regolith may interact to result in significant post fire erosion / turbidity risk profile
  - interactions between climate change, area of impact, time since rehabilitation, land slope and changes to groundwater levels may result in significant changes to fire risk and fire behaviour in the future.

The effects of bauxite mining on soils and potential long term erosion are addressed in Section 10.

9.4.1 Increased leaf area index and fuel load with rehabilitation

Macfarlane et al (2017) report the leaf area index (LAI) in five un-mined catchments of Jarrah forest as ranging from approximately 1 to 2.2, with variation due to the stage of regrowth from timber harvesting and fire, and the effects of *Phytophthora* Dieback. Bradshaw (2015) reports the LAI of un-mined Jarrah forest as ranging from 1.6-2 when fully stocked. Fuel loads in un-mined Jarrah forest vary in accordance with the time since last fire. Burrows (1996) reports that fuel loads in upland Northern Jarrah Forest rise to approximately 20 t/ha at ten years from fire and thereafter vary from about 20 t/ha to 25 t/ha, with the majority of fuel load (about 15 t/ha) from accumulated litter and the remainder from scrub, trash and bark (Burrows 1996). The State Government has set a target of limiting litter fuel accumulation to 8 t/ha in the Jarrah forest, the threshold at which firefighting becomes problematic and damage occurs to young trees and crowns (CALM 1994, Burrows 1996). This target typically requires a fire interval of 5-7 years (CALM 1994). Climate change may result in a slower accumulation of fuel to previous recorded rates due to reduced rainfall, soil moisture and vegetation growth.

Fuel load accumulation may be greater in lowland Jarrah forest such as valley floors, stream zones and swamps that have higher soil moisture and more dense vegetation. In the past the higher soil moisture and live vegetation may have retarded the spread of fires through lowland areas. However, there has been a sustained decline in rainfall over the Northern Jarrah Forest since the 1970s and a consequent decline in groundwater levels in the regolith and disconnection of stream zones from the groundwater table. The drying out of stream zones and swamps due to climate change may result in the dense vegetation of streams and swamps becoming more fire prone.

The effects of bauxite mine rehabilitation on LAI and fuel loads have been reviewed by Grant et al (1998), Smith et al (2004), Daws and Koch (2015) and Macfarlane et al (2017).

Daws and Koch (2015) report LAI in rehabilitation as rising to approximately 2 after eight years and thereafter ranging from approximately 2-2.5. Macfarlane et al (2017) report LAI from mined catchments as rising to approximately 2-2.5. The reported LAI from these studies is for past rehabilitation prescriptions that included establishment targets of 3000 tree stems/ha in the 1990s. The past rehabilitation prescriptions were developed in agreement with Government and reflected the standards for timber production and knowledge of tree survival at the time. Since then the density of trees has been deliberately reduced and the current rehabilitation prescription, adopted since 2016, has an establishment target of 1000 stems/ha.

Figure 9.1 presents estimated data for the variation in LAI for the current rehabilitation prescription (Grigg, pers. comm.). As presented, the LAI of newly established rehabilitation is expected to reach approximately 2 after two decades from establishment, which is comparable to the range of LAI for un-mined Jarrah forest. Understorey LAI is expected to peak at about eight years and thereafter decline as the understorey senesces, with the canopy dominating the LAI after about 15 years.

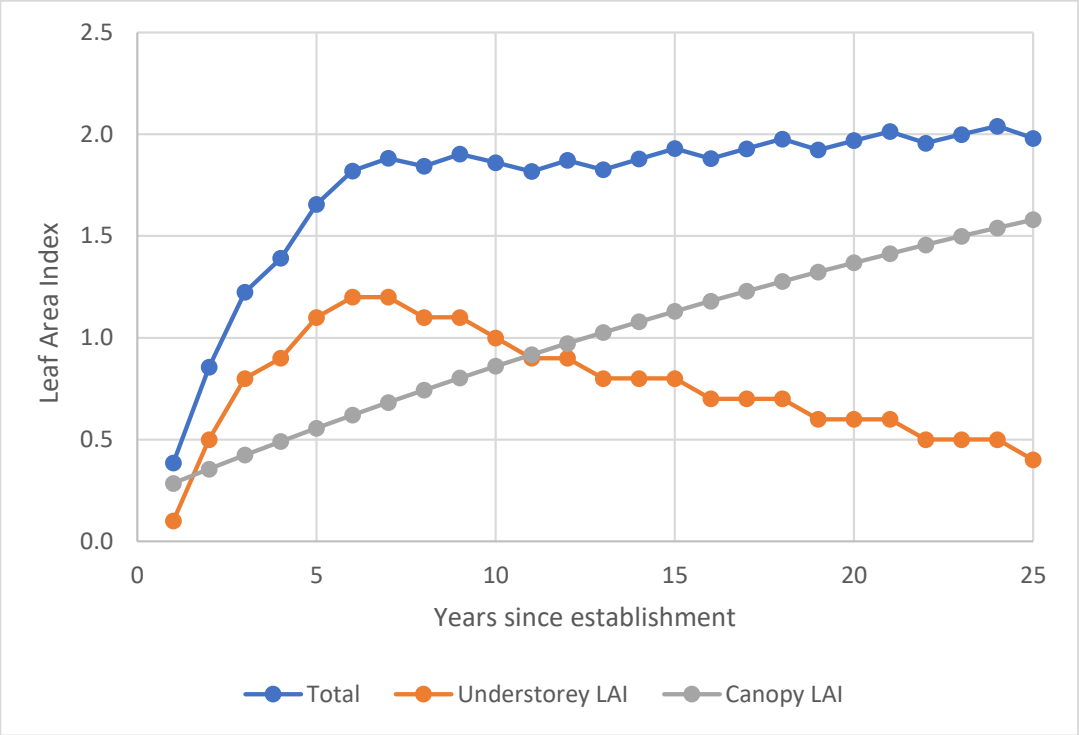


Figure 9.1 Estimated leaf area index of current rehabilitation prescriptions

Grant et al (1998) note that rehabilitation in the 1980s and 1990s seeded the understorey with legumes (e.g. Acacias) to prevent erosion and fix nitrogen. The legume species grew rapidly however they were short lived species and senescence led to accumulated fuel loads of 16-62 t/ha at 10 to 20 years from establishment. The accumulation of fuel in dead understorey/trash differs from that of un-mined Jarrah forest, in which fuel predominantly accumulates in the litter layer. Smith et al (2004) reported fuel loads ranging from 2.2-60.8 t/ha in rehabilitation, with an average of 15.0 t/ha at five years and 29.8 t/ha at eight years from establishment. Prescribed burns in the five year rehabilitation were of low intensity (< 250 kW/m) and in eight year rehabilitation were of very high intensity (> 7000 kW/m) (Smith et al 2004). The lower intensity at five years was due to lower fuel loads and a greater proportion of live plants which inhibited burns. While the fuel accumulation exceeds that of un-mined forest, Grant et al (1998) notes that fuel loads are highly variable and patchy.

Current rehabilitation prescriptions have reduced the seeding of legume species and application of fertiliser, which reduces the dominance of legume species and encourages greater floristic diversity (Daws et al 2013, Daws et al 2021). Current rehabilitation prescriptions are expected to result in less vigorous understorey development and a lower fuel accumulation in the shrub/trash layer compared to the measurements by Grant et al (1998) and Smith et al (2004).

9.4.2 Fire management in mining regions

Alcoa collaborates with DBCA in planning an annual prescribed burn program, and funds the DBCA burns conducted within and surrounding mining and rehabilitation areas. Prescribed burns are conducted by a combination of aerial and ground methods and occur adjacent to mining operations and infrastructure. Mining operations temporarily cease in the vicinity of burns during and for a period after prescribed burns, for safety reasons (i.e. heat, smoke, falling dead trees). Following DBCA inspection and clearance of burnt areas, mining operations recommence. Alcoa has operated in the Northern Jarrah Forest for over fifty years and has mature experience in managing operations during prescribed burning and collaborating with DBCA to plan prescribed burns around mine operations and infrastructure.

Alcoa's operations and infrastructure are less sensitive to smoke impacts compared to urban and rural land uses, which are a key constraint to DBCA's prescribed burn operations in the Northern Jarrah Forest. For example, Alcoa can temporarily suspend or relocate operations away from impacted areas, whereas urban and rural land uses are relatively fixed. Mine infrastructure and equipment are relatively resilient to smoke impacts compared to domestic properties, agricultural crops and stock animals. Accordingly, the Huntly Mine operations are able to accommodate smoke impacts from prescribed burns that would otherwise result in prescribed burns being delayed or cancelled due to public health risks or neighbouring landowner disputes. This provides more flexibility to DBCA in conducting prescribed burns within mining regions, subject to constraints posed by urban or rural land uses in the vicinity.

The integration of rehabilitation areas into forest prescribed burns utilises a fire risk matrix based on fuel ages in rehabilitated areas and adjacent unmined forest. Rehabilitation up to approximately six years of age has relatively low fuels with a discontinuous litter layer which provides opportunities to conduct prescribed burning in the surrounding un-mined forest. Rehabilitation from approximately six to 15 years requires fire exclusion to protect the crowns of young canopy tree saplings, which have not yet separated from the shrub layer. From approximately 15 years onwards, rehabilitation tends to form a two-tiered fuel structure, trees have developed a thick bark layer that provides greater protection and prescribed burning can be reintroduced within the rehabilitation and surrounding un-mined forest (Grant et al 1998, Grant et al 2007).

Though past rehabilitation prescriptions have generated high yet patchy fuel accumulation in the understorey, past prescribed burns conducted within mining regions have successfully reduced fuel levels and have not resulted in wildfires spreading outside of mining regions. This is in part due to the varying fuel loads in rehabilitation that occupy relatively small areas of the landscape and are interspersed by fire breaks created by open mine pits, mine infrastructure and the negligible fuel loads of newly established rehabilitation. Fire behaviour in prescribed burns is substantially affected by the fuel loads in the surrounding un-mined forest, which form the majority of the landscape.

Alcoa rehabilitation prescriptions require the reinstatement of forest access tracks and roads to DBCA approval, which enable forest management including prescribed burns and fire response activities. Alcoa's mine road network and the re-instated forest access tracks enable prescribed burn operations to be conducted within mine regions during mining and rehabilitation stages. During emergency fire events, Alcoa's mine road network and mine facilities can be used to provide access and emergency response management.

It is expected that the transition of mining into the Myara North and Holyoake regions will continue to enable DBCA's prescribed burning program to be effectively planned, funded and implemented, as has been demonstrated within the Huntly Mine to date. Accordingly, the Proposal is expected to maintain and support the State Government's program to limit fuel accumulation in the Northern Jarrah Forest, thereby reducing the likelihood of large wildfires occurring in the PDWSAs that lie within the mine regions.

10. Long term rehabilitation and erosion risks assessment

10.1 Effects of mining on Jarrah forest soils

Superficial soils on the Darling Plateau comprise a thin veneer of topsoil (typically less than 0.1 m thick), which contains sand, silt and the majority of the seedbank, over a sandy gravel overburden layer (Hickman et al 1992). The overburden ranges from about 0.2-4 m thick and averages about 0.5 m. The overburden is underlain by lateritic bauxite, which is approximately 4-6 m thick and comprises a caprock (duricrust) layer and underlying friable fragmental layer. The caprock layer is discontinuous and varies from absent to a thickness of a few metres. The friable fragmental layer contains nodules, pisoliths and weathered rock fragments in fine-grained, loose earths or sands. The friable fragmental layer is generally about 2 m thick but can be up to 10 m thick on the Darling Plateau (Hickman et al 1992). Beneath the bauxite layers lies mottled, pallid and saprolite clay layers that are typically 20-30 m thick, which transition into weathered saprock and then fresh bedrock (Hickman et al 1992).

The mine development stage involves stripping and stockpiling the superficial soils and blasting or ripping the caprock layer. Mining then involves removing the bauxite caprock and friable fragmental layers, which are transported to stockpiles, then crushed and conveyed to Pinjarra Alumina Refinery.

The mine floor remaining after mining contains a diverse range of lateritic regolith materials from the lower mottled, pallid clay and saprolite layers, which mostly comprise sandy loams and clays (Mengler et al 2005). In areas where the regolith is thin and has been mostly removed by mining, the mine floor may contain partly weathered material that retains the texture of the original bedrock. Other areas of the regolith have existing root channels, adequate structure and stable aggregates that support root exploration and plant re-establishment. The majority of pit floors require ripping to create macrostructure and alleviate high strength and high bulk density (Mengler et al 2005). Soils derived from dolerite bedrock tend to be more clay rich and have more pedal structure, whereas soils derived from granite typically contain macropores (Raper and Croton 1996).

Following the completion of mining, rehabilitation is undertaken including pre-ripping of compacted floors to at least 1.2 m, landscaping batters, spreading overburden and topsoil (typically 300 mm combined depth), then contour ripping to create a furrowed surface.

The net effect of bauxite mining of Jarrah forest soils is the removal of an approximately 4-6 m thick layer of caprock and friable fragmental material, and replacement of the seed rich topsoil and overburden over a ripped, friable substrate of sandy loams and clays. The total depth of friable material created is about 1.5 m, including topsoil, overburden and ripped substrate.

10.2 Vegetation use of Jarrah forest soils

The LAI of Jarrah forest vegetation is dominated by the predominant canopy tree Jarrah (*Eucalyptus marginata*), which comprises about 60 to 80 per cent of the LAI depending on the presence of other trees (Crombie 1992). Shallow rooted vegetation (i.e. small shrubs and groundcovers with roots confined to shallow soils above the caprock) is estimated to comprise less than 10 per cent of LAI and medium rooted vegetation (i.e. larger shrubs with roots that penetrate the caprock but not far into the underlying clays) approximately 10 per cent of LAI (Crombie 1992).

Jarrah has a dimorphic root system, comprising dense lateral roots in the topsoil and overburden above the caprock, from which ‘sinker’ roots extend vertically to penetrate cracks and fissures in the caprock and gain access to moisture bearing clay through ancient root channels (Dell et al 1983, Farrington et al 1996). Dell et al (1983) suggest that each tree may access 100-200 ancient root channels of up to 40 m from the surface. The root channels are permanent features of the profile and occupied by successive generations of trees (Dell et al 1983).

Carbon et al (1980) report that the bulk of Jarrah roots are in shallow soils (topsoil and overburden) above the caprock, which has the greatest potential to supply water in winter but dries over the summer and autumn. Measurements by Carbon et al (1980) indicate that the shallow soils have root density (root depth per area of

ground surface) about an order of magnitude greater than the deeper sandy loam and clay layers. While trees have deeper roots, substantial groundwater use is limited to shallower depths, being recorded in Jarrah forest at sites with depths of 6 metres below ground level (mbgl) but not at 14 mbgl or 30 mbgl (Farrington et al 1996). Deeper rooted vegetation such as Jarrah and large shrubs can maintain higher photosynthetic activity into summer and autumn compared to shallow rooted vegetation (Crombie 1992). However, both deep and shallow rooted vegetation exhibit daily cycling of water potentials and stomatal conductance and a rapid response following rainfall during summer (Crombie 1992). This suggests that Jarrah forest vegetation remains physiologically active during summer and is tolerant of low water potentials, which would be necessary to enable deeper rooted vegetation to use water held in clayey subsoils (Crombie 1992).

The establishment of a 1.5 m thick friable layer of topsoil, overburden and ripped substrate provides a comparable, though generally thicker, stratum than the topsoil and overburden present above the caprock prior to mining. The friable layer enables development of a dense root structure of Jarrah forest vegetation as occurs in the topsoil and overburden present prior to mining. Deeper rooted vegetation establishing within the friable layer is expected to re-colonise ancient root channels present in the underlying regolith materials, as have been used by successive generations of trees prior to mining (Dell et al 1983). There is expected to be a partial loss of soil water capacity due to the removal of the bauxite friable fragmental layer, which comprised about 2 m of loamy soils that previously were accessed by deep and medium rooted vegetation. Loss of this layer represents approximately 10 per cent of the regolith thickness, however the loamy layer may have had a higher plant available water than that of the underlying mottled and pallid clays. Loss of the bauxite caprock layer is not expected to substantially reduce the soil water capacity, as the layer was primarily cemented material that provided discrete pathways for water and roots to enter the underlying un-cemented layers.

Loss of the bauxite friable fragmental layer has not been observed to result in impaired growth or health of rehabilitation. Monitoring of rehabilitation has demonstrated the successful establishment and persistence of an LAI of 2-2.5, comparable to that of un-mined Jarrah forest. Monitoring has also indicated a floristic diversity of about 80 to 100 per cent of un-mined forest, declining weed cover and sustained understorey coverage. During the 2010/11 drought and heat waves, Jarrah forest canopy die-off was observed at sites across the Northern Jarrah Forest, including un-mined forest and some areas of rehabilitation. Widespread die-off of rehabilitation did not occur nor was rehabilitation affected in greater proportion than un-mined forest. Browers et al (2012) report that canopy dieback was more frequent on:

– rocky soils with low water holding capacity
– sites that were close to rock outcrops
– areas that received a slightly higher amount of annual rainfall compared to the surrounding landscape
– sites at high elevations or on steep slopes
– in areas that were generally slightly warmer than their surroundings.

The results of monitoring collectively demonstrate that Alcoa's rehabilitation establishes and persists, including during drought and heat wave events, indicating that the 1.5 m thick friable substrate over regolith containing ancient root channels is an effective growth medium.

10.3 Erodibility of mine rehabilitation

Mengler et al (2006b) surveyed topsoil and overburden samples in rehabilitated mine pits at the Huntly Mine. The survey indicated predominantly sandy gravel texture, comprising an average of 60 per cent gravel (>2 mm diameter, range 38-78 per cent), 38 per cent sand (2-0.02 mm diameter, range 24-65 per cent) and 3 per cent silt and clay (<0.02mm diameters, range 0-6 per cent) for Huntly Mine. Due to the predominant sandy gravel texture, the soils had calculated low erodibility coefficients (RUSLE equation K factors) averaging 0.009 (range 0.000-0.019).

The skeletal topsoil and overburden materials are distinct to most agricultural soils and mining waste due to the low combined clay and silt contents and very high gravel contents, which develop with time a protective surface layer of gravel covering 70-80 per cent of the land surface. The high porosity and coarse texture also enable rapid infiltration of rainfall within the topsoil, overburden and ripped regolith material. However, thinly applied topsoil and overburden can be mixed with finer grained pit floor materials during contour ripping, which can introduce more erodible (and potential dispersive) clayey material into the shallow subsurface surface. The regolith beneath the

ripped zone typically comprises low permeability saprolite clays, therefore rainfall infiltration is limited to the water storage in the overburden and ripped zoned, accordingly surface runoff occurs following extended rainfall periods that fill up the permeable materials.

Gullies form in the rehabilitated landform through an erosion sequence (Mengler et al 2006). The fine grained content is displaced from the coarser topsoil/overburden, depositing within the furrows and filling their volume such that surface water overflows and erodes through the fine grained materials in downslope furrows. The gully that is initially created in the fine grained materials concentrates flow and creates knickpoints that enable erosion of the coarser topsoil/overburden and underlying ripped regolith materials.

Analysis of gully erosion at the Huntly, Willowdale and Boddington bauxite mines suggested a minimum catchment of 0.3 ha for gully development, with gully volumes typically remaining small (20-100 m3) but potentially increasing for higher slopes (> 10°) and shallower topsoil/overburden placement (< 200 mm). Erosion was highest in the first two to three years following rehabilitation completion until rehabilitation establishes, though there was a lack of long term data with which to compare the erodibility of rehabilitation to that of un-mined Jarrah forest (Mengler et al 2006). For the period at higher risk of erosion, the major triggers for gully erosion were identified as:

– directing excessive off-site runoff into the rehabilitation
– poor surface completion (e.g. ripping that does not adhere to contours) that concentrates flow or impairs infiltration
– insufficient depth of returned topsoil and overburden (< 200 mm combined)

11. Major diesel spill assessment

11.1 Potential for diesel exposure

GHD (2021) examined the effect of mining activity-related cryptosporidium and diesel spill incidents in the catchments. This included simulated diesel spill incidents, with the assumption that a 15 m^3 tanker load was directly discharged into a stream at a haul road crossing. The modelled processes leading to decreased diesel concentrations were river dilution, reservoir mixing and dispersion, and withdrawals from the dams. These were simulated to occur in three catchments of Serpentine Main Dam and South Dandalup Dam catchments, and both of the two Pipehead Dam catchments, with existing (Serpentine Main Dam, South Dandalup Dam) and proposed (Serpentine Main Dam, South Dandalup Dam) mining scenarios. No losses due to volatilisation, degradation, adsorption and settling were included in the simulation, so the modelled outputs are regarded as conservative.

The simulation results included the following:

– Serpentine Main Dam - predicted peak diesel concentrations of up to 1 µg/L, with all levels below 0.2 µg/L within 6-7 months of the spill.
– South Dandalup Dam - predicted peak diesel concentrations of up to 1 µg/L, with all levels below 0.4 µg/L within 6-7 months of the spill.
– Pipehead Dam catchment 24 (mid reservoir) - predicted peak diesel concentrations of up to 5 µg/L, and levels were predicted to fall to ~0 µg/L within ~10-12 months of the spill, because of SPD's relatively small volume and high outflow.
– Pipehead Dam catchment 23 (upper reservoir) - predicted peak diesel concentrations in withdrawals of up to 1.5 µg/L, and levels were predicted to fall to ~0 µg/L within ~10-12 months of the spill.

It is recommended that some monitoring of the concentrations of diesel and other hydrocarbons is performed prior to the proposed mining transition, so as to establish baseline concentrations in the storages. Such monitoring will support the assumptions of background concentrations used in the simulation.

11.2 Interpretation of diesel exposure

Diesel itself is a complex mixture of chemicals, primarily hydrocarbons, which can separate and behave uniquely in the environment. Although there are numerous contaminants in diesel fuel, it is practical to consider a selection as part of this assessment. This selection focuses on the most prevalent light fraction component (benzene) and the most prevalent heavy fraction component (xylene) with guideline values recommended in the ADWG.

The ADWG recommends a health based guideline limit for benzene of 1 µg/L, consistent with WHO guidance for this parameter. Additionally, health based limit for xylenes of 600 µg/L and an aesthetic based limit of 20 µg/L are included in the ADWG.

Heath et al (1993) and Friebl and Nadebaum (2010) describe the component characteristics of diesel fuel. Benzene constitutes 0.5 per cent of the mass of fuel diesel, and xylene 0.03 per cent.

From the diesel spill incident modelling, the largest predicted peak diesel concentration was up to 5 µg/L. With <1 per cent of diesel constituted by benzene and xylene, the ADWG health-based limits for these parameters are not exceeded for the modelled incidents. The xylene aesthetic limit of 20 µg/L is also not exceeded.

The ADWG notes that diesel contamination in drinking water has a taste and odour threshold of 5 µg/L. This could be reached with the largest predicted peak diesel concentration of up to 5 µg/L.

12. PFAS and minor discharges of hazardous materials

12.1 PFAS

Alcoa have committed to using PFAS-free firefighting foams for the Myara North and Holyoake regions. All water supplies to construction and operations in the Myara North and Holyoake regions will be sourced from public drinking water sources, captured onsite stormwater or from licensed onsite water treatment facilities where approved for reuse within the drinking water catchment. PFAS would be limited to minor quantities in materials such as workforce clothing, paper packaging, carpets or wire insulation, which are unlikely to be discharged to the environment as all wastes will be recycled or disposed off-site at licensed waste facilities. Accordingly, the direct discharge of PFAS from construction and mining is expected to pose a low risk to drinking water quality.

The existing land uses and baseline monitoring program (GHD 2021) do not indicate the presence of substantial PFAS contamination within the Myara North or Holyoake regions. PFAS are relatively persistent and water-soluble compounds which readily mobilise through the unsaturated zone and into groundwater, which discharges into streams. It is therefore expected that any existing substantial PFAS contamination of the catchments would be detectable in stream flows. Due to the absence of existing substantial contamination, any hydrological changes from construction and mining (i.e. the clearing of vegetation causing groundwater mounding and increased stream flows) are not expected to mobilise substantial quantities of PFAS into reservoirs. Accordingly, the indirect mobilisation of historical PFAS from catchments due to construction and mining is expected to pose a low risk to drinking water quality.

12.2 Minor discharges of hazardous materials

Diesel is the predominant hazardous material used at the Huntly Mine, and to a lesser extent hydraulic and lubricating oils. Minor quantities of other hazardous materials include solvents, adhesives and other chemicals are used for vehicle and equipment maintenance or water treatment.

Haul trucks, some wheeled earthmoving equipment and light vehicles are refuelled at fuel bays. Planned maintenance of haul trucks, light vehicles and some earthmoving equipment is undertaken at workshops. The fuel bay and workshop buildings are located at mine facilities and have roofs and sealed floors, which are expected to capture spills or leaks during refuelling or maintenance. Diesel and oil storage tanks are located at mine facilities and are double-lined and above ground to minimise and detect leaks. Smaller quantities of hazardous materials stored at mine facilities inside buildings or on sealed floors.

Excavators, bulldozers and other earthmoving equipment are refuelled and maintained in the field. Refuelling and maintenance in the field have potential to cause spills and leaks that contaminate soils. There is also potential for ongoing, low level oil leaks from vehicles and equipment, and rare collisions that result in fuel or oil spills.

The majority of spills and leaks, particularly those from major incidents and involving large volumes, are expected to be identified quickly and the contaminated soils excavated and disposed off-site at a licensed waste facility. Smaller spills and leaks may potentially be missed and the contaminants leach through the unsaturated zone. The smaller spills and leaks are expected to remain predominantly adsorbed to soil particles beneath the spill site. Diesel and particularly oil contain larger chain hydrocarbons that are weakly water soluble and readily adsorb to soils with organic matter and clay content. Accordingly small volumes of diesel and oil that escape detection and remediation are unlikely to result in substantial migration of hydrocarbons that reach streams and can be transported into the reservoirs.

13. Risk Assessment

13.1 Definitions

13.1.1 Likelihood

Likelihood is defined as the chance that the risk event and associated consequences will occur. The likelihood definitions used by Water Corporation (2018) match those used by ADWG (2011), and are reproduced in Table 13.1 below. At Water Corporations request, the Water Corporation likelihood definitions have been adopted for this report.

Table 13.1 Likelihood ratings

Descriptor	ADWG example description	Water Corporation Corporate Description	Water Corporation Corporate Frequency
Almost Certain	Is expected to occur in most circumstances	The event is expected or known to occur more than once per year	Will occur more than once a year
Likely	Will probably occur in most circumstances	Known to re-occur approximately annually. Known to occur across likeindustries or within corporation.	Will occur once per year
Possible	Might occur or should occur at some time	The event should occur at some time. Has occurred several times acrosslike industries.	Will occur once every 5 years
Unlikely	Could occur at some time	The event could occur at some time. Known to have occurred once or twicewithin industry.	Will occur once in 10 years
Rare	May occur only in exceptional circumstances	The event may occur in exceptional circumstances. An example of this hasoccurred historically, but is not anticipated.	Will occur once in 30 years or less

13.1.2 Consequence

Water Corporation (2018) define consequence as the outcome of an event affecting objectives expressed qualitatively or quantitatively, being a loss, injury, disadvantage or gain. The severity of the consequence is the most plausible, (credible) outcome should the risk manifest into an event, not the most severe/worst case. They note that consequences are typically measured after a consideration of the barriers in place. Any variation on this (e.g. inherent risk) needs to be clearly specified 'in context' for the risk assessment being undertaken.

At Water Corporations request, the Water Corporation consequence definitions have been adopted for this report, where relevant. The definitions that relate to employee consequences have been ignored.

Table 13.2 Consequence ratings

Rating	Descriptor	ADWG example description	Water Corporation People and Public	Water Corporation Customer Service Interruption
5	Catastrophic	Major impact for large population, complete failure of systems	Multiple fatalities, and/or Onset of life shortening illness for multiple persons	Significant widespread degradation of operations or services, and Long, sustained, loss of operations or services for residential customers or key, sensitive and unregulated customers

Rating	Descriptor	ADWG example description	Water Corporation People and Public	Water Corporation Customer Service Interruption
4	Major	Major impact for small population, systems significantly compromised and abnormal operation if at all, high level of monitoring required	Single fatality, and/or Injury/illness resulting in significant permanent disability or life shortening illness	Widespread degradation of operations or services, and Sustained service cessation for residential customers (>24 hours) or key, sensitive and unregulated customers
3	Moderate	Minor impact for large population, significant modification to normal operation but manageable, operation costs increased, increased monitoring	Injury/illness, requiring specialist medical treatment, or hospitalisation, resulting in loss of functional ability (Restricted Work Injury (RWI)), or time off work (Lost Time Injury (LTI))	Wide-spread customer impacts or inconvenience – entire regional centre or country scheme, multiple metropolitan suburbs, and Temporary loss of operations and services for residential customers (<24 hours) or key, sensitive and unregulated customers
2	Minor	Minor impact for small population, some manageable operation disruption, some increase in operating costs	Injury/illness requiring medical treatment, nil loss of functional ability (Medical Treatment Injury (MTI))	Localised operations or service interruption/ inconvenience for customers, and Temporary, short term service cessation for residential customers (<6 hours) or key, sensitive and unregulated customers Multiple occurrences in one location
1	Insignificant	Insignificant impact, little disruption to normal operation, low increase in normal operation costs	Injury/illness requiring no treatment or first aid treatment only (Minor Injury (MI))	Brief loss of local services, or inconvenience for customers, and No measurable operational impact

13.1.3 Risk

Risk is the combination of likelihood and consequence. The risk matrix used by Water Corporation differs to the ADWG (2011) matrix. At Water Corporations request, the Water Corporation risk matrix has been adopted for this report.

Table 13.3 Risk matrix

Likelihood Consequence	Rare E	Unlikely D	Possible C	Likely B	Almost Certain A
Catastrophic 5	High	High	Extreme	Extreme	Extreme
Major 4	Medium	High	High	Extreme	Extreme
Moderate 3	Low	Medium	High	High	High
Minor 2	Low	Low	Medium	High	High
Insignificant 1	Low	Low	Low	Medium	Medium

13.2 Residual risks *(unmitigated)*

The hazardous events defined between Sections 7 and 12 have been summarised in Table 13.4. Each hazardous event has been assigned likelihood and consequence ratings, and the resultant residual risk (*unmitigated*) from that rating. These have been assigned subjectively from within the defined risk framework, and the residual risk is the risk present without mitigation measures being in place, apart from existing intrinsic barriers such as decay and dilution.

Table 13.4 Residual risks (unmitigated) from defined hazardous events

Residual risk event	Likelihood	Consequence	Risk (*unmitigated*)
Raw sewage overflow in STP located within any catchment area, followed by heavy rainfall	Unlikely	Moderate	Medium
Treated effluent accumulates at surface of irrigation site within any catchment, followed by heavy rainfall resulting in washout	Unlikely	Moderate	Medium
Treated effluent accumulates in shallow perched aquifer, transferred to creek or downslope seepage face, and then into any reservoir	Unlikely	Moderate	Medium
Staff member with asymptomatic cryptosporidiosis in Pipehead Dam catchment area defecates in gully or riparian zone, followed by heavy rainfall	Possible	Major	High
Staff member with asymptomatic cryptosporidiosis in Serpentine or South Dandalup Dam catchment area defecates in gully or riparian zone, followed by heavy rainfall	Possible	Moderate	High
Mining-related inputs in reservoir results in 5 NTU or greater turbidity of source waters	Possible	Moderate	High
Substantial diesel fuel spill into Pipehead Dam reservoir	Unlikely	Moderate	Medium
Substantial diesel fuel spill into Serpentine or South Dandalup Dam reservoir	Unlikely	Minor	Low

14. Barriers and preventive measures

This section includes discussion of the existing and proposed barriers to identified water quality hazards, related to Alcoa's current and future activities in the study area. As defined in the ADWG section 3.3, barriers and preventive measures are those actions, activities and processes used to prevent hazards from occurring or reduce them to acceptable levels. Many preventive measures may control more than one hazard, while, as prescribed by the multiple barrier approach, effective control of some hazards may require more than one preventive measure.

These barriers and preventive measures are summarised in Appendix I.

14.1 Pathogen barriers - workforce in the field

Demountable ablution block (existing): A crib room and ablution block are provided within the mine region at a location closer to active mine pits, so as to provide support to the field workforce working away from the mine facilities. The ablution block drains into a tank, which is periodically pumped out by a tanker for disposal at a licenced facility.

Mandated work breaks (existing): Work breaks provide an opportunity for field staff to access the ablutions block or mine facilities.

Haul truck refuelling at mine facilities (existing): Haul truck refuelling provides an opportunity for field staff to access ablutions at mine facilities.

Workforce education (existing): Inductions for all staff and contractors at commencement, with regular refresher training. The inductions are proposed to include education about drinking water catchment sensitivity, the risks from pathogens to the catchment, and mandatory procedures to minimise those risks.

Workforce health monitoring (existing): Employees and contractors are encouraged, and required, to not attend the workplace if unwell, particularly if experiencing specific gastrointestinal symptoms, or contact with individuals with gastrointestinal symptoms. This requirement is communicated in the inductions and regular refresher training.

Waste bagging and removal (proposed): A procedure where human waste will be bagged and disposed of appropriately is proposed.

Incident reporting and response (proposed): It is proposed that all accidental human waste discharges are to be reported and cleaned up consistent with a hazardous material spill.

Drinking water protection signs (proposed): It is proposed that hazard signs are installed at active mine pits, with a warning statement on drinking water protection and mandatory off-site waste disposal.

Workforce access restrictions (proposed): It is proposed that access within designated buffers from streams and reservoirs, is only permitted to those employees and contractors that have completed the appropriate training package, to understand the drinking water catchment sensitivity, and mandatory procedures to minimise those risk. Refresher training is to occur annually with acknowledgement of employee and contractor obligations.

Riparian reservoir buffers – overland flow attenuation (existing): In the event of failure of the earlier described barriers, some attenuation of pathogen load is expected during overland flow, due to filtration in Jarrah forest understorey vegetation and litter layer.

Seasonal stream attenuation (existing): Streams flow seasonally for several months of the year and then are dry. Some attenuation of pathogen loads will occur if discharging to a dry stream, when there is no flow for a few to several months. Limited attenuation may occur in flowing streams, however travel time is likely to be in the order of minutes to hours until discharge into the reservoir.

Reservoir attenuation (existing): Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Some dilution and inactivation of pathogens is expected due to natural mixing and retention processes in the reservoir.

In addition to the above barriers, Alcoa have opted not to mine withing the Serpentine Pipehead catchment, thus eliminating field activities in this particular PDWSA and RPZ.

14.2 Pathogen barriers – workforce at mine facilities

Reservoir protection zone (existing): Mine facilities are located outside of the RPZ, increasing travel pathways and attenuation for pathogens prior to discharge into the reservoir.

Sewage treatment and disinfection (existing and proposed): Sewage at mine facilities is treated in a sewage treatment plant, with primary and secondary treatment followed by chlorine disinfection. Consideration will be given to additional treatment with advanced processes such as ultraviolet disinfection and filtration to provide additional pathogen removal, including of *Cryptosporidium* as the key pathogen of concern in the drinking water catchments.

Treated sewage effluent irrigation (existing): Drip irrigation of treated effluent over Jarrah forest vegetation is performed within the mine facilities complex. Water is lost to evapotranspiration, with some leaching of effluent to prevent the salt build-up. Pathogens are captured in the shallow soil layer and die-off through natural processes.

Overland flow attenuation (existing): In the event of failure in the sewage treatment or irrigation barriers, effluent may travel downslope of the STP or irrigation area. Some pathogen attenuation during overland flow is expected due to filtration in the Jarrah forest understorey vegetation and litter layer. Overland flow is unlikely to reach streams or reservoirs, unless heavy rainfall or wet catchment conditions are present.

Subsurface flow attenuation (existing): In the event of failure in the sewage treatment or irrigation barriers, pathogens may be transported with infiltration through the unsaturated zone and then transported downslope with groundwater. Some pathogen attenuation during subsurface flow is expected due to filtration in the subsurface matrix.

Seasonal stream attenuation (existing): Stream flows within the drinking water catchments are seasonal for several months of the year, and are then dry. Some pathogen attenuation is expected with discharge to a dry stream bed, where there is no flow for a few to several months. Limited attenuation may occur in flowing streams however travel time is likely to be in the order of minutes to hours until discharge into the reservoir.

Reservoir attenuation (existing): Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Some dilution and inactivation of pathogens is expected due to natural mixing and retention processes in the reservoir.

14.3 Turbid discharge barriers

No mining in areas of high slope (existing): Slope is a demonstrated key factor in the generation of channelised flow, higher runoff velocities and volumes, and higher soil erosion. Mine planning to reassess the slope (or slope-length) at which clearing and/or mining is excluded.

Staged and seasonal approach to development and clearing (existing): Mine development, mining and rehabilitation occurs in a staged manner within a mine region. The average timeframe between clearing and completion of mine rehabilitation is 3-4 years.

Clearing contour windrows (existing): Cleared wood waste is arranged in windrows on the contour, prior to burning or reuse. Windows intercept runoff to prevent flow concentration and subsequent erosion of mine pit and overflow of drainage protection shots. Clearing contour windrows are a temporary, seasonal barrier applied as cleared wood waste is available.

In-pit drainage (existing): Engineered and maintained mine drainage bunds and trenches intercept and convey runoff and sediment to in-pit sumps, preventing uncontrolled discharge.

In-pit drainage protection shots (existing): Drainage shots, also called water shots, comprise shallow (~1.8 m) blasted or ripped ground on the downslope perimeter of each mine pit. Drainage shots capture and infiltrated surface runoff within the blasted voids.

In-pit sumps (existing): Some mine pits have in-pit sumps that collect runoff from pit floors and/or in-pit drainage. In-pit sumps are designed to retain runoff from major storm events.

Interception sumps (existing): All paved areas at mine facilities and all haul roads drain to interception sumps. Paved areas upstream of major rivers (e.g. Big Brook) drain to triple interceptor sumps. All sumps are designed to retain rainfall from major storm events.

Rehabilitation revegetation prescription (existing): Revegetation establishes a native understorey and overstorey with more than 80 per cent of the floristic diversity of un-mined forest. Substantial establishment of understorey coverage within five years.

Rehabilitation substrate prescription (existing): Rehabilitation substrate includes deep ripping of regolith, application of minimum 200 mm overburden/topsoil and ripping on the contour. Deep ripping promotes infiltration of runoff into the regolith. Application of minimum overburden provides a gravel-sand layer that protects finer grained regolith materials from erosion. Contour ripping creates a furrowed surface that promotes retention and infiltration of runoff.

Rehabilitation landscape prescription (existing): Rehabilitation prescription limits final landform to slopes less than 16 degrees. Downslope toe of rehabilitated pits can have a reverse batter that creates a 'sunken' landform that retains surface runoff and prevents discharge.

Overland flow attenuation (existing): In the event of failure in above barriers, overflows from mine pits or haul road sumps will travel via overland flow downslope. Sediment will attenuate during overland flow due to filtration in Jarrah forest understorey vegetation and litter layer.

Stream attenuation (existing): In the event of failure of above barrier, sediment laden runoff will discharge into streams. Sediment in stream flow is subject to deposition, filtration and dilution prior to discharge into the reservoir.

Reservoir attenuation (existing): Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Dilution and settlement of sediment in the reservoir.

In addition to the above barriers, Alcoa have opted not to mine withing the Serpentine Pipehead catchment, thus eliminating turbidity risk in this particular PDWSA and RPZ.

14.4 Risk assessment with barriers

The hazardous events summarised in Table 13.4 have been re-assessed based in consideration of the multiple preventative barriers described above and detailed in Appendix I. In Table 14.1, the multiple barriers affect the likelihood ratings, whilst the consequence are unchanged.

Table 14.1 Mitigated risk assessment

Residual risk event	Likelihood	Consequence	Risk
Raw sewage overflow in STP located within any catchment area, followed by heavy rainfall	Unlikely	Moderate	Medium
Treated effluent accumulates at surface of irrigation site within any catchment, followed by heavy rainfall resulting in washout	Unlikely	Moderate	Medium
Treated effluent accumulates in shallow perched aquifer, transferred to creek or downslope seepage face, and then into any reservoir	Unlikely	Moderate	Medium
Staff member with asymptomatic cryptosporidiosis in Pipehead Dam catchment area defecates in gully or riparian zone, followed by heavy rainfall	Rare	Major	Medium
Staff member with asymptomatic cryptosporidiosis in Serpentine or South Dandalup Dam catchment area defecates in gully or riparian zone, followed by heavy rainfall	Unlikely	Moderate	Medium
Mining-related inputs in reservoir results in 5 NTU or greater turbidity of source waters	Unlikely	Moderate	Medium
Substantial diesel fuel spill into Pipehead Dam reservoir	Rare	Moderate	Low
Substantial diesel fuel spill into Serpentine or South Dandalup Dam reservoir	Unlikely	Minor	Low

At the catchment scale, the proposed multiple barriers are more robust than the existing barriers, result in a lower risk of contamination than the present land use. Further opportunities to improve reliability of barriers and reduce uncertainty are detailed in Appendix I.

15. Conclusion

A public drinking water risk assessment was conducted, relating to bauxite mining operations proposed for the Serpentine Main Dam, Serpentine Pipehead Dam, and South Dandalup Dam drinking water catchment areas. The risk assessment considered potential contaminants arising from mining activities and infrastructure, as well as mobilisation of existing contaminants from past catchment activities.

Water quality risks from multiple hazards were assessed for their potential to impact human health, including pathogenic microorganisms, turbidity, fuel spills, bushfires, long-term rehabilitation, and contamination from PFAS.

The major conclusions reached from the risk assessment included the following:

– The most hazardous tested event, of direct faecal deposition in the Pipehead Dam catchment, was elevated above the threshold of acceptable risk for pathogen exposure. As an elevated risk, this hazard requires attention during detailed design, so as to define how to reduce the risk to an acceptable level.
– In addition to the averaged annual concentration of *Cryptosporidium* resulting from the examined hazards, GHD (2021) predicted the peak concentrations of this organism resulting the hazards. For the highest risk hazards presented in the Serpentine Pipehead Dam catchment, these included concentrations of ~0.00001 oocysts/L and ~0.01 oocysts/L, based on the location of faecal deposition within that catchment area. From these calculated concentrations, the latter hazard presents an unacceptable short-term high risk of cryptosporidiosis, in addition to the annualized risk. This observation supports the conclusion that the mitigation of this hazard to a level of acceptable risk requires attention during detailed design.
– Serpentine Main Dam turbidity concentrations were sensitive to changes in sump failure suspended solids concentrations, as mining comprises a sufficient proportion of the catchment landscape to do so. This contrasted with South Dandalup Dam sump failure suspended solids concentrations, as the proposed mining area is a small proportion of the overall catchment area, and there is no existing mining in that catchment and previous mining areas are assumed to be fully rehabilitated.
– In the case of the examined catchments, turbidity challenges were modelled in GHD (2021) in the form of inorganic clay and silt particles, simulating turbidity inputs associated with natural waterways and mining sumps. It is noted that these inorganic particles would not be expected to affect disinfection efficacy. Where organic particles capable of impacting efficacy are present in source waters, they can still be effectively disinfected for chlorine-resistant viruses, but require longer chlorine contact times to factor in the chlorine demand from wastewater particulates. In practice, challenge testing can be performed to validate and optimise virus disinfection, where a source water is outside the tested range for disinfection parameters such as turbidity.
– The modelled diesel spill incidents in Serpentine Main Dam and South Dandalup Dam were predicted to peak at up to 1 µg/L, whilst a mid-reservoir spill in Pipehead Dam was predicted to peak at up to 5 µg/L. These concentrations did not exceed the ADWG health based guideline limits for components of diesel fuel. The ADWG notes that diesel contamination in drinking water has a taste and odour threshold of 5 µg/L. This could be reached, with the largest predicted peak diesel concentration of up to 5 µg/L. It is recommended that some monitoring of the concentrations of diesel and other hydrocarbons is performed prior to the proposed mining transition, so as to establish baseline concentrations in the storages.
– After application of multiple barriers, all risk events were deemed to have a risk rating of Medium or less.

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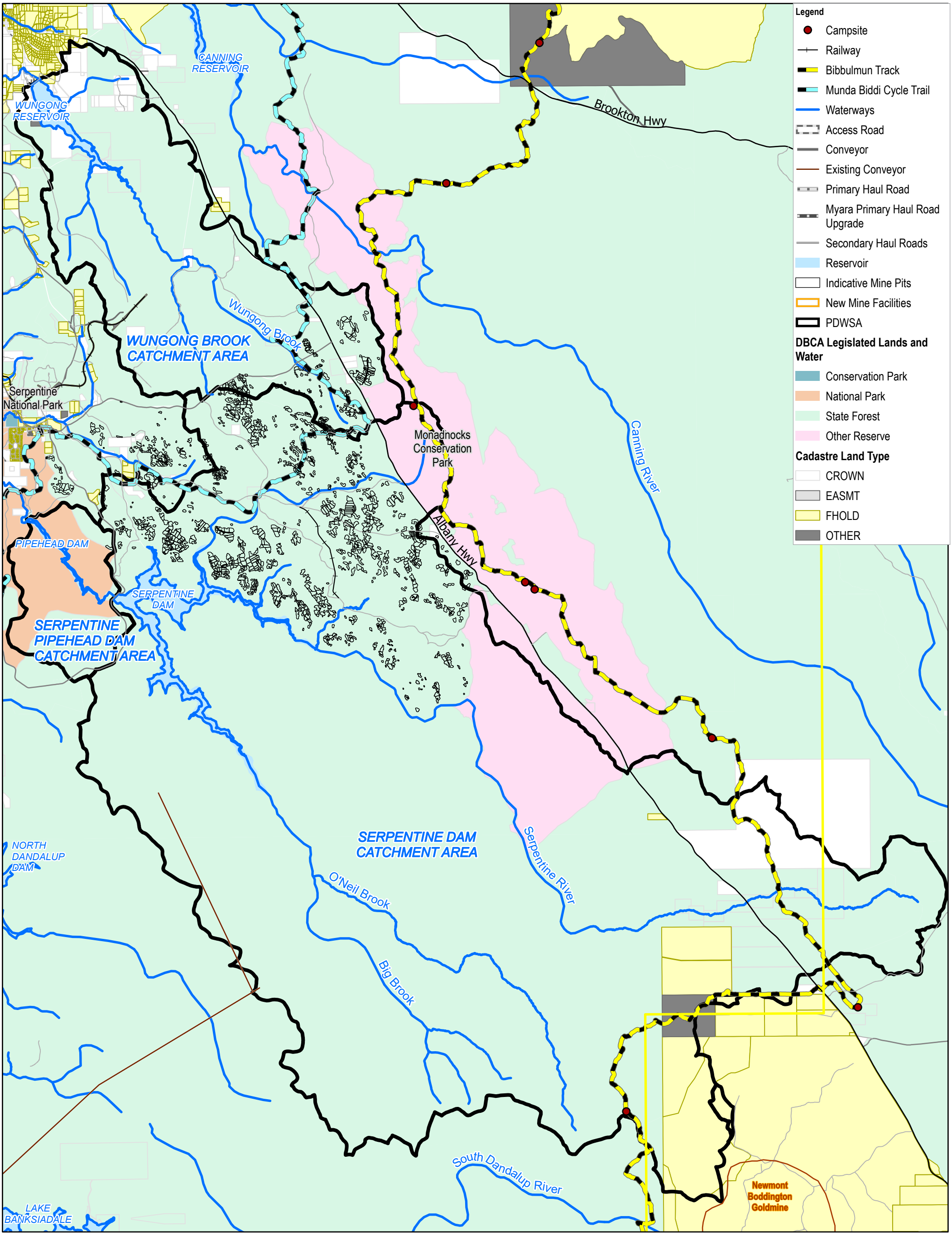
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Appendices

Appendix A

Myara North and Holyoake regions



Paper Size ISO A3

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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GHD

Alcoa of Australia

Drinking Water Risk Assessment

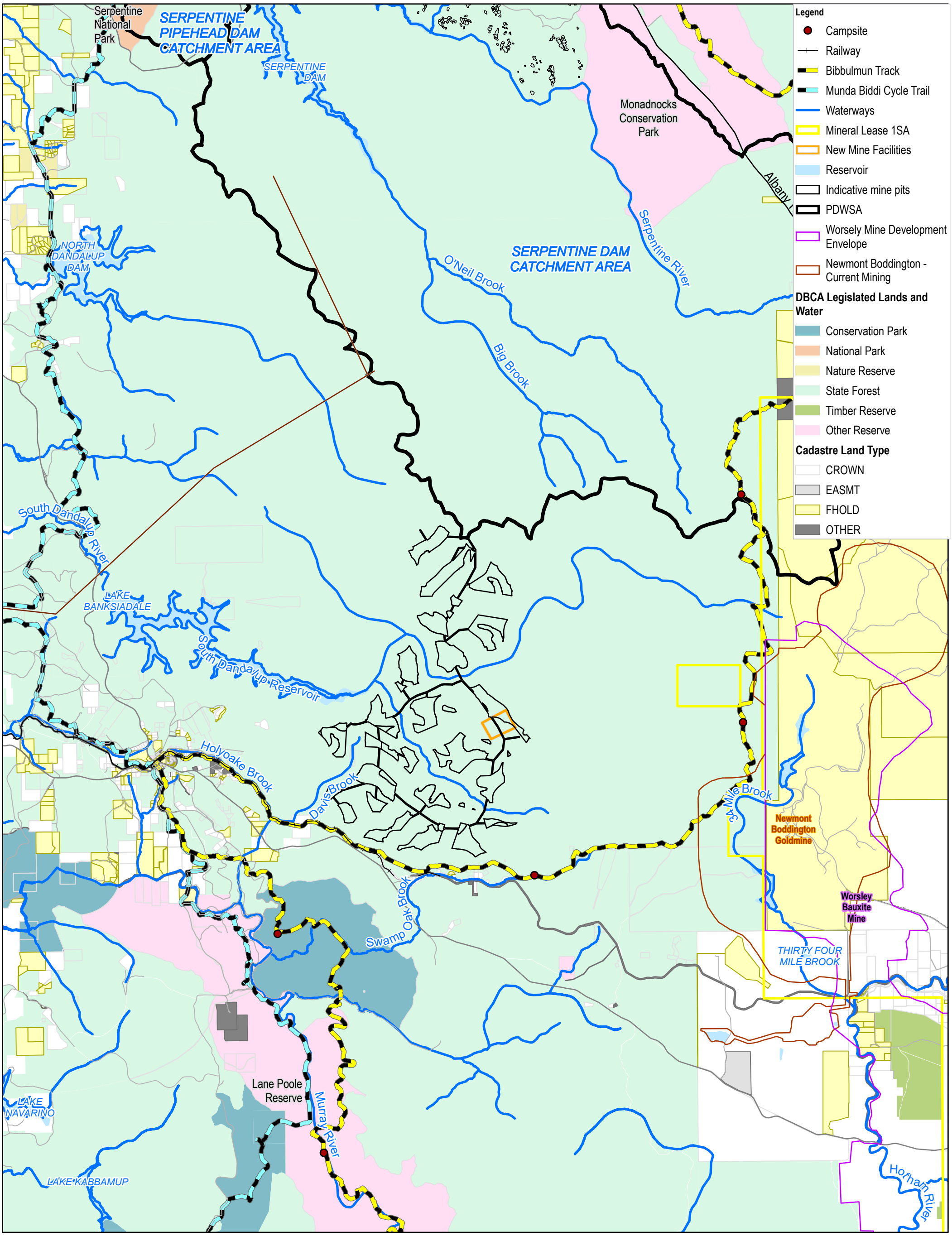
Myara North
Land Use and Tenure

Project No. **12520591**
Revision No. **-**
Date **15/10/2021**

FIGURE A-1

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Kilometers

Map Projection: Transverse Mercator
Horizontal Datum: GDA 1994
Grid: GDA 1994 MGA Zone 50

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Land Use and Tenure

Project No. **12520591**
Revision No. **-**
Date **15/10/2021**

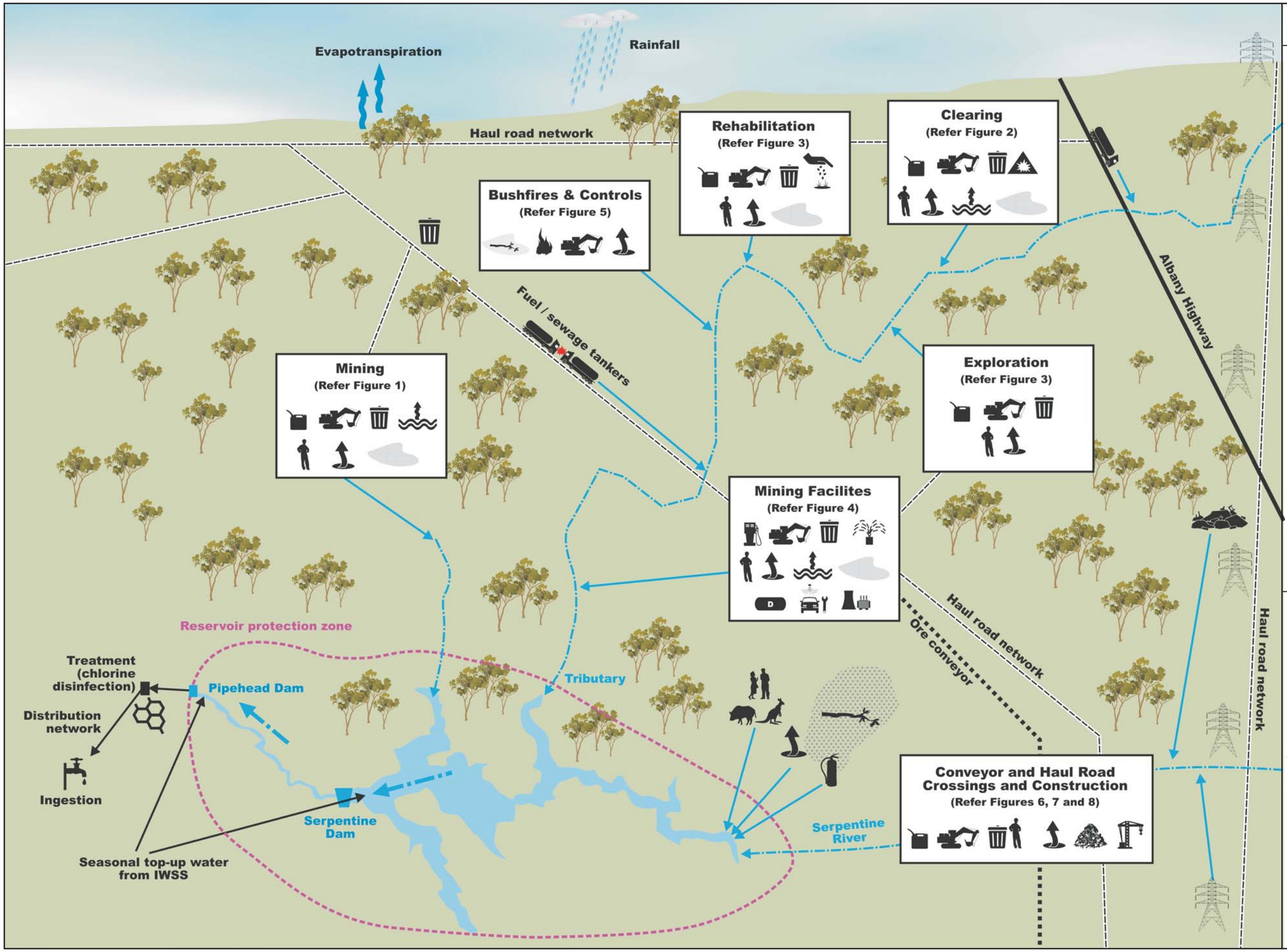
FIGURE A-2

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Appendix B

Conceptual Site Models



LEGEND

Source types	Contaminant
Mining sources	
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Fuel storage / use (leaks and spills)	Hydrocarbons
Vehicles / heavy machinery (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Hazardous chemicals storage	Hydrocarbons, organic solvents, surfactants, PFAS
Treated wastewater irrigation	Nutrients
Diesel power plant and transformers	Hydrocarbons
Washbay and vehicle maintenance	Hydrocarbons, microplastics, suspended solids, nutrients, metals
Fertiliser / herbicide application	Fertilisers and herbicides
Diesel fuel storage	Hydrocarbons
THM formation via disinfection, organic carbon deposition	Trihalomethanes, organic carbon
Waste disposal	Nutrients, hydrocarbons, metals, pathogens
Rising groundwater table	Salts / contaminants in soils
Material stockpile	Suspended solids
Cleared area (clearing, mining)	Suspended solids
Existing land uses	
Existing fauna	Pathogens
Feral amimals	Suspended solids, pathogens
Human presence from recreation and other land uses	Pathogens
Rubbish dumping	Nutrient, chemicals, heavy metals, hydrocarbons
Cleared area (timber harvesting)	Suspended solids
Power / telephone lines (maintenance)	Herbicides, suspended solids
Legacy fire fighting foams	PFAS
Vehicles (associated with most existing land uses)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Roads and tracks	Herbicides

CONTAMINANT PATHWAYS

- Overland flow and / or infiltration and subsurface flow
- Seasonal flow path
- Perennial flow path
- Gravity / pump fed flow path

Conceptual diagram only - not to scale

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Huntly Mine Expansion
Drinking Water Quality Risk Assessment

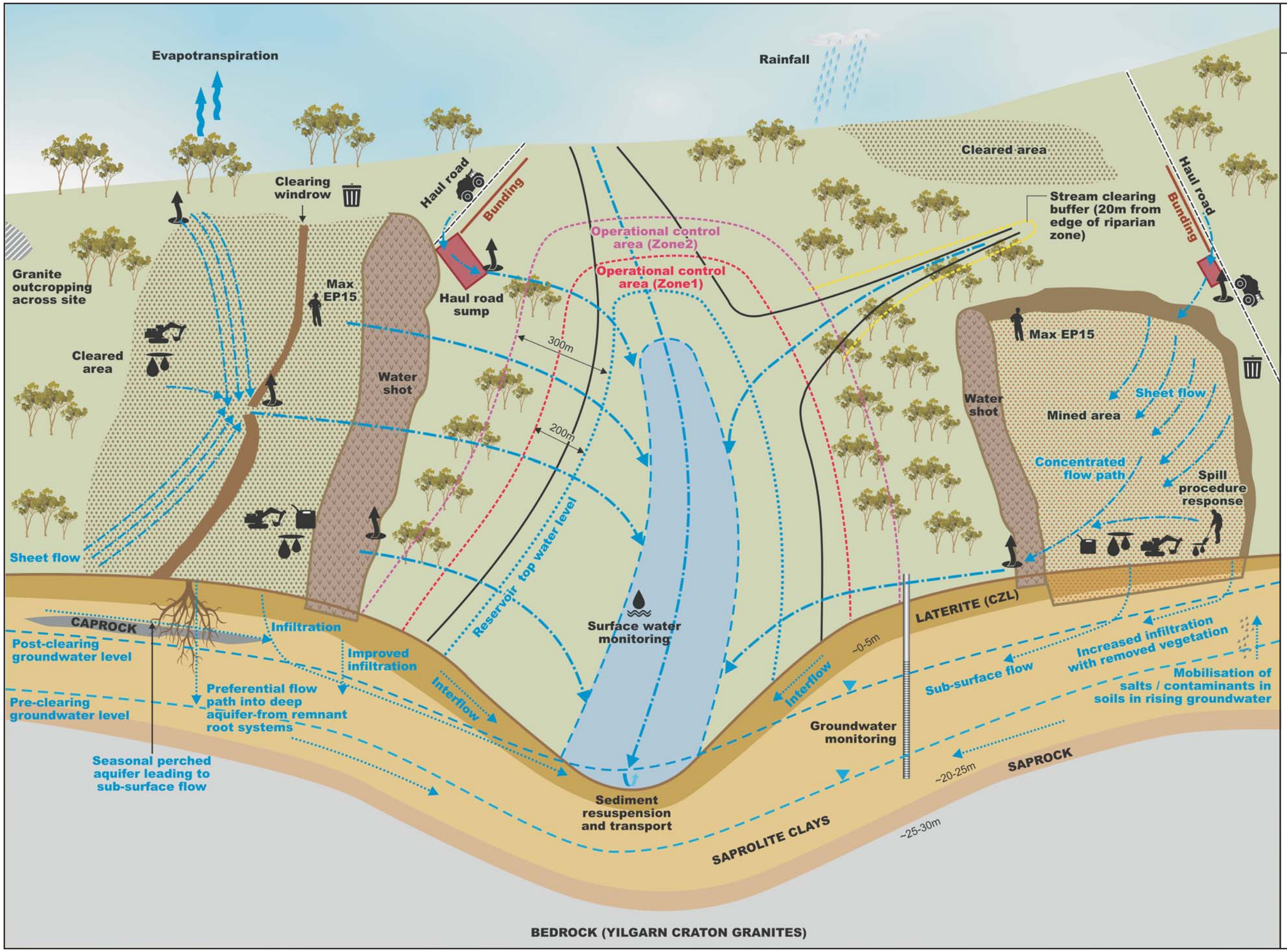
Conceptual model overview

Job Number	12542267
Revision	A
Date	18 Oct 2021

Figure B-1

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LEGEND

Source types	Contaminant
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Fuel storage / use (leaks and spills)	Hydrocarbons
Vehicles / heavy machinery (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Waste disposal	Nutrients, hydrocarbons, metals, pathogens
Cumulative undetected leaks and spills	Hydrocarbons

CONTAMINANT PATHWAYS

- Overland flow path
- Seasonal flow path
- Infiltration and subsurface flow

Conceptual diagram only - not to scale

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Huntly Mine Expansion
Drinking Water Quality Risk Assessment

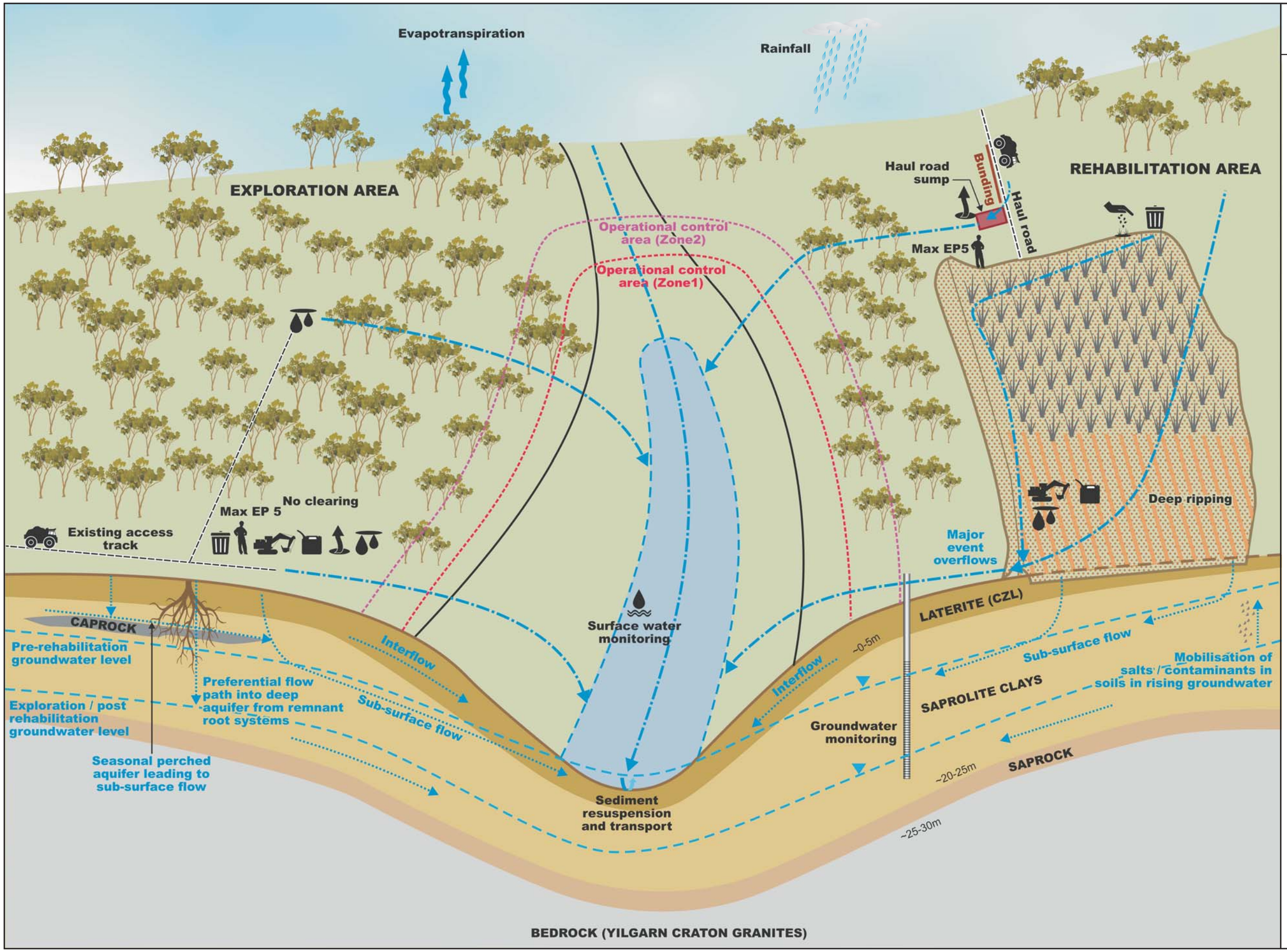
Clearing / mining conceptual model

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Figure B-2

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LEGEND

Source types	Contaminant
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Fuel storage / use (leaks and spills)	Hydrocarbons
Vehicles / heavy machinery (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Waste disposal	Nutrients, hydrocarbons, metals, pathogens
Cumulative undetected leaks and spills	Hydrocarbons
Fertiliser and herbicide application	Nutrients, herbicides

CONTAMINANT PATHWAYS

- Overland flow path
- Seasonal flow path
- Infiltration and subsurface flow

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

Exploration / rehabilitation conceptual model

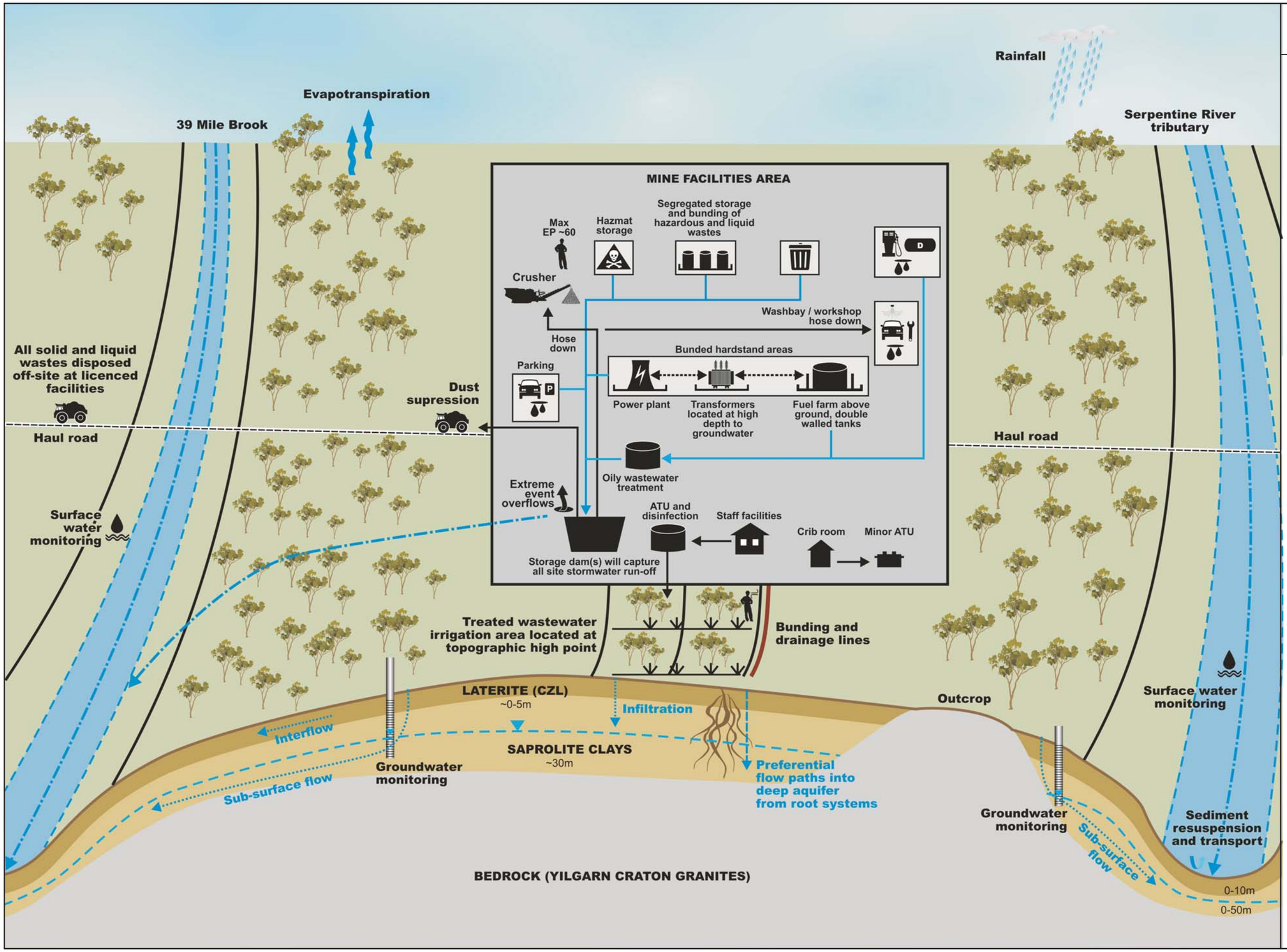
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Date 18 Oct 2021

Figure B-3

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LEGEND

Source types	Contaminant
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Fuel storage / use (leaks and spills)	Hydrocarbons
Vehicles / heavy machinery (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Waste disposal	Nutrients, hydrocarbons, metals, pathogens
Cumulative undetected leaks and spills	Hydrocarbons
Washbay water, vehicle maintenance (spills / leaks)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Refuelling bay	Hydrocarbons
Power plant	Hydrocarbons
Treated wastewter irrigation	Nutrients, pathogens

CONTAMINANT PATHWAYS

- Overland flow path
- Infiltration and subsurface flow
- Seasonal flow path
- Direct inhalation
- Controls: Gravity / pump fed flow
- Bunded hardstand areas to control spills / leaks

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

Mine facilities conceptual model

Job Number 12542267
Revision A
Date 31 Mar 2021

Figure B-4

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Rainfall

Evapotranspiration

Vehicles / machinery induced fire (collisions / leaks / spills / sparks)

Haul road network

Mining in predominantly cleared areas

Prohibition on field activities during fire bans - no drilling, blasting or clearing

Access track

Burnt area with fine sediments, increased erosion and organic carbon

Operational control areas (water working arrangements)

Surface water monitoring

Tributary

Mine facilities within cleared area

Haul road network

Treatment (chlorine disinfection)

Pipehead Dam

Serpentine Dam

Distribution network

Ingestion

Seasonal top-up water from IWSS

Reservoir protection zone

Fire response procedures, training and equipment

Fire station at McCoy mine facilities

LEGEND

Source types	Contaminant
Mining sources	
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Fuel storage / use (leaks and spills)	Hydrocarbons
Vehicles / heavy machinery (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Waste disposal	Nutrients, hydrocarbons, metals
THM formation via disinfection, organic carbon deposition	Trihalomethanes, organic carbon
Organic carbon deposition	Organic carbon
Cumulative undetected leaks and spills	Hydrocarbons

CONTAMINANT PATHWAYS

- Overland flow and / or infiltration and subsurface flow
- Seasonal flow path
- Perennial flow path
- Gravity / pump fed flow path

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

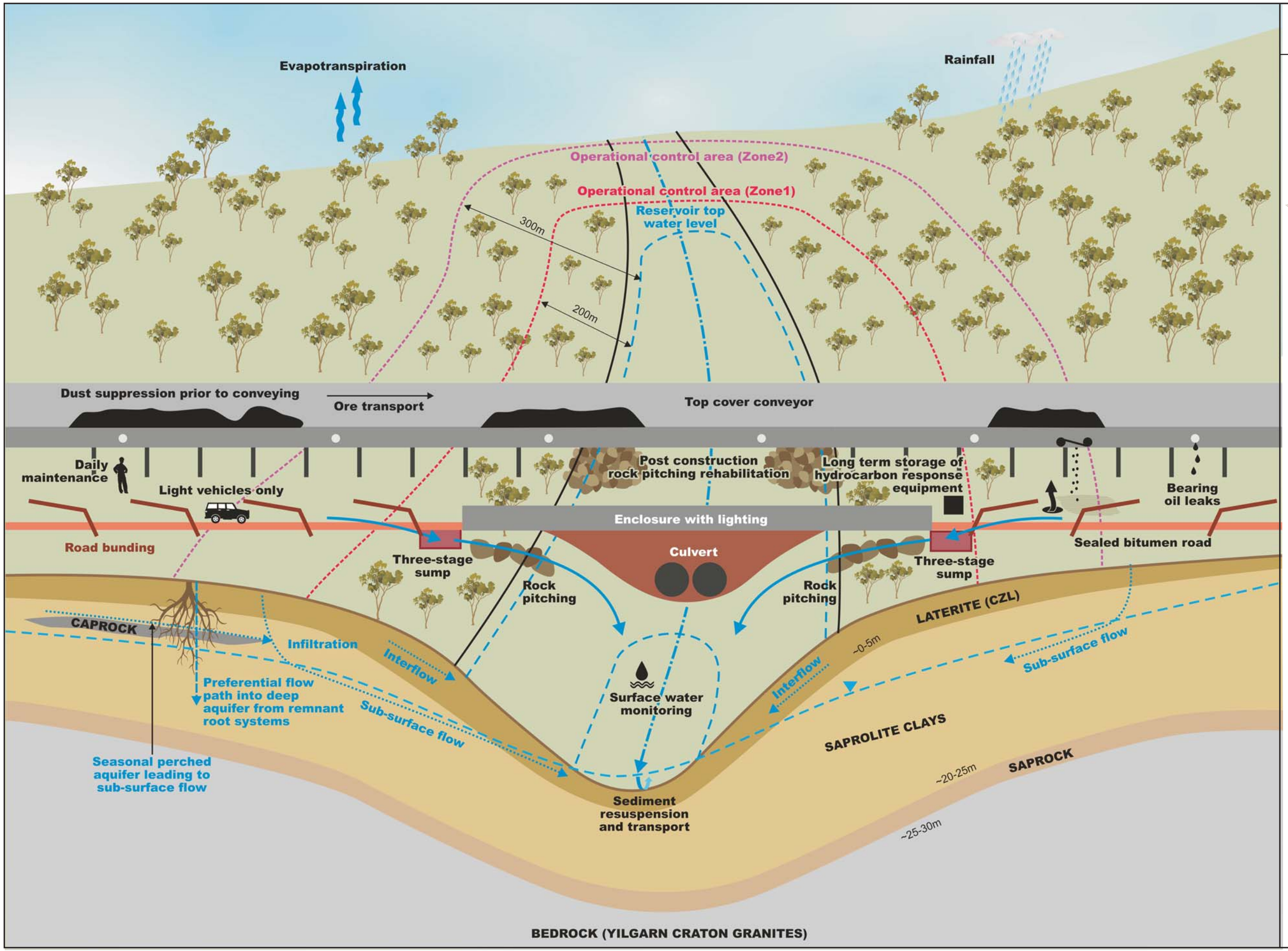
Job Number 12542267
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Date 18 Oct 2021

Bushfire and controls conceptual model overview

Figure B-5

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LEGEND

Source types	Contaminant
Surface water and sediment releases	Suspended solids
Workers (toileting / vomiting)	Pathogens
Vehicles (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Spilled ore / sediment from damaged equipment, belt abrasion or dusting	Suspended solids, plastics, metals, plastic additives

CONTAMINANT PATHWAYS

- Overland flow path
- Infiltration and subsurface flow
- Seasonal flow path

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Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

Conveyor operation conceptual model

Job Number 12542267
Revision A
Date 6 Apr 2021

Figure B-6

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Evapotranspiration

Rainfall

Operational control area (Zone2)

Operational control area (Zone1)

300m

200m

Bunding

Sealed dual lane haul road

Bunding

Culvert

Sump overflow

Three-stage sump

Sump overflow

Sump inspection and clean out

CAPROCK

Post-clearing groundwater level

Seasonal perched aquifer leading to sub-surface flow

Infiltration

Interflow

LATERITE (CZL)

Surface water monitoring

Interflow

~0-5m

Sub-surface flow

Pre-clearing groundwater level

Sub-surface flow

SAPROLITE CLAYS

~20-25m

SAPROCK

Sediment resuspension and transport

~25-30m

BEDROCK (YILGARN CRATON GRANITES)

LEGEND

Source types	Contaminant
Workers (toileting / vomiting)	Pathogens
Vehicles (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Cumulative / undetected leaks and spills	Hydrocarbons

CONTAMINANT PATHWAYS

- Overland flow path
- Infiltration and subsurface flow
- Seasonal flow path

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

Haul road operation conceptual model

Job Number 12542267
Revision A
Date 31 Mar 2021

Figure B-7

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Works to occur in late spring to autumn

Evapotranspiration

Rainfall

Operational control area (Zone2)

Operational control area (Zone1)

Reservoir top water level

300m

200m

Top cover conveyor

Laydown area

Long-term storage of hydrocarbon response equipment

Removal of bed / bank vegetation

Temporary infiltration ponds

Temporary bunding around footings

Concrete and asphalt imported to site, no local batching facilities

Hay bales

Light vehicles only

Sealed road

Road bunding

Three-stage sump

Alcoa permit to work in close proximity to catchment areas

Road bunding

Three-stage sump

Post construction rock pitching rehabilitation

Silt curtain in reservoir

CAPROCK

Post-clearing groundwater level

Infiltration

Interflow

Pre-clearing groundwater level

Preferential flow path into deep aquifer from remnant root systems

Sub-surface flow

Seasonal perched aquifer leading to sub-surface flow

Surface water monitoring

Sediment resuspension and transport

LATERITE (CZL)

~0-5m

Interflow

Sub-surface flow

SAPROLITE CLAYS

~20-25m

SAPROCK

~25-30m

BEDROCK (YILGARN CRATON GRANITES)

LEGEND

Source types	Contaminant
Workers (toileting / vomiting)	Pathogens
Vehicles (fuel/oil leaks and spills, tyre wear)	Hydrocarbons, metals, microplastics, suspended solids, nutrients, metals
Refuelling	Hydrocarbons
Bed and bank erosion	Suspended solids
Cumulative undetected leaks and spills	Hydrocarbons
Temporary material stockpiling	Suspended solids
Waste disposal	Nutrients, hydrocarbons, metals, pathogens
Cleared area	Suspended solids

CONTAMINANT PATHWAYS

- Overland flow path
- Infiltration and subsurface flow
- Seasonal flow path
- Pump-fed flow path

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

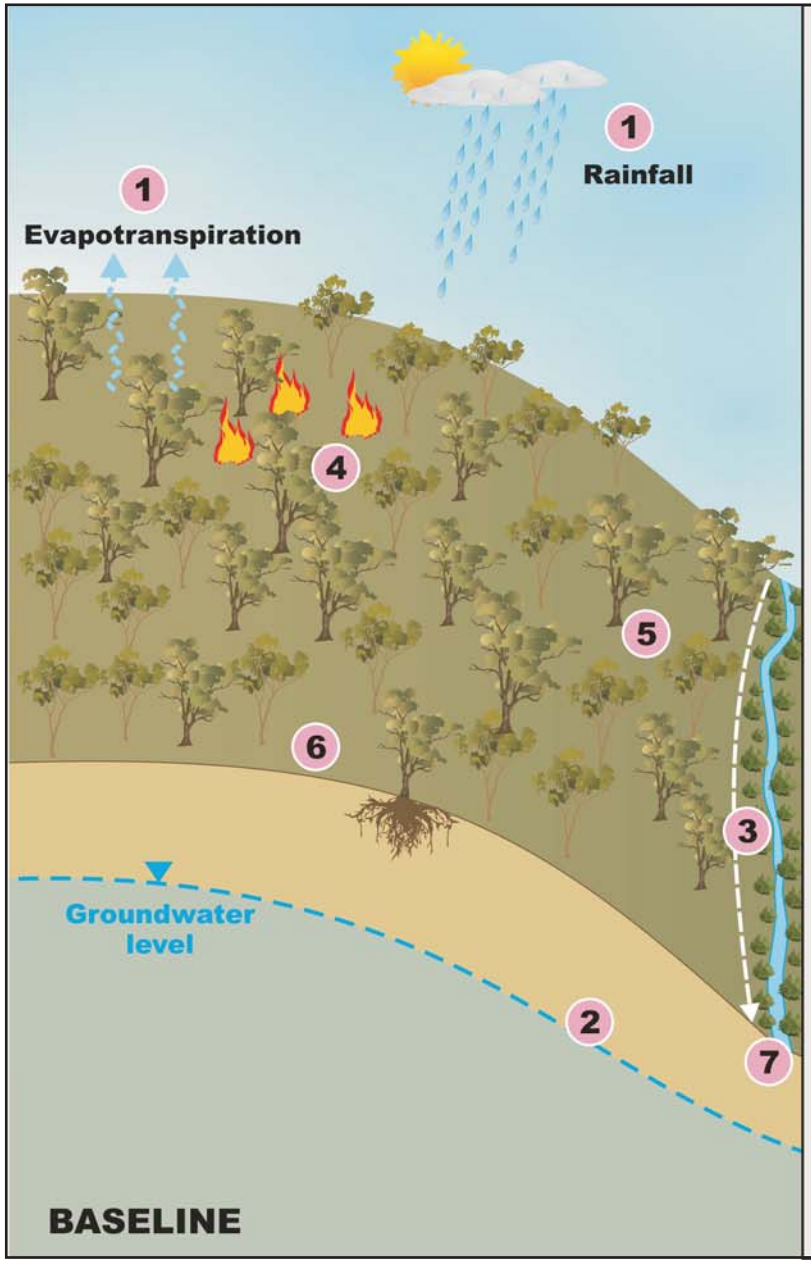
Linear infrastructure stream crossing conceptual model

Job Number 12542267
Revision A
Date 6 Apr 2021

Figure B-8

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1 **CLIMATE CHANGE**
Rising temperatures, less frequent and more intense rainfall events and declining annual rainfalls.

2 **GROUNDWATER LEVEL**
Groundwater levels are likely to decline as a result of **1**

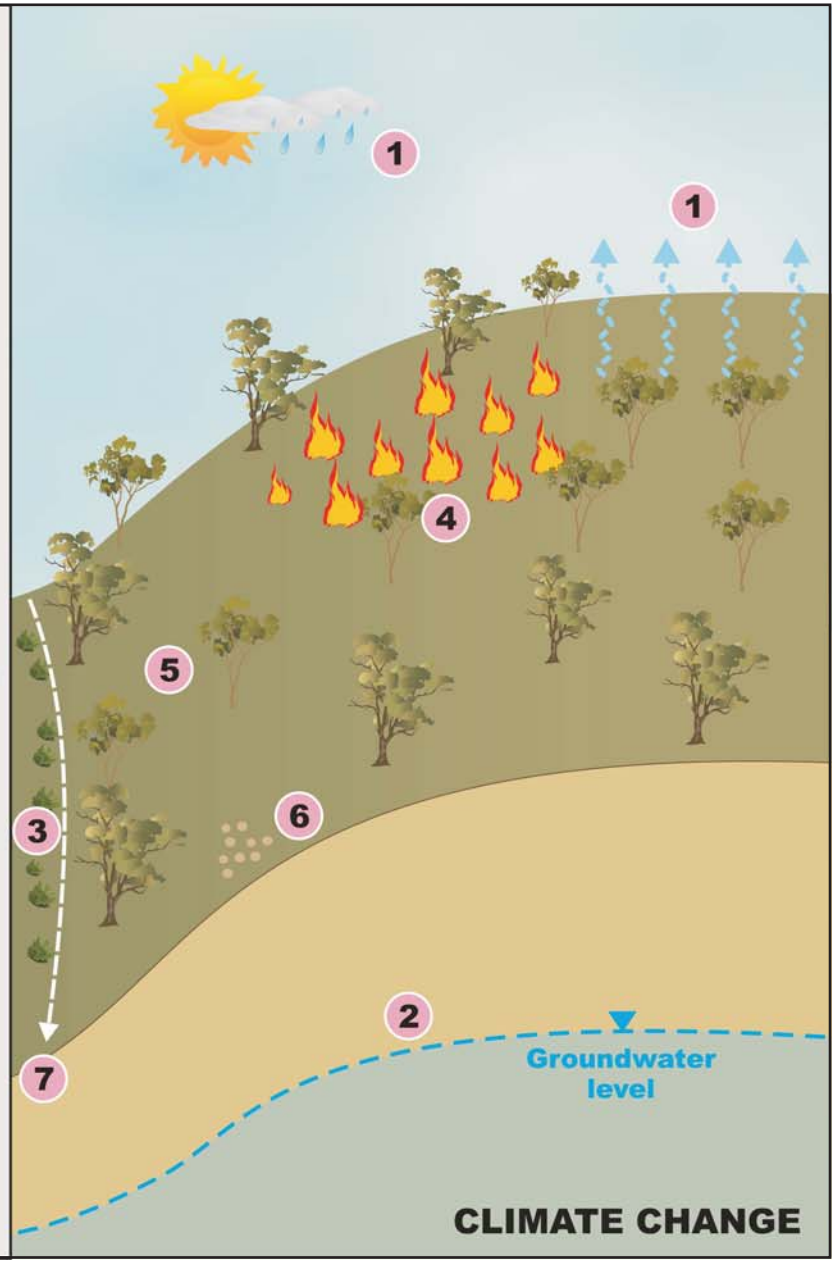
3 **STREAM FLOW**
Rivers and tributaries are likely to exhibit declining periods of flow due to **1** and **2**

4 **FIRE**
Fire intensity and frequency are likely to increase due to (1) and more frequent storm events (lightning)

5 **VEGETATION**
Decline in forest density and health are likely as a result of **1**, **2**, **3** and **4**

6 **SOIL**
Greater soil loss volumes are likely as a result of reduced soil structure from loss of vegetation as well as greater intensity of storm events and fires. Less frequent and more intense major events mean there will be higher potential for greater concentrations of pollutants to enter rivers, tributaries and reservoirs.

7 **RESERVOIR**
Average reservoir levels may decline as a result of **1**, **2**, and **3**



Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion
Drinking Water Quality Risk Assessment

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Revision A
Date 31 Mar 2021

Conceptual site model - climate change considerations

Figure B-9

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Appendix C

Model sources, pathways, and receptors

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Exploration	1) Exploration workforce in catchment and RPZ 2) Use of bushland for toileting and vomiting	Pathogenic microorganisms	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Operational Control Area between reservoir and streams (Water Working Arrangements) - vegetated surface filtration/infiltration 2) Dieback controls prohibit site access during/after heavy rainfall and wet ground conditions - reduce likelihood of overland flow 3) Seasonal stream flows, pathogen die-off over summer/autumn 4) Zero contact policy with water 5) Drinking water catchment signage 6) Limit on size of exploration teams
Construction Clearing Mining Mining support Rehabilitation	1) Operational workforce in RPZ (mine pits and haulage) and catchment (mine pits, haulage, mine facilities) 2) Construction workforce in RPZ (haul roads, conveyors) and catchment (haul roads, conveyors, mine facilities) 3) Use of bushland for toileting and vomiting	Pathogenic microorganisms	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Ablution facilities provided outside of RPZ, reducing potential for toileting/vomiting in bushland 2) Operational Control Area between reservoir and streams (Water Working Arrangements) - vegetated surface filtration/infiltration 3) Dieback controls prohibit site access during/after heavy rainfall and wet ground conditions - reduce likelihood of overland flow 4) Seasonal stream flows, pathogen die-off over summer/autumn 5) Zero contact policy with water 6) Drinking water catchment signage
Construction Clearing Mining Mining support Rehabilitation	1) Construction and operational workforce in the catchment 2) Treatment of workforce sewage 3) Irrigation of treated effluent at construction compound and mine facilities	Pathogenic microorganisms	1) Irrigation of treated sewage effluent over bushland 2) Process upsets / failure resulting in reduced treatment efficacy / higher contaminant loading 3) Overland flow during heavy rainfall and wet ground conditions, discharging into stream 4) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 5) Transport along stream during winter / spring flow period, discharging into reservoir	1) Mine facilities / WWTP sited outside of RPZ 2) Operational Control Area between irrigation area and streams - vegetated surface filtration/infiltration 3) Cutoff drains to intercept overland flow 4) Irrigation area located with high depth to groundwater - maximise unsaturated zone flow distance/attenuation 5) Single sewage treatment plant approved by Health Department 6) Single sewage treatment plant maintenance, flow metering and discharge monitoring 7) Seasonal stream flows, pathogen die-off over summer/autumn
Construction Clearing Mining Mining support Rehabilitation	1) Construction and operational workforce in the catchment 2) Mobile ablutions facilities 3) Pump out and transport of raw sewage for off-site disposal 4) Raw sewage leaks during tanker collisions	Pathogenic microorganisms	1) Overland flow, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) Mobile ablutions sited outside of RPZ 2) Mobile ablutions use dead end tanks for pump out, no site discharge 3) Mobile ablutions have bunding, to capture spills in immediate vicinity 4) Haul road/road design and sump design to prevent collisions and prevent spills from discharging outside haul roads 5) Sewage tanker movements restricted to between ablutions and public roads, no sewage tanker crossing of RPZ, Serpentine River or South Dandalup River. 6) Collision avoidance system 7) Training and fatigue management for drivers 8) Spill response procedures, equipment and training

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Construction Clearing Mining Mining support Rehabilitation	1) Exploration, construction and operational vehicles and equipment in the RPZ and catchment 2) Fuel leaks during refuelling 3) Oil leaks during vehicle/equipment maintenance 4) Fuel or oil leaks during vehicle collisions	Hydrocarbons	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Surface runoff from haul roads and other paved/compacted areas, discharging into stream or direct to reservoir 3) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 4) Transport along stream during winter / spring flow period, discharging into reservoir	1) Diesel only site - not petrol that contains higher BTEX/soluble fractions 2) In-situ refuelling limited to excavators and large equipment, all haul trucks and light vehicles refuelled at mine facilities outside RPZ 3) In-situ equipment maintenance limited to unplanned/emergencies, all planned maintenance at mine facilities at McCoy outside RPZ 4) Operational Control Area between reservoir and streams (Water Working Arrangements) 5) Haul road/road design and sump design to prevent collisions and prevent spills from discharging outside haul roads 6) Restrictions on fuel transport across Serpentine River and South Dandalup river - max 15 kL. All bulk fuel deliveries from public roads direct to mine facilities, no bulk fuel crossing of Serpentine River or South Dandalup River. 7) Collision avoidance system 8) Training and fatigue management for drivers 9) Spill response procedures, equipment and training 10) Triple sump design at haul road river crossings
Construction Clearing Mining Mining support Rehabilitation	1) Exploration, construction and operational workforce, vehicles and equipment in the RPZ and catchment 2) Bushfire due to machinery or electrical sparks	Suspended solids, organic carbon loading, trihalomethanes, haloacetic acids, haloacetonitriles and halonitromethanes.	1) Bushfire reduces soil cover and increases organic carbon loading 2) Increased erosion and sediment / organic carbon runoff from burnt areas, discharging into stream or direct to reservoir 3) Transport of sediment / organic carbon along stream during winter / spring flow period, discharging into reservoir 4) Generation of disinfection by-products, such as trihalomethanes, haloacetic acids, haloacetonitriles and halonitromethanes.	1) Prohibition on field activities during fire bans - no drilling, blasting or clearing 2) Mining and facilities activities in predominantly cleared areas 3) Operational Control Area between reservoir and streams (Water Working Arrangements) 4) Fire response procedures, equipment and training - Firestation at McCoy mine facilities 5) Prescribed burning by DBCA
Exploration Clearing and construction Roads and infrastructure Mining support Mining Rehabilitation	1) Exploration, construction and operational vehicles and equipment in the RPZ and catchment 2) Fires caused by leaks or spills during refuelling or vehicle collisions	Hydrocarbons, metals	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) Diesel only site - not petrol that contains higher BTEX/soluble fractions 2) In-situ refuelling limited to excavators and large equipment, all haul trucks and light vehicles refuelled at mine facilities outside RPZ 3) Operational Control Area between reservoir and streams (Water Working Arrangements) 4) Haul road/road design and sump design to prevent collisions and prevent spills from discharging outside haul roads 5) Restrictions on fuel transport across Serpentine River and South Dandalup river - max 15 kL. All bulk fuel deliveries from public roads direct to mine facilities, no bulk fuel crossing of Serpentine River or South Dandalup River. 6) Collision avoidance system 7) Training and fatigue management for drivers 8) Fire response procedures, equipment and training - Firestation at McCoy mine facilities 9) Spill response procedures, equipment and training 10) Triple sump design at haul road river crossings
Rehabilitation	1) Use of fertiliser for revegetation	Nutrients	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) Operational Control Area between reservoir and streams (Water Working Arrangements) 2) Aerial application of fertilisers, no surface transport or storage on site 3) Low application rates based on research 4) Seasonal application in spring

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Construction Clearing Mining Mining support Rehabilitation	1) Solid and liquid waste generation from construction and operational activities 2) On-site waste disposal	Nutrients, hydrocarbons, metals	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Surface runoff from haul roads and other paved/compacted areas, discharging into stream or direct to reservoir 3) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 4) Transport along stream during winter / spring flow period, discharging into reservoir	1) All solid and liquid wastes (apart from cleared vegetative materials and sewage effluent) disposed off-site at licensed facilities 2) Cleared vegetation salvaged by FPC and Simcoa, salvaged for fauna habitats, or else burnt 3) Sewage treated and disposed via irrigation at mine facilities 4) Concrete and asphalt will be imported to site, no local batching facilities 5) Temporary storage of solid and liquid waste at designated facilities (construction compound, mine facilities) outside of RPZ 6) Segregated storage and bunding of hazardous wastes and liquid wastes 7) Construction environmental management plan 8) Spill response procedures, equipment and training
Construction Clearing Mining Mining support Rehabilitation	1) Use of aqueous film forming foam (AFFF) to respond to fire events 2) Presence of perflouro-alkyated substances (PFAS) in AFFF	PFAS	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) Phasing out of PFAS in fire suppressants prior to commencement of construction and operations 2) All construction and operational fire response systems to use PFAS free fire suppressants
Construction Clearing Mining Mining support Rehabilitation	1) Water use for pavement construction, dust suppression, vehicle washing and other site uses 2) PFAS detected in existing mine water supply	PFAS	1) Surface runoff from treated haul roads, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) All water supplied to mine region will be from uncontaminated catchments/sources or treated to remove PFAS to below detection limits 2) PFAS investigation into existing mine water supply, informing remediation as appropriate
Clearing Mining	1) Removal of vegetation and caprock 2) Change in hydrological regime 3) Rising groundwater mobilising salts in soils	Salinity	1) Rising groundwater following clearing of vegetation 2) Salts mobilise into groundwater and flow into streams	1) Research into hydrological changes and salinity 2) Hydrological modelling to identify areas at risk and inform mining planning, scheduling and management 3) Majority of catchment in high rainfall zone 4) Groundwater monitoring 5) Scheduling of clearing and rehabilitation
Clearing Mining	1) Removal of vegetation and caprock 2) Change in hydrological regime 3) Rising groundwater mobilising pre-mining contaminants	Hydrocarbons, PFAS	1) Rising groundwater following clearing of vegetation 2) Contaminants mobilise into groundwater and flow into streams	1) Catchment assessment to identify potential contaminating land uses 2) Catchment baseline monitoring of groundwater and surface water to identify any areas at risk 3) Catchment land use predominantly State Forest, PDWSA prevents contaminating uses 4) Groundwater monitoring 5) Scheduling of clearing and rehabilitation

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Clearing	1) Clearing of vegetation for construction and mining	Suspended solids	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Surface runoff from haul roads and other paved/compacted areas, discharging into stream or direct to reservoir 3) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 4) Transport along stream during winter / spring flow period, discharging into reservoir	1) Construction water management plan 2) Operational Control Area between reservoir and streams (Water Working Arrangements) 3) 'Water shots' (mechanical fracturing of ground) to minimise runoff from mine pits infiltration and prevent runoff 4) Provision of engineering designed sumps downstream of haul roads and cleared areas 5) Schedule rehabilitation as early as practicable to minimise period of uncovered soil 6) Turbidity monitoring 7) Clearing windrow along contour 8) Haul road design and drainage management manual upgraded 9) Dedicated water crew undertaking sump cleaning program 10) Red alert checklist process 11) Changing of operational strategy to open fewer concurrent sites (big blend process in Myara North) 12) Mine pit analysis and sump design
Ore transport	1) Conveyor crossing over reservoir. 2) Spilling ore and/or sediment from damaged equipment or dusting off the belt. 3) Abrasion of the belt discharging pollutants. 4) Oil leaks from bearings on conveyor idlers 5) Fuel or oil leaks from accidents of maintenance/inspection vehicles along conveyor corridor.	Sediments, suspended solids Plastics, metals, plastic additives Hydrocarbons	1) Direct discharge from conveyor/road into reservoir. 2) Surface runoff from conveyor maintenance road, discharging into reservoir	1) Top cover conveyor 2) Maintenance road causeway is bunded (secondary bunding) to contain vehicles and spills. 3) Bitumen on causeway. 4) Drainage channel on length of causeway. 5) Daily maintenance/inspection/condition monitoring. 6) Dust suppression on ore prior to conveying. 7) Light vehicles used for inspections, diesel only site. 8) Spill response procedures, equipment and training
Exploration Clearing and construction Roads and infrastructure Mining support Mining Rehabilitation	1) Construction and operational vehicles and equipment in catchment and RPZ 2) Tyre wear releasing microplastics and other tyre additives (metals, plasticisers, antioxidants, antimicrobials, lubricants, and vulcanisers) via runoff	Metals, microplastics	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Surface runoff from haul roads and other paved/compacted areas, discharging into stream or direct to reservoir 3) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 4) Transport along stream during winter / spring flow period, discharging into reservoir	1) Construction water management plan 2) Operational Control Area between reservoir and streams (Water Working Arrangements) 3) 'Water shots' (mechanical fracturing of ground) to minimise runoff from mine pits infiltration and prevent runoff 4) Provision of engineering designed sumps downstream of haul roads and cleared areas 5) Schedule rehabilitation as early as practicable to minimise period of uncovered soil 6) Turbidity monitoring 7) Clearing windrow along contour 8) Haul road design and drainage management manual upgraded 9) Dedicated water crew undertaking sump cleaning program 10) Red alert checklist process 11) Changing of operational strategy to open fewer concurrent sites (big blend process in Myara North) 12) Mine pit analysis and sump design

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Mine power supply	1) Construction and operations power supply 2) Diesel power plant fuel farm leak or spill 3) Substations transformer oil leak or spills	Hydrocarbons	1) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Construction compound and mine facilities located outside of RPZ 2) Operational Control Area between power plant fuel farm/transformers and streams 3) Power plant fuel farm/transformers located at high depth to groundwater 4) Power plant fuel farm comprises above ground, double walled tanks 5) Hazardous material segregation / distance from fuel farm 6) Fire suppression system at fuel farm 7) Fire response equipment, procedures and training - McCoy fire station 8) Spill response equipment, procedures and training 9) Monitoring bores upstream and downstream of fuel farm
Mine facilities	1) Construction and operational vehicles and equipment in catchment and RPZ 2) Vehicle and equipment washdowns 3) Washbay washwater generation	Suspended solids Hydrocarbons Surfactants Nutrients Metals	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) All vehicle and equipment washing undertaken at construction compound and mine facilities, located outside of RPZ 2) Heavy vehicle washway located at McCoy mine facilities 3) Operational Control Area between washbays/wastewater system and streams 3) Isolated drainage system to contaminated wastewater treatment system 4) Contaminated wastewater treatment to remove sediment and hydrocarbons 5) Treated effluent tested prior to reuse 6) Monitoring and maintenance of contaminated wastewater treatment system
Mine facilities	1) Construction and operational vehicles and equipment in catchment and RPZ 2) Fuel storage and handling at mine facilities 3) Vehicle parking at mine facilities 4) Vehicle and equipment maintenance at mine facilities	Suspended solids Hydrocarbons Surfactants Metals	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 4) Transport along stream during winter / spring flow period, discharging into reservoir	1) All planned vehicle and equipment maintenance undertaken at construction compound and mine facilities, located outside of RPZ 2) Operational Control Area between fuel delivery areas, refuelling bays, carparks, maintenance areas and streams 3) Refuelling bays and vehicle/equipment maintenance in roofed buildings with sealed concrete floors to prevent rainfall ingress and contain spills 4) Isolated drainage system to contaminated wastewater treatment system 5) Contaminated wastewater treatment to remove sediment and hydrocarbons 6) Treated effluent tested prior to reuse 7) Monitoring and maintenance of contaminated wastewater treatment system 8) Speed limits apply within the mine area, with lower limits (35 km/hr) near stream crossings.
Mine facilities	1) Overflow of contaminated water ponds	Suspended solids Hydrocarbons Surfactants Nutrients	1) Overland flow during heavy rainfall and wet ground conditions, discharging into stream or direct to reservoir 2) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 3) Transport along stream during winter / spring flow period, discharging into reservoir	1) Wastewater system located outside of RPZ 2) Operational Control Area between wastewater ponds and treatment system and streams 3) Raw wastewater pond located in roofed area to prevent ingress of rain 4) Provision of freeboard in raw and treated wastewater ponds to prevent overflow during major storm events
Mine facilities	1) Construction and operation vehicles and equipment 2) Bulk diesel fuel storage for vehicle and equipment fleet	Hydrocarbons	1) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Construction compound and mine facilities located outside of RPZ 2) Operational Control Area between diesel fuel farm and streams 3) Fuel farm located at high depth to groundwater 4) Fuel farm comprises above ground, double walled tanks 5) Hazardous material segregation / distance from fuel farm 6) Fire suppression system at fuel farm 7) Fire response equipment, procedures and training - McCoy fire station 8) Spill response equipment, procedures and training 9) Monitoring bores upstream and downstream of fuel farm

Activity	Source	Contaminants	Pathway	Preventive measures / barriers - prior to discharge to reservoir Excludes dilution, settling, attenuation in reservoir, or treatment by Water Corporation
Mine facilities	1) Construction and operational vehicles and equipment 2) Hazardous materials / package chemical storage and use for vehicle and equipment maintenance	HydrocarbonsOrganic solvents SurfactantsPFAS	1) Infiltration through soils into groundwater, subsurface flow discharging into stream or direct to reservoir 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Construction compound and mine facilities located outside of RPZ 2) Operational Control Area between hazmat/chemical store and streams 3) Hazmat/chemicals stored in flammable lockers or bunded pallets, within roofed buildings with sealed concrete floor 4) Hazmat segregation 5) Fire suppression system at hazmat/chemical store 6) Fire response equipment, procedures and training - McCoy fire station 7) Spill response equipment, procedures and training 8) Phase out of PFAS materials, no PFAS containing AFFF to be used in Myara North or Holyoake
Construction	1) Haul road construction over/near waterways 2) Disturbance to bed and banks of waterways	Sediment	1) Erosion of bed and banks causing elevated sediment 2) Transport along stream during winter / spring flow period, discharging into reservoir	1) Haul road crossings limited to above 100% reservoir water level. 2) Haul road crossings minimised to the extent practical and aligned at perpendicular angle to minimise disturbance at crossing sites. 3) Construction timed outside of flow periods as far as practicable. 4) If occurring during flow periods, use of upstream/downstream coffer dams to divert water around construction site. 5) Disturbed bed and banks around crossings rehabilitated/stabilised at completion of construction to prevent erosion.
Construction	1) Conveyor / causeway construction over/near streams 2) Disturbance to bed and banks of streams 3) Conveyor / causeway construction over reservoir 4) Disturbance to bed and banks of reservoir	Sediment	1) Erosion of bed and banks of streams causing elevated sediment 2) Transport along stream during winter / spring flow period, discharging into reservoir 3) Erosion of bed and banks of reservoir	1) Conveyor and causeway crossings minimised to the extent practical and aligned at perpendicular angle to minimise disturbance at crossing sites. 2) Conveyors constructed by spans over Serpentine River and Big Brook, avoiding earthworks or footings within or adjacent to the reservoir. 3) Construction to be undertaken in periods when risk of significant rainfall events occurring is low (November to April). 4) Works will be suspended during significant rainfall events. This will depend on the frequency of rainfall during the summer period. 5) Weather forecasts will be used to assess if construction operations should continue when rainfall events are predicted, following the Alcoa Red Alert process, and/or cease when a major storm event is predicted by these forecasts. 6) Installation and maintenance of temporary erosion and sediment control measures for all works within streams. 7) Disturbed streams around crossings stabilised at completion of construction to prevent erosion. 8) Lay down yard will be provided away from the stream. Ablutions will be provided here by means of portable toilets ensuring they are more than 100 m from drainage lines and the Top Water Level (TWL) of the dam.

Appendix D

Site Images



Figure D-1 Erosion control measures (watershots, blasted drainage lines) on cleared hillside



Figure D-2 Erosion control measures (watershots, blasted drainage lines) on cleared hillside #2



Figure D-3 Temporary facilities, overhead view



Figure D-4 Temporary facilities, angle view



Figure D-5 Effluent discharge area, signage



Figure D-6 Effluent discharge area, metering



Figure D-7 Effluent discharge area, purple dripper pipe dispersing to leaf litter on ground surface



Figure D-8 Effluent discharge area, overland piping prior to discharge area



Figure D-9 20-year jarrah and marri rehabilitation at Banya

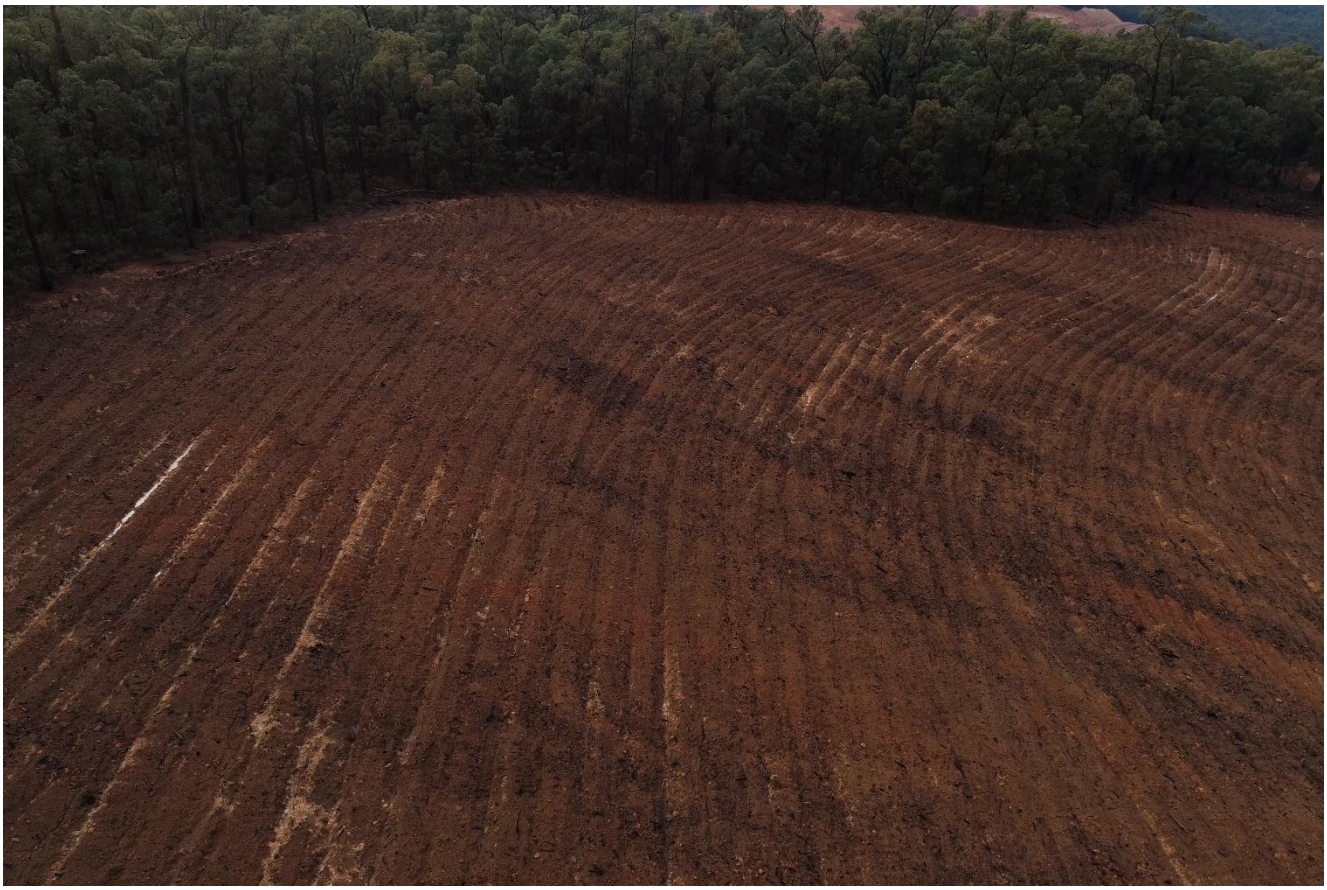


Figure 10 0-year rehabilitation at Kisler

Appendix E

Hydrologic modelling

Catchments

The reservoir receives inflow from major and minor streams, overland flow paths and as direct rainfall on the water surface. For modelling purposes, minor inflows are consolidated into the main inflow locations depicted in Figures E.1 and E.2 below. Where hydrodynamic model water levels are too low to match inflow locations, the inflow is applied at the nearest wet cell in the model. Catchments were defined in greater detail in areas subject to mining.

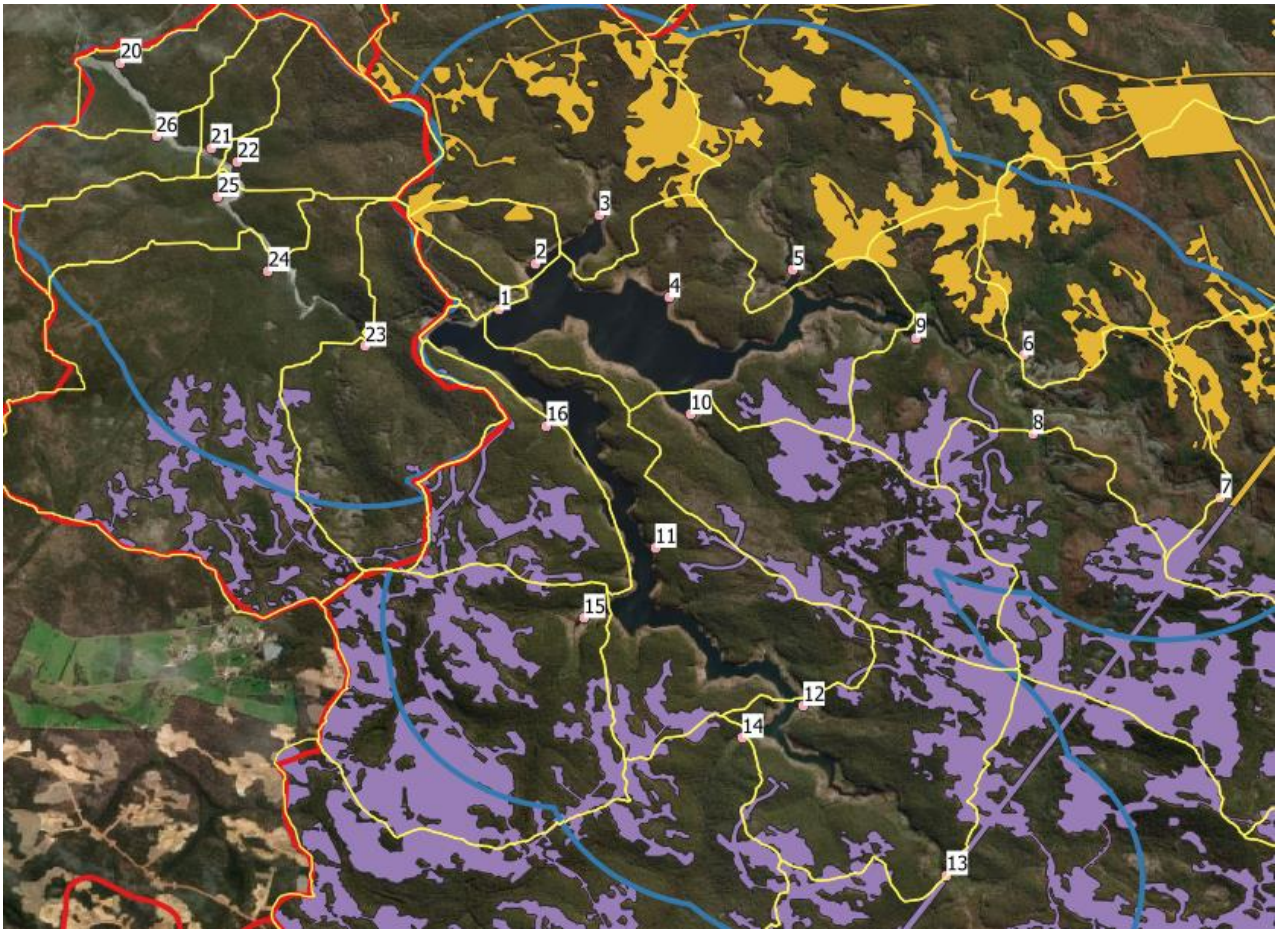


Figure E.1 Serpentine and Serpentine Pipehead catchment breakdown and hydrodynamic model input locations

Table E.1 Serpentine catchment areas (clockwise from dam wall)

Label	Total Area (ha)	Current approved mining (ha)	Proposal clearing (ha)	Total clearing (ha)
1	54	0	0	0
2	117	0	15	15
3	1064	0	243	243
4	740	49	7	56
5	6618	0	1130	1130
6	1059	0	249	249
7	29454	783	645	1428
8	982	449	0	449
9	734	67	90	157
10	718	274	0	274
11	758	74	0	74
12	664	179	0	179

Label	Total Area (ha)	Current approved mining (ha)	Proposal clearing (ha)	Total clearing (ha)
13	20889	1587	0	1587
14	1269	494	0	494
15	955	459	0	459
16	387	103	0	103

Table E.2 Serpentine Pipehead catchment areas (clockwise from dam wall)

Label	Area (ha)	Current approved mining (ha)	Propoal clearing (ha)	Total clearing (ha)
20	183	0	0	0
21	113	0	0	0
22	297	0	0	0
23	564	21	0	21
24	1295	199	0	199
25	271	0	0	0
26	163	0	0	0

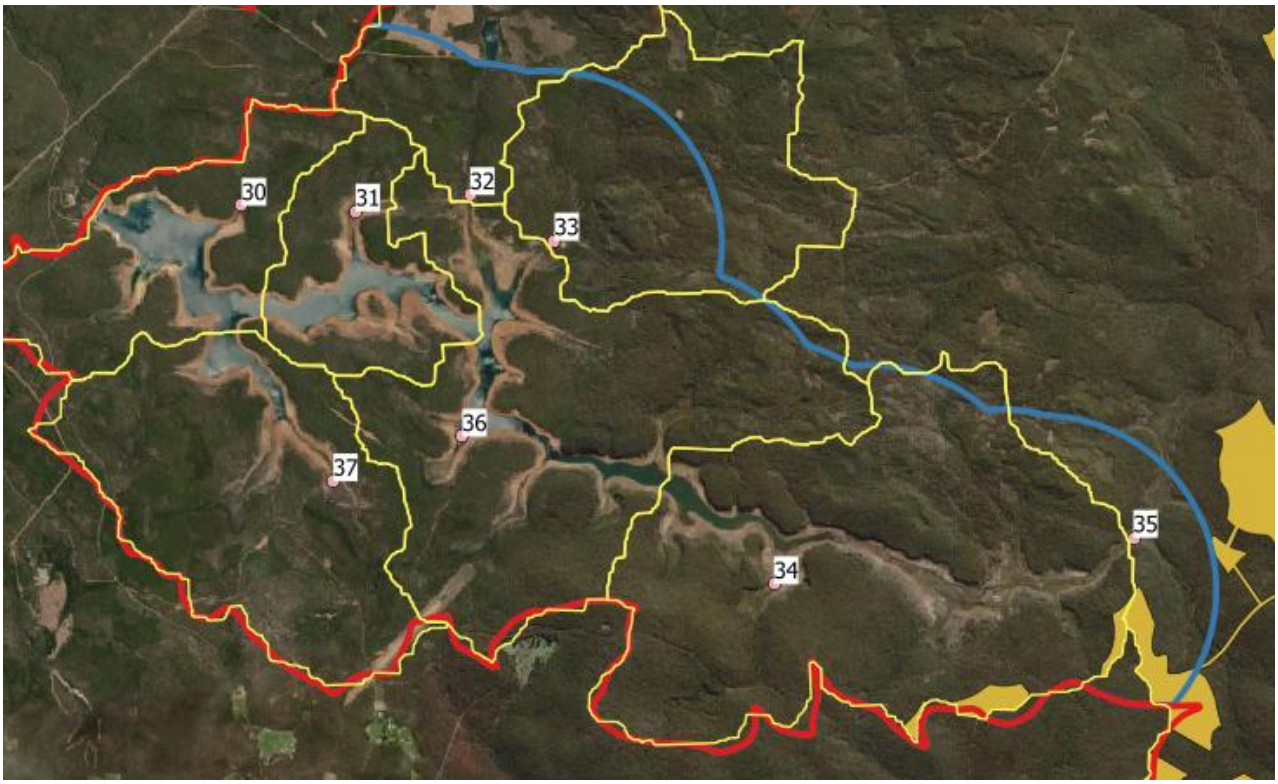


Figure E.2 South Dandalup catchment breakdown and hydrodynamic model input locations

Table E.3 South Dandalup catchment areas (clockwise from dam wall)

Label	Area (ha)	Current approved mining (ha)	Future clearing (ha)	Total clearing (ha)
30	648	0	0	0
31	458	0	0	0
32	615	0	0	0
33	903	0	0	0
34	1854	0	35	35
35	23943	0	1440	1440
36	1573	0	0	0
37	1073	0	0	0

Rainfall

Rainfall Intensity Frequency Duration (IFD) data has been obtained for the centroids of each PDWSA from the Bureau of Meteorology (Rainfall 2016 IFD Data System, 2016).

Hydrology

Approach

Referring to GHD (2021), baseflow represents between 45 and 80 per cent of streamflow. Baseflow represents a higher proportion of streamflow for long duration events compared to short duration events. For reasons explained in the Turbidity section, long duration events are critical for barriers to turbidity failure scenarios. Based on the nature of the catchment, requirements of the turbidity modelling, and standard hydrologic practices, it is proposed to analyse baseflow and mining generated quick flow separately. A conceptual runoff model is illustrated in Figure E.3. For the baseflow and interflow components of all surfaces, and the quick flow component of un-mined surfaces, streamflow is best estimated using stream gauge data, scaled relative to design rainfalls and observed runoff coefficients. The surface runoff component of mined surfaces is represented using a hydrologic event-based model.

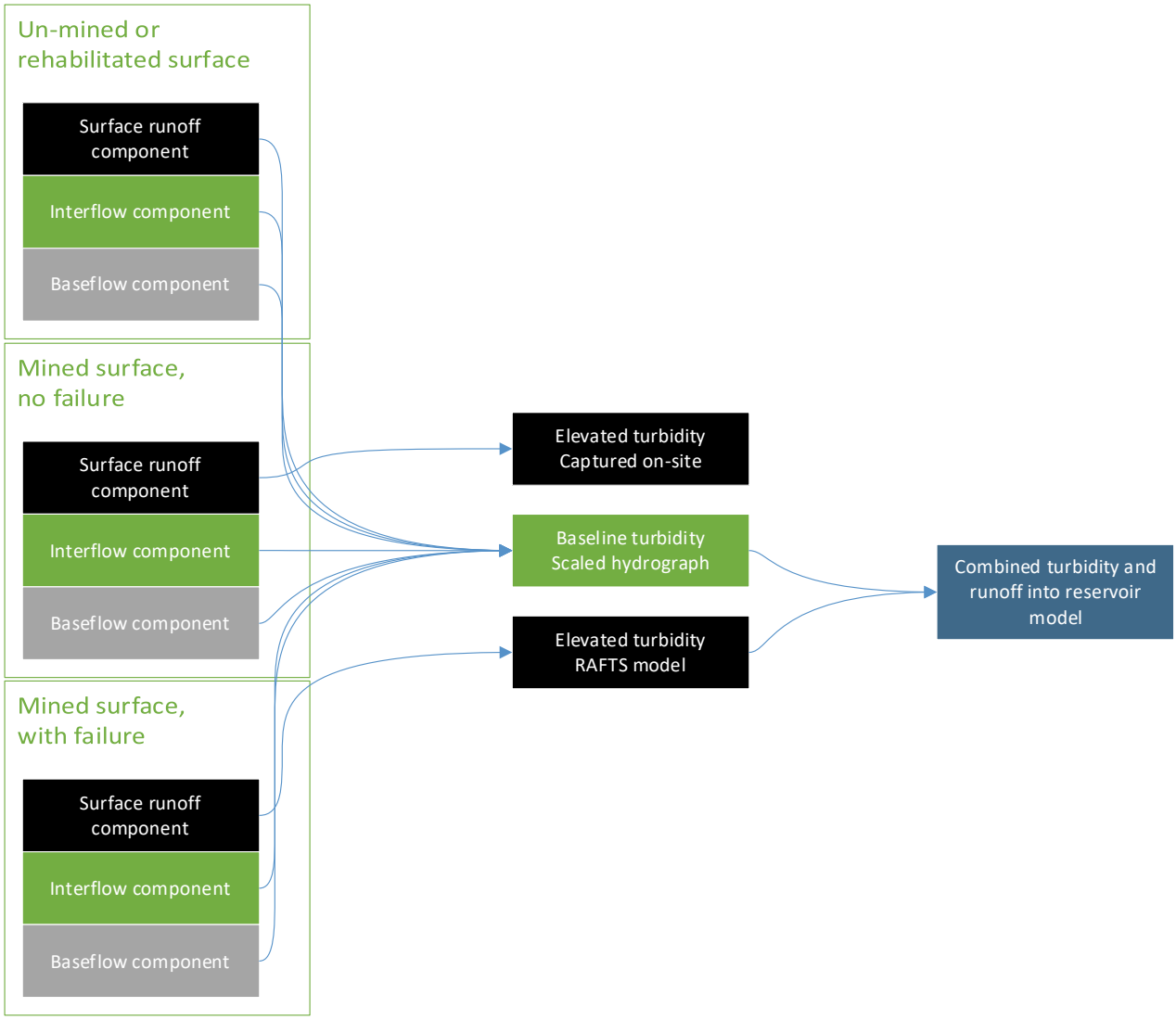


Figure E.3 Conceptual runoff model

Hydrograph scaling

Data analysis

Inspection of stream gauge data indicates that the majority of runoff (stormflow and interflow) occurs within 7-days of a rainfall event. To estimate the 14-day runoff volume for a 7-day rainfall event, the 14-day runoff coefficient was calculated for each of the gauged catchments. To understand if there is any relationship between the runoff coefficient and the magnitude of the rainfall event, a runoff coefficient was calculated for all gauged runoff events, together with magnitude of the runoff event.

Daily, spatially gridded rainfall data was analysed for the period 1970 to 2020 for each of the gauged catchments using data from SILO (2021). Rainfall IFD data was obtained for each stream gauge catchment and adjusted by an Aerial Reduction Factor (ARF) equation obtained from the Australian Rainfall and Runoff data hub (Babister, 2016). The table below summarises the frequency that the SILO data exceeded the 7-day IFD data.

Table E.4 7-Day rainfall event frequency 1970-2020 by stream flow gauging station

Rainfall AEP	614007 Del Park	614031 Jack Rocks	614035 River Rd	614037 O'Neil Rd	614059 Skeleton Road	614060 Gordon Catchment
> 1%	0	0	0	0	0	0

Rainfall AEP	614007 Del Park	614031 Jack Rocks	614035 River Rd	614037 O'Neil Rd	614059 Skeleton Road	614060 Gordon Catchment
1% to 2%	0	0	0	0	0	0
2% to 5%	8	3	0	0	0	0
5% to 10%	2	7	0	0	2	0
10% to 20%	24	7	1	2	4	7
20% to 50%	90	21	14	29	19	36
maximum recorded	204.7	229.4	178.2	170.1	195.8	176.1

The 14-day runoff coefficient was calculated for a range of 7-day rainfall events, illustrated below. The runoff coefficient increases as the frequency of the event increases. The larger catchments (614031, 614035, and 614037) have similar runoff coeffects for similar storm events, however the other smaller catchments show greater variation. To address uncertainty, the catchment weighted runoff coefficient for the 4EY event is conservatively adopted (3.50 per cent) for the 1EY, 10 per cent AEP, and 1 per cent AEP design storms.

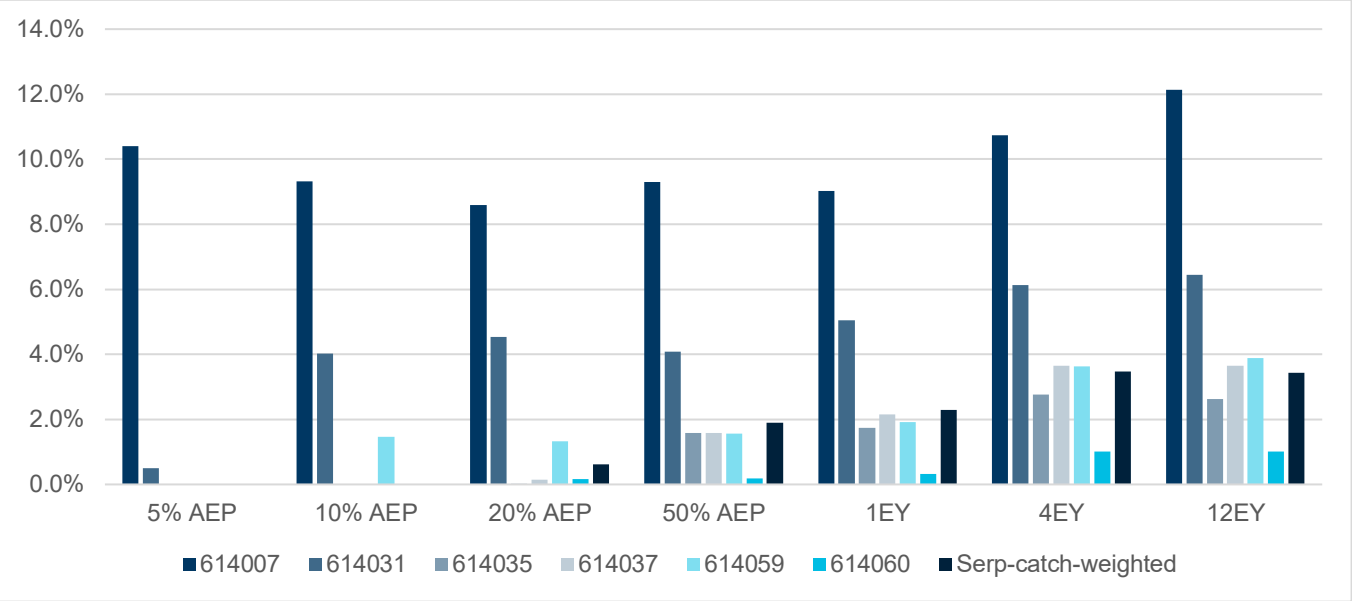


Figure E.4 14-day runoff as a percentage of 7-day rainfall

Unit hydrograph

A 14-day duration unit hydrograph was obtained from the largest recorded event at the Serpentine gauge, commencing 29th July 1996. This runoff event was assessed as a 2.4 per cent AEP (1 in 42-year) event. The hydrograph was scaled to suit the volume of runoff for each design storm (table below), using a 3.5 per cent runoff coefficient.

Table E.5 Adopted rainfall depths for each PDWSA

Catchment	1EY 7-day	10% AEP 7-day	1% AEP 7-day
Serpentine	126	183	252
Serpentine Pipehead	124	182	251
South Dandalup	118	166	228

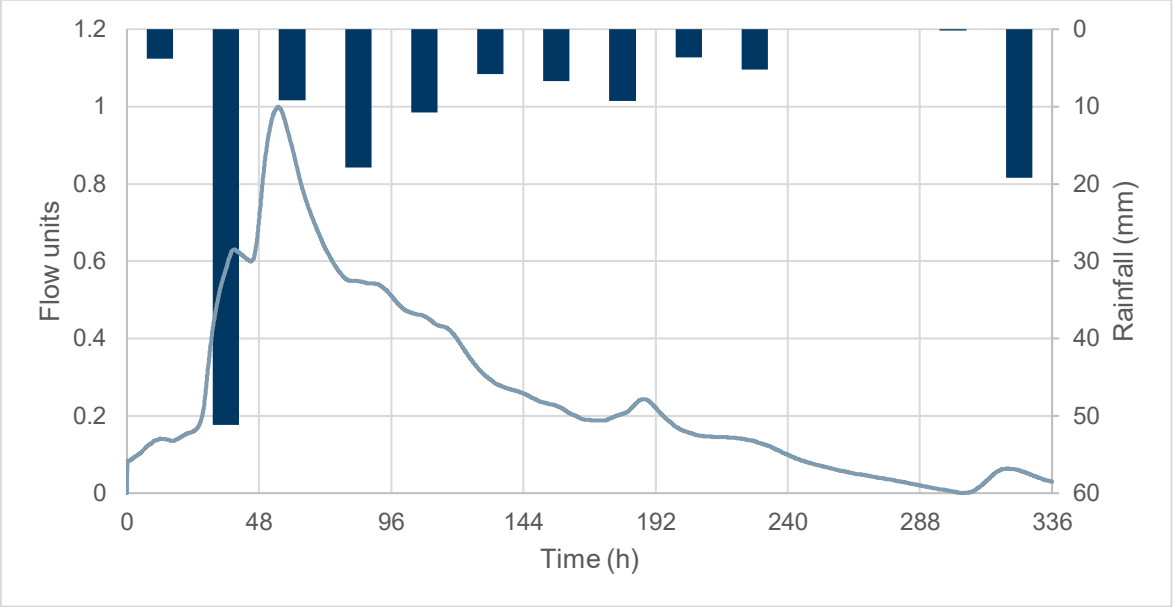


Figure E.5 Unit hydrograph

Mine surface runoff

Storm runoff rates vary according to the runoff surface, with mine pits and haul roads providing the greatest runoff. For simplicity, it will be assumed that surfaces are either undisturbed or actively mined as detailed in Table E.6.

Table E.6 Storm runoff rates by surface

Runoff surface	Runoff rates	Initial and continuing loss
Un-mined forest	Low	Modelled using scaled gauge data
Rehabilitated mining	Low-Moderate	Classified as un-mined surface
Recently rehabilitated mining	Moderate	Classified as mined surface
Cleared with topsoil	Moderate	Classified as mined surface
Cleared without topsoil	Moderate-High	Classified as mined surface
Active or recent mining, or haul road	High	15 mm, 2 mm/hr

Initial and continuing loss rates are adopted for actively mined areas in accordance with procedures detailed in Australian Rainfall and Runoff (Ball, et al., 2019). Values are estimated from anecdotal evidence and engineering judgement, taking into consideration factors such as:

– Geotechnical properties of exposed materials.
– Absence of interception loss (except for areas undergoing rehabilitation).
– Depression storage on rough mining surfaces.
– Prescence of formal and informal barriers such as deep ripping, contour ripping, and mine pits.

An XP-Rafts hydrologic model was used to represent mined runoff surfaces. For simplicity and as a means of treating uncertainty, mine runoff surfaces were assumed to be directly connected to the reservoir without any loss or attenuation associated with the overland flow paths and streams between the mine pits and the water surface. Catchment slopes were based on the topography at the date of the lidar survey.

Table E.7 summarises the areas assumed to be actively or recently mined, or haul roads.

Table E.7 Mining catchment areas

PDW SA	Mining region	Historical, current, and future clearing area within catchment (Ha)	Status	Adopted active mining catchment area (Ha)
Serpentine	O'Neil	1,153	Predominantly rehabilitated	0 (all scenarios)
	McCoy	2,140	Predominantly rehabilitated	0 (all scenarios)
	East Murray	Unknown	Rehabilitated	0 (all scenarios)
	Myara	4,517	Predominantly mined	0 (un-mined scenarios) 4,517 (existing and future scenarios)
	Myara North	2,379	Un-mined	0 (un-mined and existing scenarios) 2,379 (future scenarios)
SPH	Myara	220	Partially rehabilitated	0 (un-mined scenarios) 220 (existing scenarios) 0 (future scenarios)
South Dandalup	White	1,143	Predominantly rehabilitated	0 (all scenarios)
	Del Park	363	Predominantly rehabilitated	0 (all scenarios)
	Huntly 1&2	529	Predominantly rehabilitated	0 (all scenarios)
	Holyoake	1,475	Un-mined	0 (un-mined and existing scenarios) 1,475 (future scenarios)

Barrier failure rates

Existing and proposed turbidity barriers include sedimentation sumps, infiltration sumps, water shots, bunds, deep ripping, contour ripping, windrows, mulching, operational controls, and other ad-hoc measures. Sump failures are more likely to occur during long duration storm events where runoff volumes exceed sump volumes. Sumps are currently designed for a range of events ranging from the 10 per cent AEP 24-hour event in low risk areas to the 1 per cent AEP 7-day event in high risk areas.

Table E.8 Mine drainage design risk rating

Design Risk Rating Guide				
Location	**Facility Design Life**			
	<2-year	**2 to 5-years**	**5 to 10 years**	**10 + years**
OCA1	5	5	5	5
OCA2	5	5	5	5
RPZ	3	4	4	5
P1 Catchment	2	3	4	4
Non P1	2	2	3	4
Elsewhere	1	2	3	3

Table E.9 Mine drainage design storm event criteria

Risk Rating	Sedimentation Sump	Infiltration Sump	Conveyance (channel, drain, chute, etc.)
1	5% AEP storm of 24-hr duration	5% AEP storm of 24-hr duration	10% AEP storm of 24-hr duration
2	1% AEP storm of 24-hr duration	5% AEP storm of 24-hr duration	5% AEP storm of 24-hr duration
3	0.5% AEP storm of 24-hr duration	0.5% AEP storm of 24-hr duration	1% AEP storm of 24-hr duration
4	0.2% AEP storm of 24-hr duration	0.2% AEP storm of 24-hr duration	1% AEP storm of 72-hr duration

Risk Rating	Sedimentation Sump	Infiltration Sump	Conveyance (channel, drain, chute, etc.)
5	1% AEP storm of 168-hr duration	1% AEP storm of 72-hr duration	0.2% AEP storm of 72-hr duration

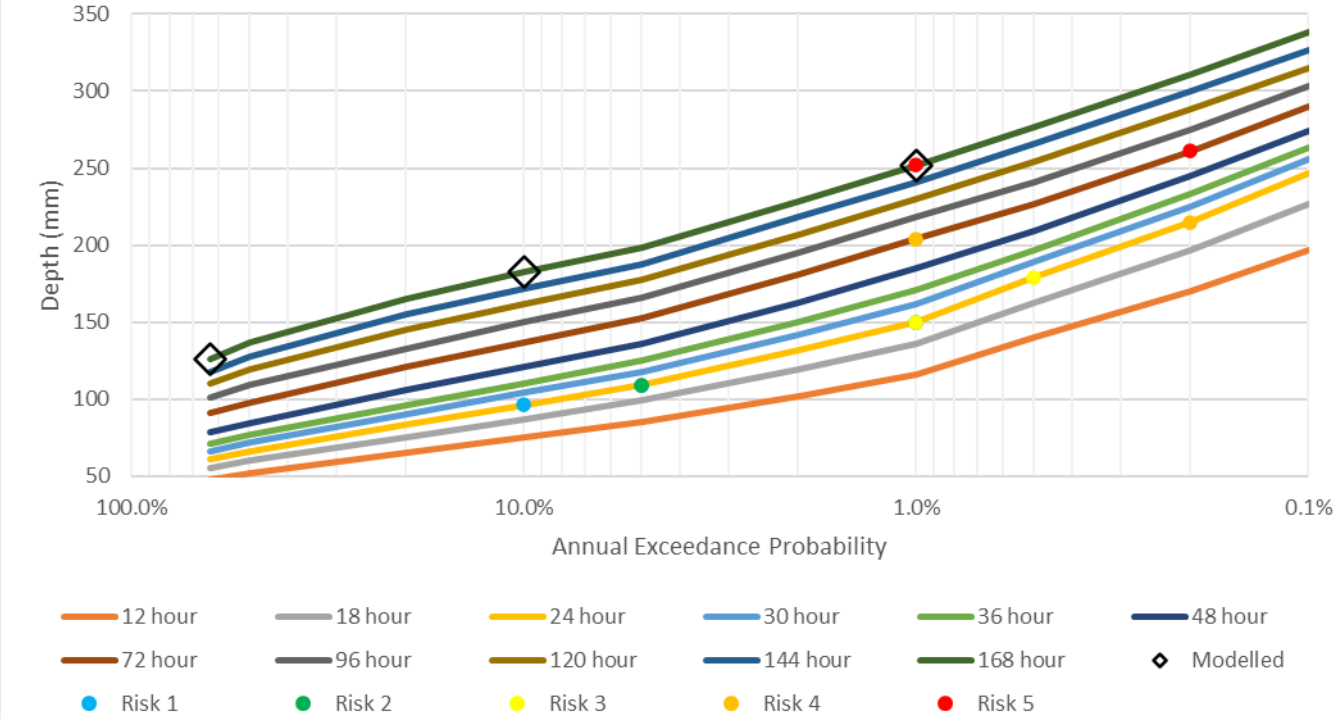


Figure E.6 Serpentine rainfall IFD

Referring to Figure E.6 in relation to Table E.9, sumps with a risk rating of 5, located in the Serpentine catchment, will cater for up to 252 mm of rainfall (1 per cent AEP 168-hour). However, all sumps with a risk rating of 4 or less will spill in this event. This event is therefore selected as the conceivable worst case failure event.

Referring to Figure E.6 in relation to Table E.9, sumps with a risk rating of 3 or above, located in the Serpentine catchment, will cater for up to 179 mm of rainfall (0.5 per cent AEP 24-hour). In a more frequently occurring 10 per cent AEP 168-hour event, 183 mm of rain will fall, causing all sumps with a risk rating of 3 or less to spill.

Referring to Figure E.6 in relation to Table E.9, sumps with a risk rating of 1 or above, located in the Serpentine catchment, will cater for up to 109 mm of rainfall (5 per cent AEP 24-hour). In a more frequently occurring 1EY 168-hour event, 126 mm of rain will fall, causing all sumps with a risk rating of 1 to spill, and infiltration sumps with a risk rating of 2 to spill.

When a sump spills, it won't necessarily fail catastrophically and release the entire content of the sump and the entire catchment runoff. However, given the uncertainty in predicting the failure behavior, and to cater for mine catchments not serviced by sumps, it has been conservatively assumed that all runoff from the mined catchment discharges to the reservoir.

Based on the number of sumps servicing the Myara mining region, it is estimated that up to 800 sumps will be active at the peak of future mining activity in the Serpentine catchment. Whilst it is not known which risk category will apply to each sump, a conservative estimate is presented in Table E.10. This is converted into a catchment proportion for each storm event.

Table E.10 Serpentine sump failure rates

Storm Event	Sump failure risk rating	Estimated number of active sumps meeting this criterion	Estimated total number of active sumps	Proportion of mined catchment
1 EY	=1 or 2 (inf.)	40	800	5%

Storm Event	Sump failure risk rating	Estimated number of active sumps meeting this criterion	Estimated total number of active sumps	Proportion of mined catchment
10% AEP	<=3	240	800	30%
1% AEP	<=4	600	800	75%

It is important to note that events shorter than 7-days will produce higher peak flows in the main streams, however, are less likely to cause a turbidity failure. The volume of runoff and the volume of turbid water is of primary concern to this assessment.

Failure likelihood

The likelihood of the design event has been assessed against Water Corporation and ADWG criteria.

Table E.11 Turbidity barrier failure likelihood

Storm event	Water Corporation Corporate Description	Water Corporation Corporate Frequency	ADWG Likelihood Rank and Descriptor
1 EY	Known to re-occur approximately annually. Known to occur across like industries or within corporation.	Will occur once per year	B – Likely
10% AEP	The event could occur at some time. Known to have occurred once ortwice within industry.	Will occur once in 10 years	D – Unlikely
1% AEP	The event may occur in exceptional circumstances. An example of this hasoccurred historically, but is not anticipated.	Will occur once in 30 years or less	E – Rare

Turbidity and Total Suspended Solids

Turbidity occurs naturally and because of clearing activities. Naturally occurring turbidity spikes are associated with large storm events. Where clearing and mining has occurred, exposed soils are subject to erosive action, mobilising sediment and suspended solids. The amount of erosion is a factor of soil properties (erodibility), catchment slope and length, rainfall intensity (erosivity), and vegetative cover.

Data analysis

The following turbidity data has been analysed:

– Water Corporation stream, reservoir, and offtake grab samples for period 2000 to 2020.
– Alcoa stream compliance monitoring continuous readings, located downstream of cleared, mined, or rehabilitated regions
– Department of Water and Environmental Regulation Water Information Reporting (WIR) measurements at stream gauges and other locations, for period 1975 to 2000

Baseline turbidity

To estimate in-stream turbidity from un-mined catchments, 4589 historical WIR turbidity measurements from the subject PDWSA's were analysed. Of this data, 1762 measurements were collected across six gauging stations at a time when flow was non-zero. These measurements were compared to flow rate for the purpose of identifying if there is a relationship between flow rate and turbidity. Where hourly streamflow data was available, streamflow was obtained for the same hour that the turbidity measurement was taken, otherwise the daily average streamflow was adopted. Given that the average daily flow readings are within ±17 per cent of the daily range, 80 per cent of

the time, this is an acceptable estimate of the flow rate on these occasions. Discharge rates were converted to specific discharge to account for the varying catchment areas between gauges.

Referring to the figure below, turbidity has negligible relationship with flow rate. Measurements were also checked for hysteresis by classifying the measurement as being collected during the rising or falling limb of the hydrograph. The rising limb turbidity was, on average, 1.2 per cent higher than the falling limb readings, indicating no statistically significant hysteresis.

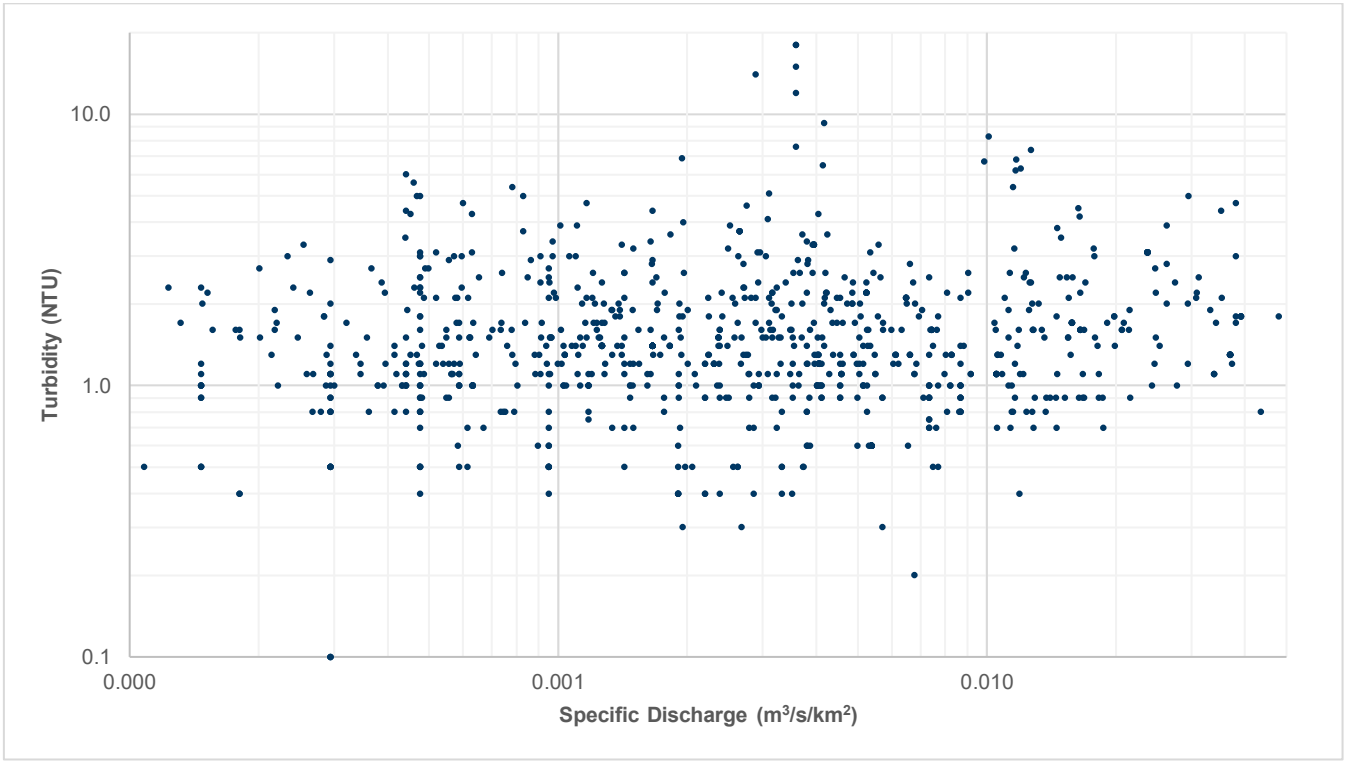


Figure E.7 Turbidity-flow relationship

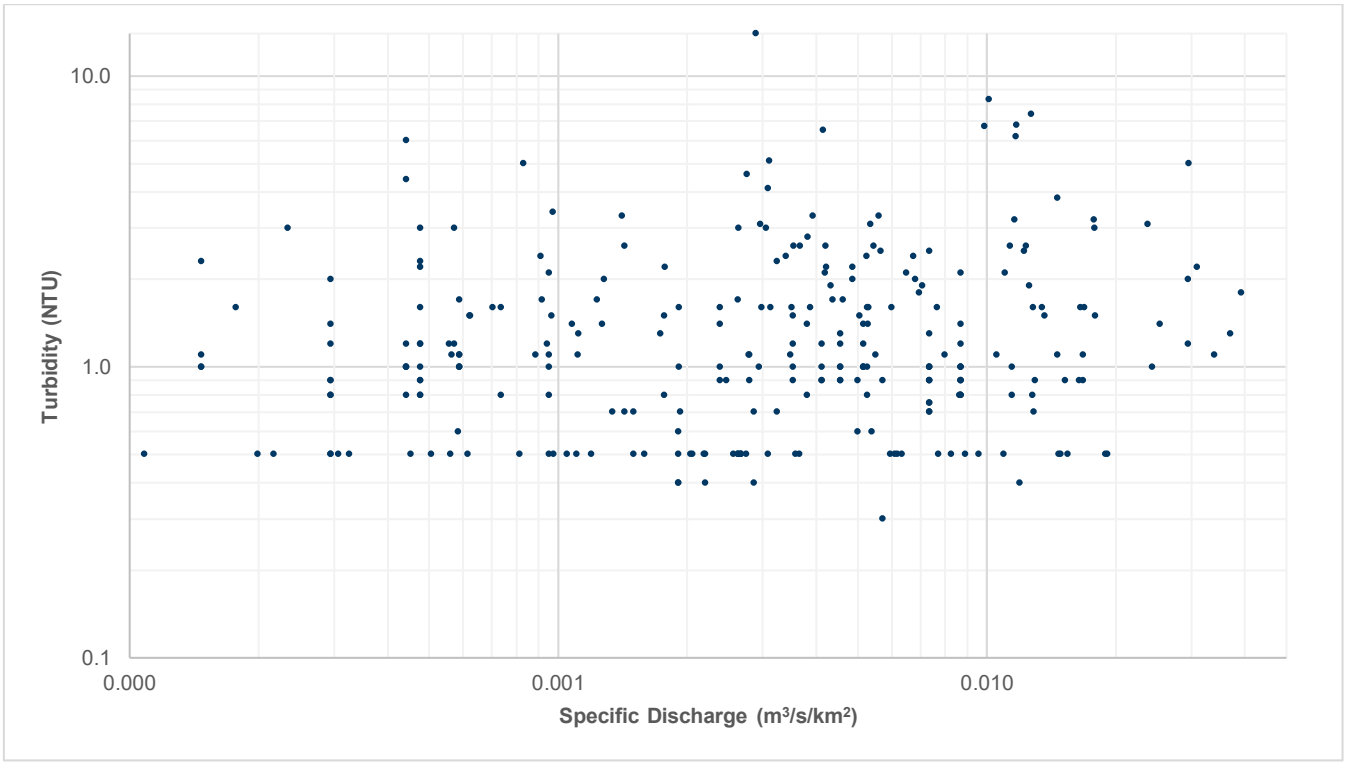


Figure E.8 Rising limb turbidity-flow relationship

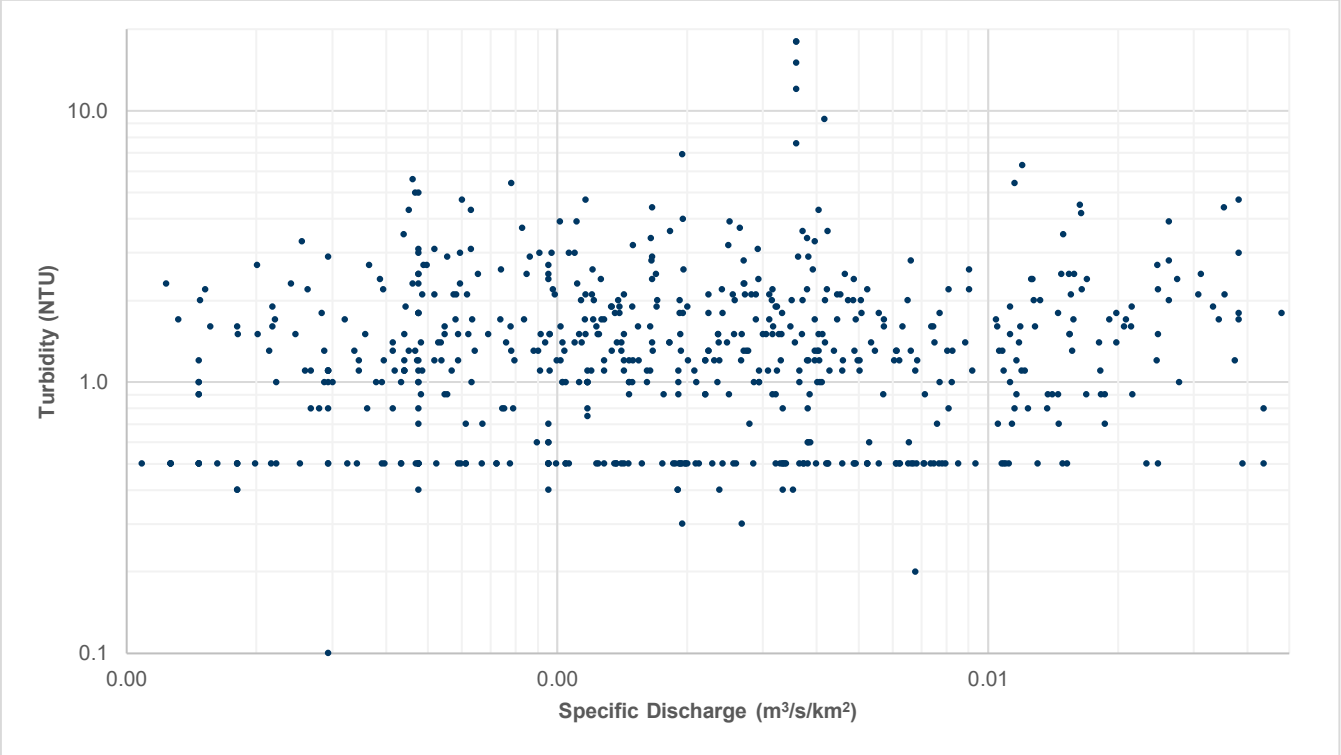


Figure E.9 Falling limb turbidity-flow relationship

In the absence of a relationship between turbidity and flow, an average turbidity of 1.6 NTU is adopted for hydrodynamic modelling of un-mined catchment discharge.

Mining turbidity

The Alcoa turbidity compliance monitoring data was used to estimate turbidity from mined catchments under a barrier failure scenario. Data from 54 monitoring stations covering a combined duration of 394-years was analysed. Despite the large volume of monitoring data and detailed incident reporting system, there is little monitoring data that corresponds to the time and location of known failures. It is understood that incident turbidity data was captured but could not be located. The monitoring stations also lack flow rate data to derive turbidity loads from concentrations.

An attempt was made to adopt a statistical analysis of the data to estimate turbidity levels following a failure event. Prior to the analysis, the data required the following cleaning and filtering steps to remove erroneous data associated with faulty instrumentation:

– Instruments appear to become dirty over time, with a gradual increase in the minimum reading. Spot readings were adjusted by a local minimum to correct this.
– Turbidity of flow months with <2 per cent annual runoff (Dec-May) was assumed to be zero due to high prevalence of erroneous readings during dry periods.
– Periods of constant and very high turbidity lasting more than 14 days presumed to be erroneous and excluded.
– Non-zero readings that are identical for 14-days or longer are assumed to erroneous and are excluded.

Figure E.0 illustrates that despite a month of zero rainfall, 16 of 36 active gauges are recording non-zero turbidity readings, with many turbidity readings extremely high.

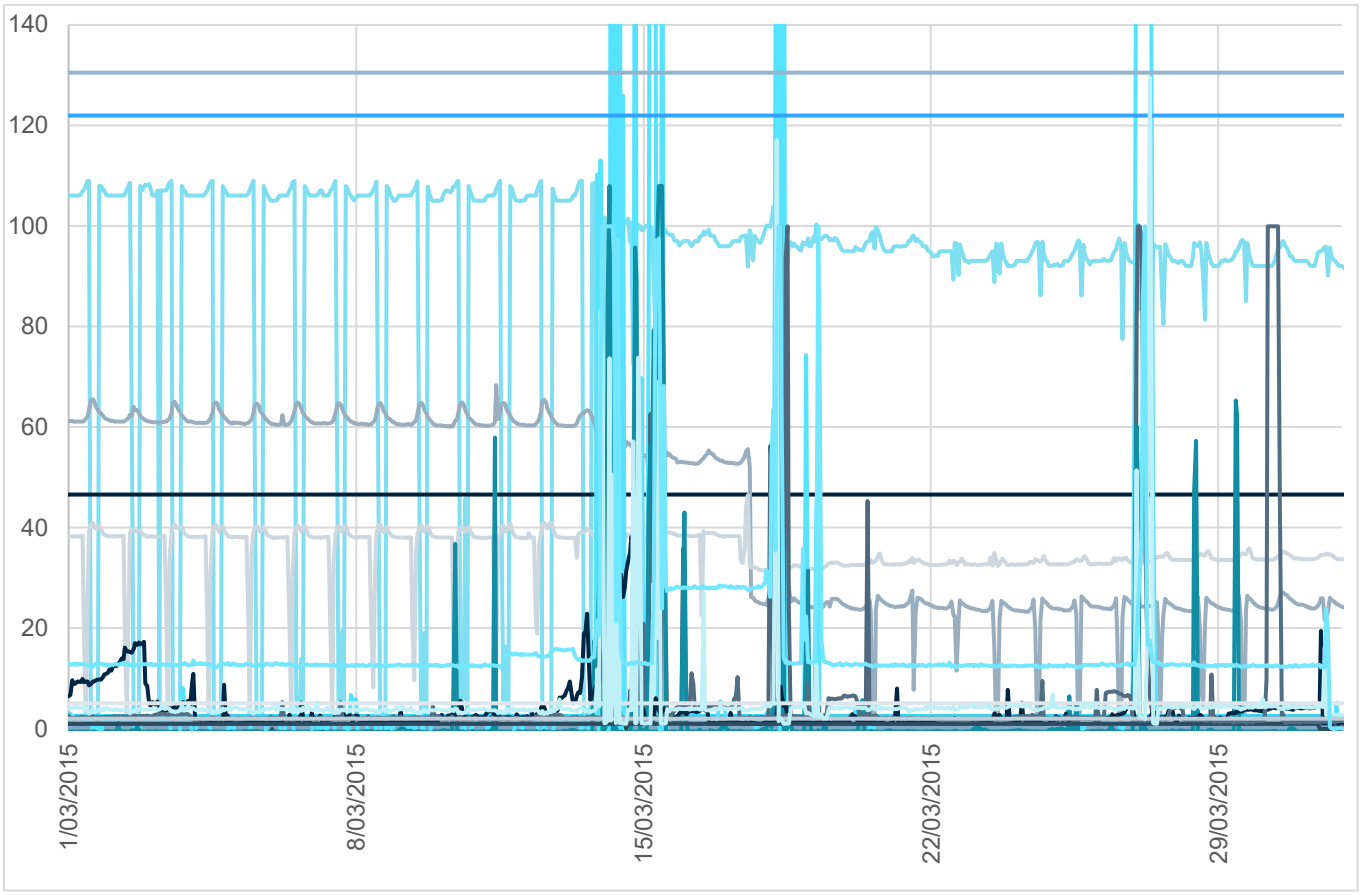


Figure E.0 Example raw turbidity data

Whilst the data cleaning removed some erroneous data, it is clear from inspection of the cleaned data that copious residual errors remain. This approach is therefore deemed unsuitable to establish turbidity levels from uncontrolled mine catchment discharge.

Turbidity readings from known failures with error-free corresponding turbidity data have been adopted as a guide to turbid discharge from mined catchments (Figure E.10). A constant sump failure turbidity of 31.5 NTU was assumed in the case of effective sump turbidity management. This is conservative in terms of the current operational stream limit in mined catchments of 25 NTU for no more than 1 hour. For the case of ineffective sump turbidity management, the continuous turbidity levels during drainage failures was doubled to 63 NTU.

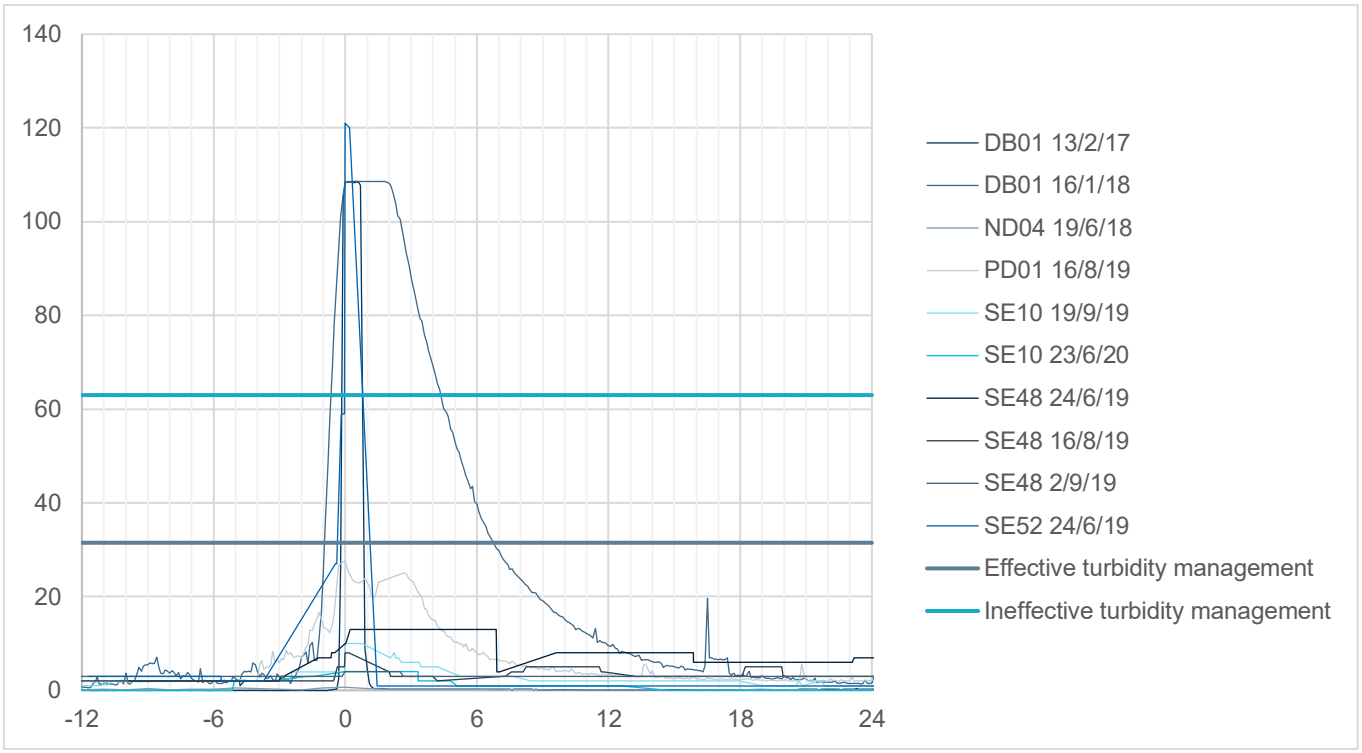


Figure E.10 Known turbidity events

TSS relationship to turbidity

Turbidity is a construct of Total Suspended Solids (TSS), used for measurement purposes. The hydrodynamic modelling requires TSS input. In the absence of continuous TSS monitoring for mined and un-mined catchments, GHD has undertaken soil sampling of three natural waterways and three mining sumps to quantify potential TSS loads mobilised during runoff events. By mixing and diluting these samples in a laboratory, a relationship between TSS and turbidity is established. Referring to Figure E.11, the natural baseline TSS is 1.42 times the turbidity value, whilst the sump failure TSS is 0.63 times the turbidity value.

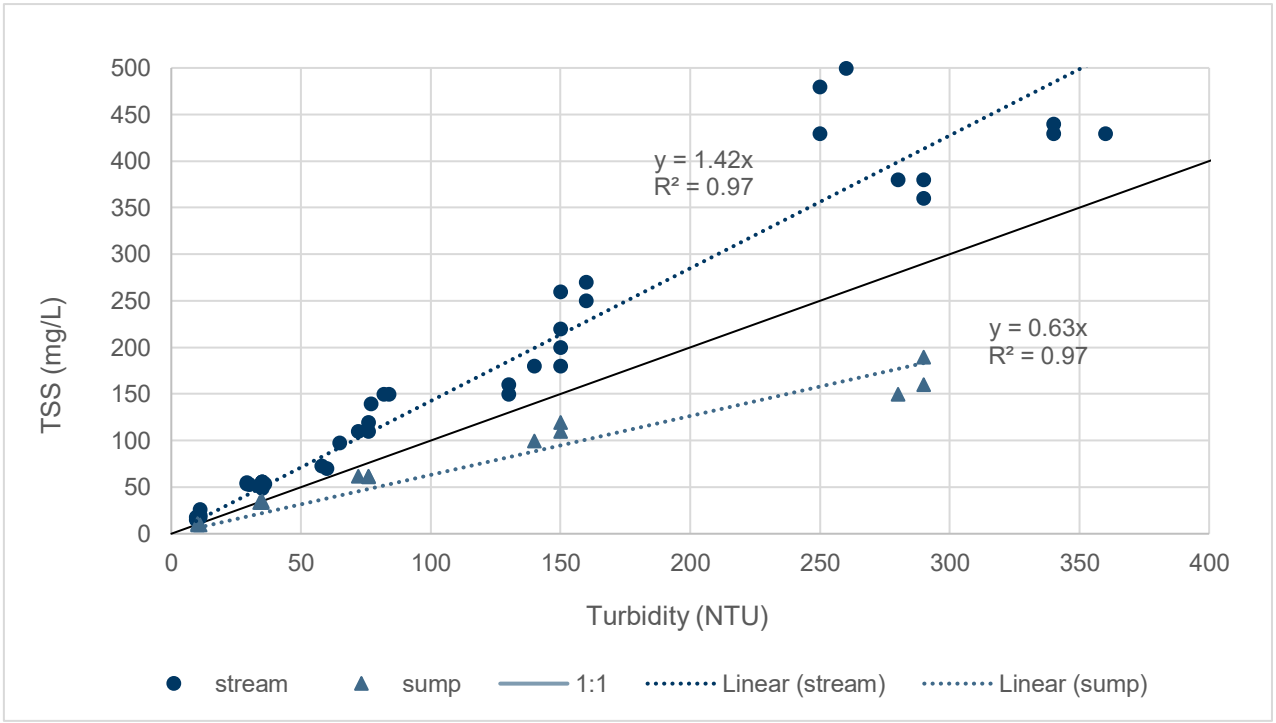


Figure E.11 Turbidity and TSS relationship

Total Suspended Solids is made up of a range or particle diameters, described by the Particle Size Distribution (PSD). Monitoring data shows that this varies depending on the runoff surface characteristics, with mined surfaces having a higher clay proportion than un-mined surfaces. Preliminary monitoring data from three sumps and one un-mined stream suggests the breakdowns listed in Table E.12.

Table E.12 Runoff surface Particle Size Distribution

Runoff surface	Clay	Silt	Sand
Mined	41%	47%	12%
Un-mined	20%	60%	20%

A TSS of 5 mg/L for the clay component was established during verification of the hydrodynamic model with available turbidity measurements in Serpentine Main Dam.

Referring to Table E.13, each runoff surface draining into the reservoir will be assigned with either:

– Zero surface runoff (and therefore zero TSS) for mined catchments with functioning sumps;
– Baseline TSS concentrations for un-mined catchments or rehabilitated catchments; or
– Sump failure TSS concentrations for mined catchments with failing sumps.

Baseflow and interflow, as distinct from stormflow, is assumed to occur at the same rate from each surface type.

Scenarios

A summary of the key input variables is tabulated below, resulting in a combination of 18 scenarios. For three reservoirs, this equates to 54 simulations. For modelling purposes, STP discharge and fuel spill will be simulated in all scenarios. The addition of another starting reservoir water level will double the number of scenarios and simulations.

Table E.13 Scenario matrix

Scenario	Catchment clearing	Reservoir starting level	Season	Storm	Sump failure rate
1	Un-mined	Historical minimum	Summer	1% AEP	Nil
2				10% AEP	Nil
3				1 EY	Nil
4			Winter	1% AEP	Nil
5				10% AEP	Nil
6				1 EY	Nil
7	Existing	Historical minimum	Summer	1% AEP	High
8				10% AEP	Moderate
9				1 EY	Low
10			Winter	1% AEP	High
11				10% AEP	Moderate
12				1 EY	Low
13	Future	Historical minimum	Summer	1% AEP	High
14				10% AEP	Moderate
15				1 EY	Low
16			Winter	1% AEP	High
17				10% AEP	Moderate
18				1 EY	Low

Table E.14 Reservoir details

Reservoir	Operating capacity (at spillway level) (GL)	Operating (spillway) level (mAHD)	30-year minimum water level (mAHD)	Total catchment area (km^2)
Serpentine	138	212.39	192.45 (~15%)	664
Serpentine Pipehead	2.63	165.51	153.00 (~0%)	28
South Dandalup	138	252.82	236.20 (~7%)	311

Uncertainty

The modelling scenarios are defined to minimise uncertainty. For example, extreme runoff and sump failure scenarios are included to understand uncertainty limits. Where there is parameter uncertainty, the more conservative value is adopted. Whilst there is uncertainty in runoff rates and inflow turbidity levels, there is low uncertainty in the hydrodynamic modelling.

Results

Peak flows and runoff volumes are tabulated below, together with an example of the combined hydrograph used for input into the hydrodynamic model. Compared to the unit hydrograph, spikes in discharge can be observed representing mine surface turbid runoff from individual storm bursts within the 7-day event.

Table E.15 Peak flow by catchment, method, event, and scenario (m^3/s)

Catchment	1EY unit hydrograph	1EY existing stormflow	1EY future stormflow	10% AEP unit hydrograph	10% AEP existing stormflow	10% AEP future stormflow	1% AEP unit hydrograph	1% AEP existing stormflow	1% AEP future stormflow
1	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01
2	0.01	0.00	0.00	0.02	0.00	0.05	0.03	0.00	0.23
3	0.13	0.00	0.04	0.19	0.00	0.82	0.27	0.00	3.41
4	0.09	0.01	0.01	0.13	0.19	0.19	0.18	0.81	0.81
5	0.82	0.00	0.07	1.19	0.00	3.69	1.65	0.00	7.54
6	0.13	0.00	0.05	0.19	0.00	0.85	0.26	0.00	3.68
7	3.65	0.03	0.04	5.31	2.32	4.02	7.36	3.69	5.96
8	0.12	0.09	0.09	0.18	1.54	1.54	0.25	6.73	6.73
9	0.09	0.02	0.03	0.13	0.23	0.53	0.18	1.04	2.28
10	0.09	0.06	0.06	0.13	0.94	0.94	0.18	4.16	4.16
11	0.09	0.00	0.00	0.14	0.10	0.10	0.19	0.14	0.14
12	0.08	0.04	0.04	0.12	0.62	0.62	0.17	2.75	2.75
13	2.59	0.06	0.06	3.77	4.74	4.74	5.22	7.64	7.64
14	0.16	0.07	0.07	0.23	1.65	1.65	0.32	5.92	5.91
15	0.12	0.08	0.08	0.17	1.55	1.54	0.24	6.48	6.48
16	0.05	0.03	0.03	0.07	0.37	0.37	0.10	1.64	1.64
20	0.03	0.00	0.00	0.04	0.00	0.00	0.05	0.00	0.00
21	0.02	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00
22	0.04	0.00	0.00	0.06	0.00	0.00	0.08	0.00	0.00
23	0.08	0.01	0.01	0.11	0.08	0.08	0.16	0.34	0.34

Catchment	1EY unit hydrograph	1EY existing stormflow	1EY future stormflow	10% AEP unit hydrograph	10% AEP existing stormflow	10% AEP future stormflow	1% AEP unit hydrograph	1% AEP existing stormflow	1% AEP future stormflow
24	0.18	0.05	0.05	0.26	0.70	0.70	0.36	3.17	3.17
25	0.04	0.00	0.00	0.05	0.00	0.00	0.08	0.00	0.00
26	0.02	0.00	0.00	0.03	0.00	0.00	0.05	0.00	0.00
30	0.08	0.00	0.00	0.12	0.00	0.00	0.16	0.00	0.00
31	0.06	0.00	0.00	0.08	0.00	0.00	0.12	0.00	0.00
32	0.08	0.00	0.00	0.11	0.00	0.00	0.16	0.00	0.00
33	0.12	0.00	0.00	0.17	0.00	0.00	0.23	0.00	0.00
34	0.24	0.00	0.00	0.34	0.00	0.12	0.47	0.00	0.42
35	3.13	0.00	0.03	4.40	0.00	3.70	6.04	0.00	4.99
36	0.21	0.00	0.00	0.29	0.00	0.00	0.40	0.00	0.00
37	0.14	0.00	0.00	0.20	0.00	0.00	0.27	0.00	0.00

Table E.16 Runoff volume by catchment, method, event, and scenario (m^3)

Catchment	1EY unit hydrograph	1EY existing stormflow	1EY future stormflow	10% AEP unit hydrograph	10% AEP existing stormflow	10% AEP future stormflow	1% AEP unit hydrograph	1% AEP existing stormflow	1% AEP future stormflow
1	2,128	0	2	3,097	0	84	4,294	0	230
2	4,601	0	81	6,697	0	3,192	9,285	0	8,633
3	41,690	0	1,330	60,673	0	52,631	84,124	0	142,478
4	28,989	302	302	42,189	11,981	11,981	58,495	32,431	32,431
5	259,415	0	6,191	377,541	0	244,638	523,462	0	662,409
6	41,527	0	1,363	60,437	0	53,917	83,796	0	145,957
7	1,154,604	4,290	7,816	1,680,362	169,566	309,124	2,329,826	459,213	837,217
8	38,500	2,456	2,456	56,032	97,111	97,091	77,688	262,874	262,819
9	28,757	366	859	41,851	14,521	33,983	58,027	39,303	91,998
10	28,156	1,497	1,497	40,977	59,202	59,187	56,815	160,262	160,218
11	29,703	386	386	43,228	15,928	15,928	59,936	43,189	43,189
12	26,023	978	979	37,873	38,697	38,741	52,511	104,757	104,875
13	818,853	8,692	8,692	1,191,724	343,580	343,580	1,652,329	930,471	930,471
14	49,747	2,705	2,704	72,399	106,976	106,923	100,382	289,607	289,458
15	37,431	2,512	2,512	54,475	99,353	99,333	75,529	268,947	268,895
16	15,160	561	561	22,063	22,218	22,209	30,590	60,138	60,114
20	7,951	0	0	11,670	0	0	16,094	0	0
21	4,892	0	0	7,181	0	0	9,903	0	0
22	12,909	0	0	18,948	0	0	26,131	0	0
23	24,465	115	115	35,909	4,560	4,560	49,523	12,339	12,339
24	56,191	1,089	1,089	82,474	43,089	43,089	113,741	116,644	116,644
25	11,749	0	0	17,245	0	0	23,783	0	0
26	7,069	0	0	10,375	0	0	14,309	0	0
30	26,778	0	0	37,671	0	0	51,741	0	0
31	18,917	0	0	26,612	0	0	36,551	0	0
32	25,394	0	0	35,723	0	0	49,066	0	0
33	37,295	0	0	52,465	0	0	72,061	0	0
34	76,566	0	190	107,711	0	7,582	147,940	0	20,535
35	988,853	0	7,862	1,391,098	0	311,441	1,910,665	0	843,596
36	64,981	0	0	91,413	0	0	125,556	0	0
37	44,332	0	0	62,365	0	0	85,658	0	0

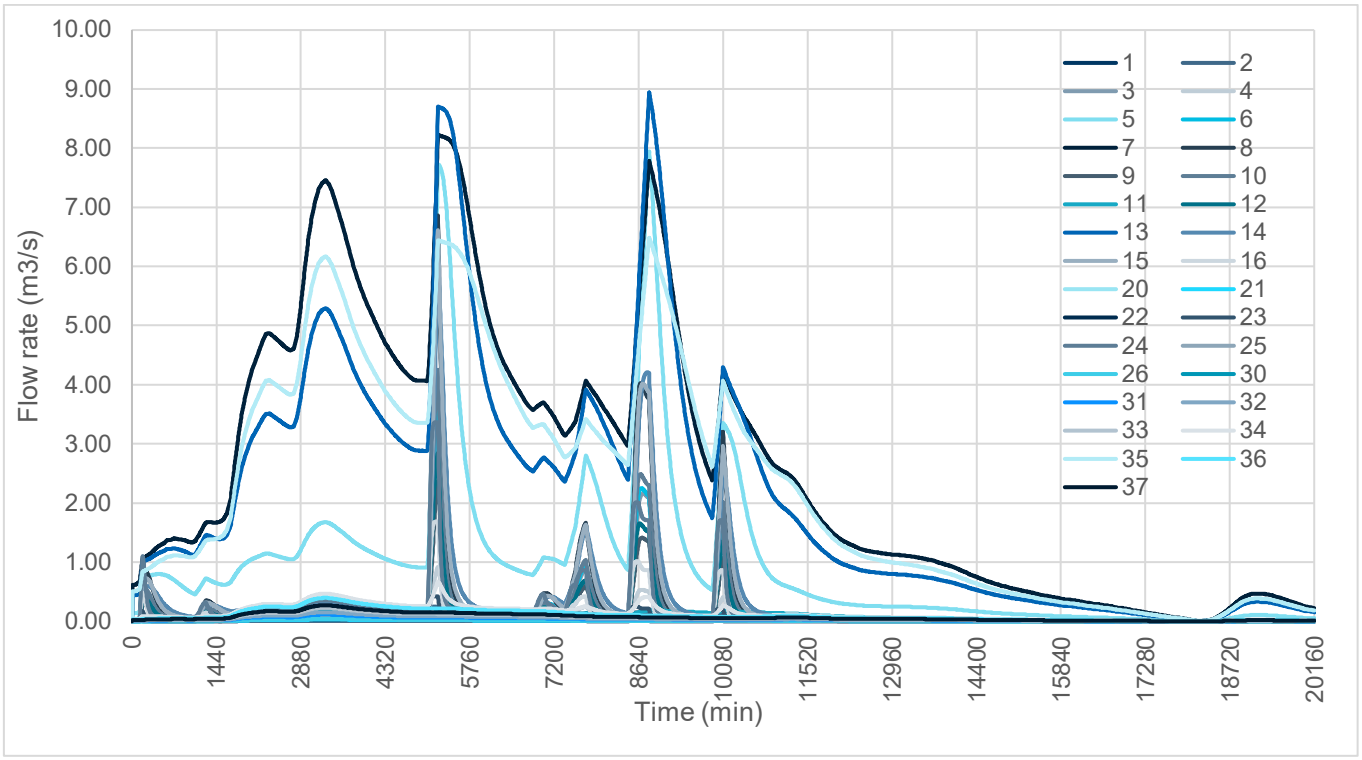


Figure E.12 1% AEP Future scenario combined hydrograph

Appendix F

Hydrodynamic modelling report

Drinking Water Quantitative Assessment

Reservoir Modelling

Alcoa of Australia Limited

09 December 2021

→ The Power of Commitment

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Executive summary

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery by 5 percent from 5.0 Mtpa to 5.25 Mtpa and transition the Huntly Bauxite Mine to the proposed Myara North and Holyoake mine regions (the Proposal). The Proposal is located in the Peel Region of Western Australia (WA), approximately 100 km southeast of Perth.

The Proposal will be subject to environmental impact assessment under Part IV of the WA *Environmental Protection Act 1986* (EP Act), and the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act). The environmental impact assessment will be via a Public Environmental Review (PER).

This report describes numerical modelling to predict reservoir and withdrawal water quality (i.e. inorganic suspended solids (SS), cryptosporidium and hydrocarbons (diesel)) associated with incidents or spills from the proposed transition of Alcoa mining operations in the catchments of three dams (Serpentine Main Dam [SMD], Serpentine Pipehead Dam [SPD], South Dandalup Dam [SDD]) that are part of the Perth's Integrated Water Supply Scheme (IWSS). The purpose of the study is to assess the relative degree to which the transition to the proposed Myara North and Holyoake mine regions will affect the reservoir and withdrawal water quality relative to existing mining activities, and to inform a public drinking water risk assessment of the proposal.

Model Description

A three-dimensional (3D) hydrodynamic model (AEM3D) was used to predict the SS, cryptosporidium and diesel concentrations in the reservoir and withdrawals from catchment inputs of baseline (no mining so only SS considered), and existing and proposed mining scenarios as follows:

– SS was configured to settle according to Stoke's Law through defining conservative (i.e. low settling velocities) characteristic particle densities and diameters for silt and clay. Silt and clay have sufficiently low settling velocities to be potentially transported from stream confluences to the reservoir supply intakes towers in proximity to the dam wall.
– Cryptosporidium oocysts were configured with a process-based model of microbial pollution. Cryptosporidium was selected to evaluate potential microbial risks because chlorination is not an effective treatment process for this pathogen.
– Diesel was configured as a conservative numerical tracer where concentrations within the reservoir are due solely to transport and dispersion, and losses from withdrawals. This is a conservative assumption as volatilisation to the atmosphere, microbial degradation, and settling to adhered particles are not considered.

Supporting Data

Available information and its implementation in the study included:

– Monthly water balance from 2000-2020 of the three dams served to define model inputs of discharge (i.e. external transfers, withdrawals, Alcoa extractions) and to verify simulated water levels.
– Department of Water and Environmental Regulation (DWER) measurements of daily stream flow in three large SMD catchments were used to estimate discharge from ungauged catchments of all three reservoirs to serve as model inputs. DWER stream temperature measurements in one of the large SMD catchments served as model inputs for all simulated stream model inputs.
– Measurements of turbidity (2000-2020) and water temperatures (2000-2008) near the dam walls of the three reservoirs served as model verification data. Simulated SS was compared to measured turbidity assuming a 1:1 relation over the low range of values at the dam wall (i.e. SS and turbidity typically <2 mg/L and <2 NTU, respectively).
– Hourly meteorological model inputs were sourced from the National Centers for Environmental Prediction's (NCEP's) Climate Forecast System, version 2.
– As there were no available digital elevation models of the three reservoirs, the 3D bathymetries were developed from historical topographic data prior to the construction of the dams and the use of GIS

interpolation algorithms. The digital elevation models were then parsed into 100 m by 100 m grids for SMD and SDD, and a 50 m by 50 m grid for SPD.

– Particle size distributions of streambed sediments in natural and existing mining catchments were used to estimate the relative proportion of clay and silt that comprise SS.

The primary data gaps in this study were stream SS (and/or turbidity) measurements in natural and mined catchments. During model verification constant SS concentrations of clay (SS_{clay} of 5 mg/L) and silt (SS_{silt} of 15 mg/L) were used across unmined and/or fully rehabilitated catchments of all three reservoirs, which yielded a reasonable match with the turbidity measurements at the dam walls. Additionally, constant SS_{clay} and SS_{silt} concentrations of external transfers into SDD and SPD were assumed. These SS data gaps represent the highest degree of uncertainty in this investigation. One of the main aims of this study is to determine the 'relative' effect of the proposed mine transition on reservoir and withdrawal SS, which is achieved.

Model Verification

Verification of simulated water levels, water temperatures and SS were through comparisons with available information/measurements of the three reservoirs from July 2017 to October 2019. This model verification period encompassed two moderate-sized winter inflow events (2017 and 2018) following a dry period from 2011-2017 that maintained low reservoir levels, which can be summarised as:

– Simulated SMD and SDD water levels over 2+ years were reproduced well after increases in the discharge of estimated winter inflows during the winters of 2018. SPD water levels and outflow discharge were simulated well with the application of a dynamic outflow boundary condition, where the withdrawal rates were a function of the reservoir's water level.

– Water temperature measurements in the three reservoirs were only available from 2000-2008. A subset of this 2000-2008 measurement period to compare to simulated water temperatures in each reservoir was selected on the basis of the similarity in water balance components. The surface and bottom water temperatures were simulated well in all three reservoirs. Seasonal thermal stratification was simulated in SMD and SDD with a longer duration near the dam wall than at comparative up-reservoir sites. In contrast, the much shallower SPD reservoir does not seasonally stratify, but does undergo intermittent periods of thermal stratification.

– Simulated SS_{clay} comprised most of the SS near the dam walls of the three reservoirs and matched well with turbidity measurements during the 2018 winter in SMD, both the 2017 and 2018 winters in SDD and over the entire simulation in SPD. However, simulated summer SS_{Clay} in both SMD and SDD were underestimated compared to turbidity measurements, which is likely due to a high proportion of organic particles (e.g. phytoplankton) that are not simulated in this study. In response to catchment inflow events, elevated SS_{clay} remains suspended in the water column due to low settling velocities during transport to the dam walls, often as turbid underflows down the bed slope. SPD has substantially lower simulated SS_{Clay} at the dam wall than SMD and SDD because of the relatively small SS loads from the limited catchment area. Further, the high SPD external transfers with low SS, which short-circuit to the nearby intake tower, substantially dilutes the relatively small catchment-derived SS loads. Based on this model verification of SS, there is a good level of confidence in regards to predicted relative changes in the suspended inorganic climate near/at the dam wall in response to inflow events from the proposed additional mining in the catchments.

Scenario Hydrology

The effect of mining activity-related cryptosporidium and diesel spill incidents in the catchments were evaluated over the model verification period (July 2017 to October 2019). To evaluate the relative effects of proposed mining activities on reservoir turbidity due to drainage (primary turbidity control measure) failures relative to the baseline condition (no mining) and existing mining activities, estimates of the 1% and 10% 7-day annual exceedance periods (AEP) from a companion study (GHD 2021b) were spliced into the 2017 winter event and the 2018 summer period as scenario hydrological inputs.

Predicted Effect of Cryptosporidium Incidents

The following simulated cryptosporidium incidents from the catchments are defined in a companion study (GHD 2021a):

– Incident 1: Sewage treatment plant (STP) overflow over 2 days after heavy rainfall.
– Incident 2: Washout of STP effluent irrigation area over 2 days after heavy rainfall.
– Incident 3: Subsurface seepage from STP effluent irrigation area over 3 winter months.
– Incidents 4A-4D: Mobilisation of an infected stool in 3 mining catchments (4A-4C) within each reservoir and a reference catchment closest to each of the dam walls (4D) over 2 days following heavy rainfall (inflow) events.

These cryptosporidium incidents were simulated to occur in 3 catchments in SMD and SDD, and 2 SPD catchments for existing (SMD, SPD) and proposed (SMD, SDD) mining activity scenarios. The predicted effects of these incidents were:

– For SMD, incidents 1, 2 and 3 are predicted to yield relatively low cryptosporidium levels at the dam (~<1×10^{-5} oocysts/L) relative to the mobilisation of infected human stool events (incidents 4A-4C) from existing and proposed mined catchments and the reference unmined catchment closest to the dam wall (reference incident 4D) (~<5×10^{-4} oocysts/L). The typical timescale of elevated cryptosporidium at the dam wall and withdrawals is ~3-4 months. The STP location is proposed to be moved to a catchment with a reservoir confluence closer to the dam wall (and intake tower) than the existing location. This change results in a ~2 fold increase in peak cryptosporidium concentrations, but concentrations remain very low relative to predictions for incidents 4A-4D. Generally, simulated oocyst concentrations in the SMD withdrawals for incidents 4A-4D are similar between the existing and proposed mining catchments.
– As with SMD, SDD incidents 1, 2 and 3 were predicted to yield relatively low cryptosporidium levels at the dam (~<3×10^{-6} oocysts/L) relative to the mobilisation of infected human stool events (incidents 4A-4C) in the proposed mining catchments (~<1×10^{-4} oocysts/L) and with the unmined reference catchment closest to the dam wall (refence incident 4D) (~1<×10^{-3}) oocysts/L). Simulated large scale transport processes in SDD did not distribute pathogens to the same degree throughout the up-reservoir volume as for SMD, in part due to the smaller inflow event to reservoir volume ratio. As with SMD, the typical timescale of elevated cryptosporidium at the dam and withdrawals was ~3-4 months. Due to reduced horizontal transport, cryptosporidium concentrations for incidents 4A-4C were ~2-4 fold lower than for SMD. However, peak SDD concentrations for incident 4D (closest catchment to dam wall) was 2 fold greater than SMD because of reduced horizontal transport and dispersion.
– Simulated SPD cryptosporidium predictions differed substantially from those of SDD and SMD for incidents 4A, 4B and reference incident 4D (incidents 1-3 and 4C not applicable for SPD), which is primarily driven by short-circuiting of external transfers to the intake tower. This short-circuiting leads to low water ages (i.e. duration a water parcel remains in the reservoir) near the dam wall and increasing water age with distance up-reservoir due to the relatively low catchment inputs and low SMD releases. These high short-circuiting volumes induce a hydrodynamic barrier effect in close proximity to the dam wall that inhibits transport and dispersion of up-reservoir waters where the confluences of the two existing (and proposed) mining catchments occur. These factors contribute to the large difference between cryptosporidium concentrations at the dam wall with reference incident 4D (<1-2×10^{-2} oocysts/L for the catchment closest to the dam wall) that are ~1,000- and ~10- fold greater than incidents 4A (<1×10^{-5} oocysts/L for the uppermost mined catchment) and 4B (<1×10^{-3} oocysts/L for the mid-reservoir mined catchment), respectively. In addition, there is a delay of ~1-2 months in the arrival of cryptosporidium to the dam wall and intake for incident 4A relative to incidents 4B and 4D due to this hydrodynamic barrier effect.

Predicted Effect of Diesel Spill Incidents

Simulated diesel spill incidents during moderately low winter inflows assumed the entire 15 m^3 load of fuel transport tanker was directly discharged into a stream at a haul road crossing with no losses due to volatilisation, degradation, adsorption and settling. Hence, the only processes that decrease diesel concentrations upon being spilled into the stream and throughout the reservoir volumes are via dilution in the river and reservoir mixing and dispersion.

These diesel spill incidents were simulated to occur in 3 catchments in SMD and SDD, and 2 SPD catchments for existing (SMD, SPD) and proposed (SMD, SDD) mining scenarios. The predicted effects of these diesel spill incidents include:

– Simulated diesel concentrations at the downstream dam and withdrawals from spills in the existing and proposed SMD mining catchments had peaks of up to 1 µg/L that decreased to <0.2 µg/L within 6-7 months.

– Simulated diesel concentrations at the downstream dam and withdrawals from spills in the proposed SDD mining catchments were similar to SMD predictions with peaks of 1 µg/L that decreased to 0.4 µg/L within 6-7 months.
– Simulated diesel concentrations at the downstream dam and withdrawals from spills in the existing SPD mining catchments had similar spatial and temporal patterns as the cryptosporidium predictions in this reservoir. The diesel concentrations varied from 5 ug/l for a spill in in the mid-reservoir catchment to 1 µg/L for a spill in the up-reservoir catchment. There was also a delay in the arrival of diesel to the dam and withdrawals of ~2 months for a spill in the up-reservoir mining catchment relative to a spill in the mid-reservoir mining catchment. As with variations in cryptosporidium, the hydrodynamic barrier effect induced by short-circuiting of the primary inflow (external transfers) and outflow (withdrawals) in the region of the dam wall effectively decreased the transport and dispersion of diesel from the upper reservoir catchment. Because of SPD's relatively small reservoir volume and relatively high outflow discharge, diesel levels were simulated to decrease to ~0 µg/L within ~10-12 months of the spill.

Predicted Effect on Inorganic Suspended Solids during Large Inflow Events

Scenarios to evaluate the relative differences of large winter and summer inflow events on reservoir and withdrawal SS levels used as model inputs the estimated GHD (2021a) 1% and 10% AEP hydrology for baseline (no mining effects on SS for all three reservoirs), existing (for SMD and SPD, no existing mining activity in SDD) and proposed (for SMD and SDD, no additional SPD catchments for proposed mining activity) mining scenarios. The 1% and 10% AEP inflow events were assumed to have 30% and 75% drainage (i.e. primary turbidity control through retention of mining area water) failure rates. Additionally, two constant SS concentrations in the event of drainage failures (i.e. for water exiting drainage controls and flowing into proximal streams) from mining catchments were simulated that assumed moderate (12.6 and 15.8 mg/L of SS_{Clay} and SS_{Silt}, respectively) and high (25.2 mg/L and 31.5 mg/L of SS_{Clay} and SS_{Silt}, respectively) drainage failure SS levels. Baseline (no mining and fully rehabilitated mining catchments) scenarios had SS_{clay} and SS_{silt} stream concentrations of 5 and 15 mg/L, respectively. The same SS concentrations were adopted for those portions of mining catchments with no mining activity.

The predicted effects of these large inflow events and associated drainage failures on the SS in the reservoirs and withdrawals include:

– Increases to SS_{silt} in all reservoirs and for all scenarios were short duration due to the relatively rapid settling as described beforehand for the verification simulations. Most SS variations were due to SS_{Clay}.
– For SMD with moderate drainage failure SS levels, minimal changes were predicted in the SS at the dam and withdrawals between the baseline, existing and proposed scenarios for either the winter or summer 10% AEP inflow events. SS increases of up to ~0.5 mg/L and ~0.2-0.3 mg/L were simulated with the moderate drainage failure SS levels for the summer and winter 1% AEP inflow events, respectively. With high drainage failure SS levels, minimal variations were again predicted for the 10% AEP winter and summer events. SS increases of up to ~1 mg/L and ~0.3-0.4 mg/L were simulated with the high drainage failure SS levels for the summer and winter 1% AEP events, respectively.
– For SDD, material differences in SS at the dam wall and withdrawals were not predicted for the 1% and 10% AEP summer and winter inflow events between the baseline and proposed scenarios (note no existing mining scenario for SDD) for both moderate and high drainage SS levels. The relatively small proportion of the SDD catchment that is proposed to undergo mining activity does not generate sufficient additional SS loads over the baseline (no mining) scenario to cause a substantive increase.
– As with SDD, material differences in the 1% and 10% AEP summer and winter inflow events between the baseline and proposed SPD scenarios (note no existing mining scenario for SDD) for moderate and high drainage failure SS levels are not predicted. The hydrodynamic barrier effect induced by the SPD primary inflow and outflow in proximity to the dam wall increases the duration of particle settling in the up-reservoir volume prior to transport to the dam wall. Further, the high external transfers with low SS concentrations also dilutes the elevated catchment-derived SS_{clay} levels as they are transported to the dam wall after inflow loading events.

This report is subject to, and must be read in conjunction with, the limitations set out in Section 1.4 and the assumptions and qualifications contained throughout the Report.

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Appendices

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Appendix D SMD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)

Appendix E SDD: 1% and 10% AEP Flood Event Inputs (Moderate Drainage Failure SS Levels)
Appendix F SDD: 1% and 10% AEP Flood Event Simulations (Moderate Drainage Failure SS Levels)
Appendix G SDD: 1% and 10% AEP Flood Event Inputs (High Drainage Failure SS Levels)
Appendix H SDD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)
Appendix I SPD: 1% and 10% AEP Flood Event Inputs (Moderate Drainage Failure SS Levels)
Appendix J SPD: 1% and 10% AEP Flood Event Simulations (Moderate Drainage Failure SS Levels)
Appendix K SPD: 1% and 10% AEP Flood Event Inputs (High Drainage Failure SS Levels)
Appendix L SPD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)

Acronyms, Abbreviations and Units

Acronym, Abbreviation, Unit	Description
°C	Degrees Centigrade
µm	Micrometre
3D	Three Dimensional
AEP	Annual Exceedance Period
AHD	Australian Height Datum
BoM	Bureau of Meteorology
CFSv2	Climate Forecasting System Version 2
DWER	Department of Water and Environmental Regulation
EP Act	Western Australia Environmental Protection Act 1986
EPA	Environmental Protection Authority
EPBC Act	Environment Protection Biodiversity Conservation Act 1999
ESD	Environmental Scoping Document
E.Y.	Exceedance per Year
FSL	Full Supply Level
GL	Gigalitre
hr	Hour
IWSS	Integrated Water Supply Scheme
km	Kilometre
m	Meter
m^3/s	Cubic Meters per Second
mg/L	Milligrams per Litre
MAFRL	Marine and Freshwater Research Laboratory
mm	Millimetre
ML	Megalitre
Mtpa	Million Tonnes per Annum
NA	Not Applicable
NTU	Nephelometric Turbidity Units
PER	Public Environmental Review
psu	Practical Salinity Units
Q	Discharge
s	Second
SDD	South Dandalup Dam
SMD	Serpentine Main Dam
SPD	Serpentine Pipehead Dam
SS	Inorganic Suspended Solids
SS_{clay}	Clay Component of Inorganic Suspended Solids
SS_{silt}	Silt Component of Inorganic Suspended Solids
T	Temperature
TSS	Total Suspended Solids

Acronym, Abbreviation, Unit	Description
W	Watt
WA	Western Australia
WTP	Water Treatment Plant

1. Introduction

Alcoa of Australia Limited (Alcoa) is proposing to increase production at the Pinjarra Alumina Refinery by 5 percent from 5.0 Mtpa to 5.25Mtpa and transition the Huntly Bauxite Mine to the proposed Myara North and Holyoake mine regions (the Proposal). The Proposal is located in the Peel Region of Western Australia (WA), approximately 100 km southeast of Perth.

The Proposal will be assessed by the Environmental Protection Authority (EPA) under Part IV of the WA *Environmental Protection Act 1986* (EP Act), and the *Environment Protection Biodiversity Conservation Act 1999* (EPBC Act). The Proposal will be assessed via a Public Environmental Review (PER).

This report describes numerical modelling that was undertaken to predict in-reservoir and withdrawal water quality risks from inorganic suspended solids, cryptosporidium and hydrocarbons associated with the transition to the proposed Myara North and Holyoake mine regions in the catchments of three dams (Serpentine Main Dam [SMD], Serpentine Pipehead Dam [SPD], South Dandalup Dam [SDD]) that are part of the Perth's Integrated Water Supply Scheme (IWSS).

1.1 Purpose of this Report

This report provides support for the elements in regards to reservoirs of items 49 and 50 of the Environments Scoping Document (ESD) for the Alcoa Revised Proposal where the following portions of the following Required Work items that are addressed here are underlined:

49. Characterise the hydrology of the Serpentine and South Dandalup Rivers and upper Wungong Brook catchment, and the beneficial use of the Serpentine, Pipehead and South Dandalup reservoirs, including reservoir protection zone. Characterise the current water quality and hydrodynamics of the Serpentine, Pipehead and South Dandalup reservoirs. Describe the impacts from this Proposal on the water yield and water and sediment quality of Serpentine, Pipehead and South Dandalup reservoirs, upstream rivers, tributaries, upper Wungong Brook, and Peel-Yalgorup System Ramsar Site. This is to include a detailed description of the development of river crossings for access/haul roads and conveyors.

50. Undertake a public drinking water risk assessment for the Serpentine, Pipehead and South Dandalup Dam reservoirs and upper Wungong Brook catchment, including source vulnerability assessment, in accordance with the Australian Drinking Water Quality Standards and relevant contemporary guidance. The risk assessment should consider potential contaminants arising from mining activities and infrastructure, as well as mobilisation of existing contaminants from past catchment activities. For identified high risks to public drinking water beneficial uses, undertake a detailed assessment of potential impacts to human health in accordance with contemporary guidance.

1.2 Scope

The scope of this reservoir numerical modelling study is to address ESD items 49 and 50 through:

– Developing a three-dimensional (3D) hydrodynamic model of SMD, SPD and SDD to simulate the fate and transport of contaminants of potential concern (i.e. inorganic suspended solids [SS], microbial pathogens, hydrocarbons from fuel spills) that may arise from existing and proposed mining activities in the catchments.
– Carrying out model verification through comparisons with available in-reservoir measurements of water levels, temperature, and turbidity.
– Predicting water quality variations within the reservoir and the withdrawals for existing and proposed mining activities, specifically:
    - Increases to SS during sizeable rainfall (and reservoir inflow) events due to the failure of water retention mining infrastructure.
    - Cryptosporidium loads into the reservoirs during high reservoir inflow events due to accidental overflow from sewage treatment plants, washout of treated sewage from irrigated woodlots and mobilisation of infected human stools. Additionally, subsurface drainage of treated sewage from irrigated woodlots into

nearby streams was also considered as a potential pathogen hazard to the water quality of the reservoirs and withdrawals.

- Accidental diesel spills from fuel tankers into streams.

The findings from this study served to inform a public drinking water risk assessment of the proposed mining activity transition (GHD 2021a).

1.3 Overview of Approach

The study's approach to predict the effects of the mining transition proposal was to:

– Define the reservoir inputs (e.g. inflows) and outputs (e.g. withdrawals) of the three dams (Section 2.2).
– Refine a monthly water balance of the past 20 years (2000-2020) to serve as model inputs for catchment inflows, withdrawals and external transfers (Section 3.1), and as water level model verification data (Section 4.2.1).
– Collate measurements of stream discharge and temperature (Section 3.2), in-reservoir temperature and turbidity (Section 3.3), and meteorology (Section 3.4) to serve as model inputs (Section 4.1) and model verification data (Sections 3.3).
– Carry out reservoir model verification simulations (Section 4.1.7) and describe key patterns of thermal stratification and SS within the reservoir and the withdrawals (Section 4.3).
– Evaluate the effects between baseline (no mining activity), and existing and proposed mining activity scenarios (Section 5), which includes:
    - Establishment of catchment hydrological inputs for 'representative' (Sections 3.1 and 3.2) and 'high' rainfall/catchment inflow (Section 5.1.3) scenarios.
    - Characterisation of SS (Sections 4.1.7 and 5.1.3), pathogen (cryptosporidium) (Section 5.1.2) and hydrocarbons (Section 5.1.2) catchment loads to evaluate water quality effects from existing and proposed mining activity in the catchments of the three dams.
    - Reservoir simulations of a suite of scenarios to predict the relative difference between the baseline, and existing and proposed mining activity for SMD (Section 5.2), SDD (Section 5.3) and SPD (Section 5.4).
– Discuss the predicted relative differences in the water quality risks between the baseline, and existing and proposed mining activity.

1.4 Limitations

This report: has been prepared by GHD for Alcoa of Australia Limited and may only be used and relied on by Alcoa of Australia Limited for the purpose agreed between GHD and Alcoa of Australia Limited as set out throughout this report.

GHD otherwise disclaims responsibility to any person other than Alcoa of Australia Limited arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report. GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Alcoa of Australia Limited and others (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Assumptions

Modelling assumptions in this assessment include:

- Temperature is the primary driver of water density variations in the three reservoirs in this study. The modelling does not evaluate the very small effect of variations in conductivity between the reservoirs and the various catchments. All reservoir and catchment stream salinity values are set to a value of 0.1 psu in this assessment. Further, the effect of inorganic suspend solids (SS) on water density is not considered, as the levels required to generate density variations do not likely occur.
- Total suspended solids (TSS) is a combination of inorganic and organic particles. There are only measurements of turbidity available for the three reservoirs. It is assumed that the primary contribution to SS during and for several months after inflow events are inorganic particles, of which those transported to the dam wall are primarily small particle sizes (e.g. clay and fine silt) that remain in suspension.
- A 1:1 relation between SS and turbidity is adopted for model verification (simulated SS versus measured turbidity) and to inform the GHD (2021a) drinking water risk assessment (to translate simulated SS to drinking water guideline turbidity values). A 1:1 relation between SS and turbidity is typically a reasonable approximation in many relatively clear water bodies. In this study, all three dams can be categorised as clear water bodies with typical turbidity measurements of <2 NTU.
- Algal and other organic matter particles are not considered in the model due to the lack of data for model verification. True colour measurements are available (i.e. indicative of dissolved organic matter), but there is insufficient data to simulate organic matter dynamics.
- From a land use change perspective and the associated risks of increased SS at the dam wall due to failures of sediment retention control infrastructure around existing and proposed mining areas, it is primarily inorganic SS that is likely to cause deleterious water quality impacts at the intake towers of the reservoirs during and the aftermath of inflow events. Catchment discharge and SS loads are as described in GHD (2021b).
- Cryptosporidium is the simulated pathogen here because of the ineffectiveness of chlorination, which is the primary WTP treatment process of the SPD draws. Estimates of cryptosporidium loads during inflow events due to STP infrastructure failure (i.e. STP overflow, washout of treated wastewater irrigated woodlot, transport of infected human stool near a water course) and over the winter wet season (i.e. subsurface drainage of treated wastewater irrigated woodlot) are as described in GHD (2021a). Further, once the pathogens are routed to a stream, no further deactivation of cryptosporidium is considered until the confluence with the reservoir. Only dilution with catchment waters is used to determine the model input concentration into the reservoir.
- Worst case fuel spill scenarios are defined as an accidental release of the entire diesel tank volume into a stream. The diesel spill is simulated as a conservative tracer (e.g. no reduction due to fate processes such as volatilisation) with only dilution of catchment inflows to estimate hydrocarbon concentrations that enter the reservoir.

2. Reservoir Model

2.1 Numerical Model

AEM3D is a 3D numerical model that includes hydrodynamic, thermodynamic and biogeochemical modules to simulate the temporal behaviour of stratified water bodies from environmental forcing (Hodges and Dallimore 2018). AEM3D simulates the velocity, temperature and salinity of surface waters that are subjected to environmental and anthropogenic forcing such as wind, tides, surface heating and cooling, inflows, withdrawals, bubblers and mixers. Additionally, AEM3D can be configured to optionally simulate nutrients, biogeochemistry, particle and aquatic biology dynamics based on a water quality module adapted from the Computational Aquatic Ecosystem Dynamics Model (Romero et al 2004).

In this study, AEM3D was configured to simulate the relative effect of various mining-related scenarios in the catchments on the spatial and temporal variations of SS, cryptosporidium and diesel where:

– Inorganic suspended solids (SS) were configured to settle according to Stoke's Law through defining the characteristic particle density and diameter of silt and clay. Silt and clay are the catchment soil types with sufficiently low settling velocities to be potentially transported from stream confluences with the reservoirs to the intake towers in proximity to the dam wall.
– Cryptosporidium oocysts were configured on the basis of Hipsey et al's (2008) process-based model of microbial pollution. Cryptosporidium was selected as the most conservative pathogen to evaluate potential microbial risks associated with mining activity because chlorination is not an effective treatment process.
– Diesel was configured as a conservative numerical tracer and therefore concentrations within the reservoir from catchment inputs are due solely to transport and dispersion, and losses from withdrawals. This is a conservative assumption as volatilisation to the atmosphere, microbial degradation, and settling to adhered particles are not considered.

2.2 Primary Inputs and Outputs of Water

Figure 1 provides a schematic of the primary inputs and outputs of water for the three dams, which can be summarised as:

– Serpentine Main Dam (SMD) (reservoir model #1) has inputs of potential contaminants via the catchments and releases (draw) directly into the Serpentine Pipehead Dam (SPD).
– South Dandalup Dam (SDD) (reservoir model #2) has catchment inputs and releases (draw) as SMD. In addition, there are also extractions for existing (and proposed) Alcoa mining operations and transfers from outside the catchment.
– Serpentine Pipehead Dam (SPD) (reservoir model #3) has catchment inputs, releases (draw to IWSS after chlorination at the WTP), transfers from outside the catchment (a large proportion from the Southern Seawater Desalination Plant), and releases from SMD.

Environmental releases from SPD for downstream water users, and ecological and social values are managed as per DWER (2017). Environmental releases from SPD were not simulated as they comprise a small proportion of this reservoir's water balance.

Rainfall is a model input, and evaporation is simulated by the model on the basis of simulated surface water temperatures, and model inputs of air temperature, relative humidity and wind speed. No groundwater inputs or losses were considered.

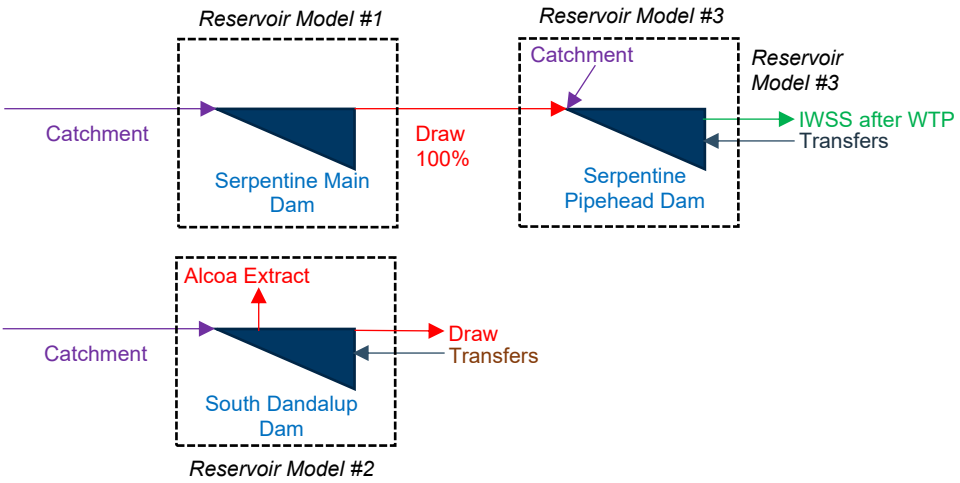


Figure 1 ***Primary inputs and outputs of water of the three dams in the study.***

3. Data

3.1 Monthly Water Balance

Table 1 summarises the relevant monthly water balance data that was provided on April 19th, 2021, by Water Corporation for the three reservoirs.

Table 1 Monthly water balance data availability from Water Corporation of the three reservoirs.

Data	SMD	SDD	SPD
Bathymetry	NA	NA	NA
Water Level	Monthly 2000-2020	Monthly 2000-2020	Monthly 2000-2020
Inflows[1]	Monthly 2000-2020	Monthly 2000-2020	Monthly 2000-2020
Draw (Supply)	NA Not calculated by Water Corporation	Monthly 2000-2020 as IWSS+Dwellingup Draw & Alcoa Extraction	Monthly 2000-2020
Withdrawals Levels (depth of water draw or extraction)	NA	NA	NA
Transfers (Sources)	None	Monthly from Lower South Dandalup	NA

[1] Not available

Where data was not available in the monthly water balance data in Table 1 for each of the three dams, the following estimates were made:

– Annual monthly averages of rainfall and pan evaporation from the Bureau of Meteorology (BoM) station at Karnet (Station Number: 00911) were incorporated into the monthly water balance.
– Relations of volume and surface area versus water level for SMD and SDD were derived from hypsographic information. A relation between volume versus water level for SPD was developed from Water Corporation's 2000-2020 monthly water balance. SPD surface area was assumed to be at Full Supply Level (FSL) (0.62 km^2) to estimate evaporation and rainfall, which are both relatively small components of the water balance of this reservoir (i.e. dominated by external transfers and draws).
– The water balance residual was used to estimate additional monthly inputs or outputs to the reservoirs in the following manner:
    - Excess water was estimated as additional draws (supply).
    - Shortfalls of water were estimated as additional transfers (SPD) or inflows (SMD, SDD)

Figure 2 summarises the monthly water balance from 2000-2020 where key patterns include:

– Catchment inflows and draws from both SMD and SDD have decreased over the past 20 years. In particular, the SMD draws have decreased substantially over the past decade with very low extractions to supply SPD from July 2017-October 2019.
– The primary water source of SPD has transitioned from SMD draws prior to 2006 to external transfers from other sources.
– The selected modelling period (Section 4.1.1) from 1 July 2017 to 1 October 2019 corresponds to low reservoir water levels in SMD and SDD with two relatively wet winters in 2017 and 2018 and then a dry 2019 winter. In contrast, SPD maintains a relatively constant level approximately 1 m below the FSL of 165.5 m AHD due to this water body's highly managed balance between external transfers and draws (supply).

[1] Estimates of the basis of monthly water balances for SMD, SDD and SPD.

– Temperature measurements in the dams were available from 2000-2008, but not thereafter (see Section 3.3). The selection of a year for each reservoir over this 2000-2008 period to compare with 2017-2019 simulated temperatures was based on the similarity of monthly water balance components in Figure 3, which were:
  - For SMD the 2002-3 measurements are compared to the 2017-18 simulation period.
  - For SDD the 2003-4 measurements are compared to the 2017-18 simulation period.
  - For SPD the 2006-7 measurements are compared to the 2017-18 simulation period.

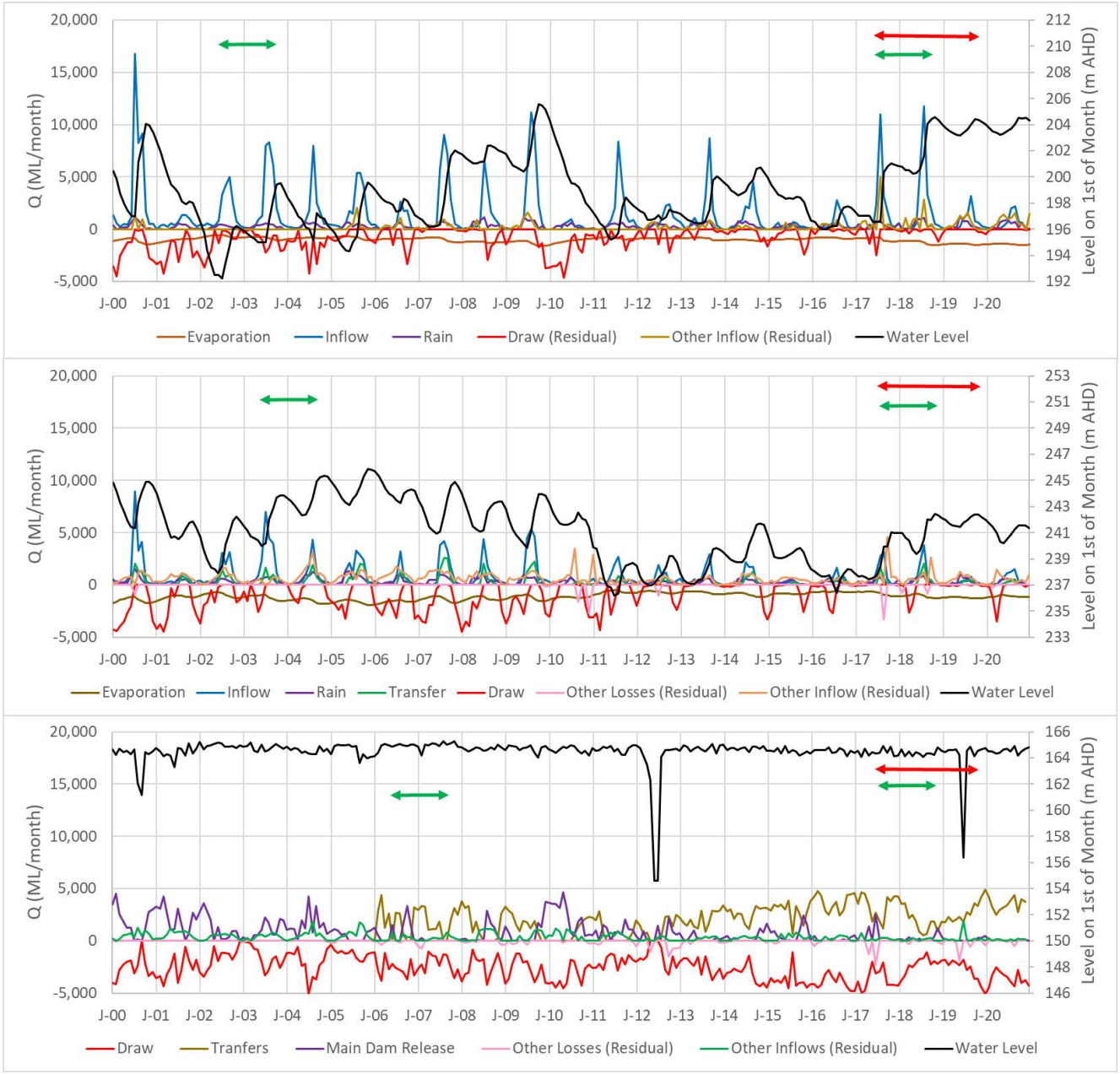


Figure 2 ***Monthly water balance from 2000-2020 for Serpentine Main Dam (SMD) (top), South Dandalup Dam (SDD) (middle) and Serpentine Pipehead Dam (SPD) (bottom).[2] Red arrow shows model period from 1 July 2017-1 October 2019. Green arrows show periods in which thermal stratification is compared between measurements (2000-2008) and simulations (2017-2019).***

[2] Maximum value of level on plots approximately correspond to each reservoir's full supply level (FSL).

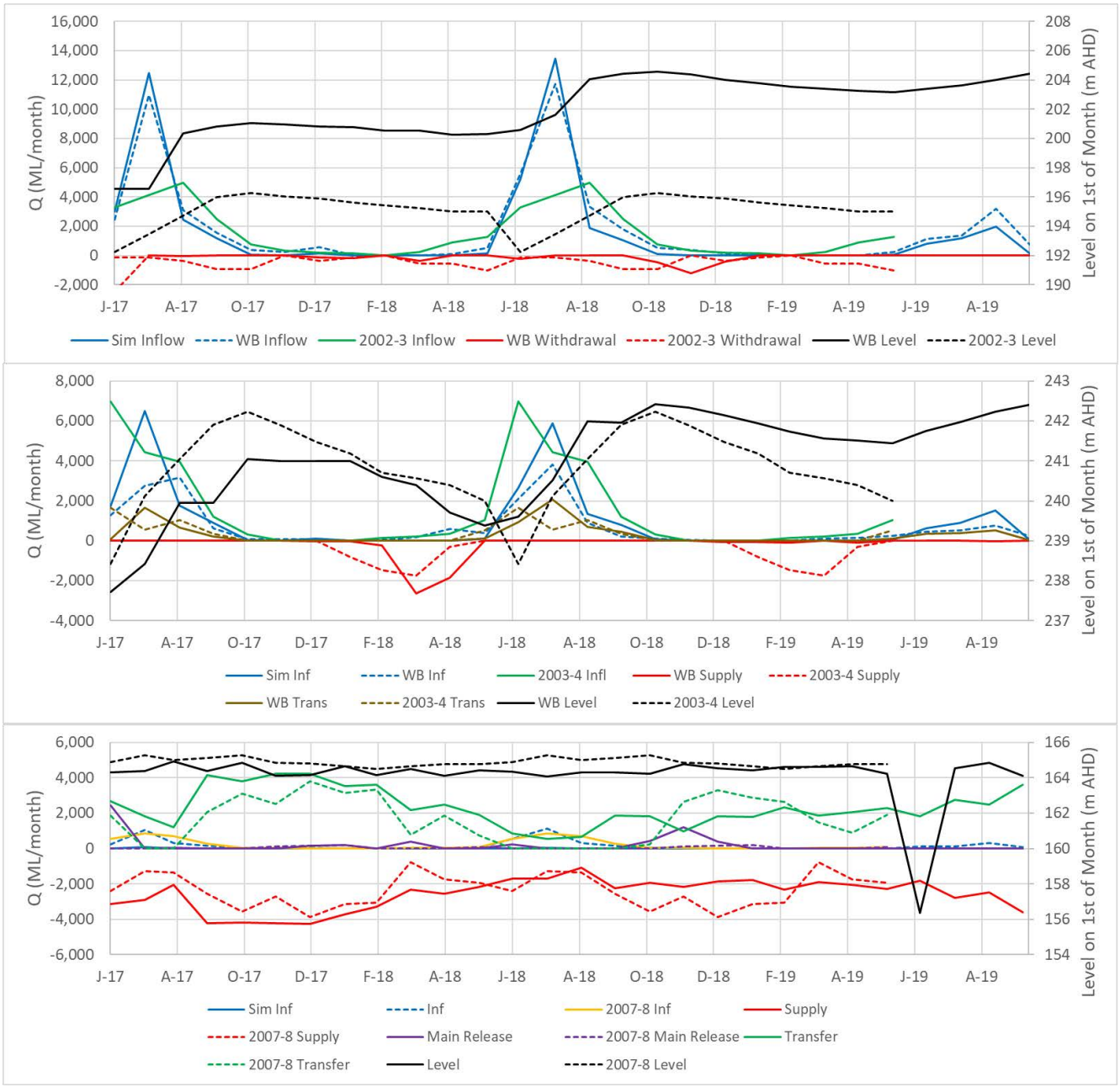


Figure 3 ***Monthly water balance comparison of simulation period (1 July 2017-1 November 2019) and measurement periods for thermal stratification of Serpentine Main Dam (SMD) (top, 2002-3), South Dandalup Dam (SDD) (middle, 2003-4) and Serpentine Pipehead Dam (SPD) (bottom, 2006-7).***

3.2 Stream Data

3.2.1 Gauged Daily Stream Inflows into Serpentine Main Dam

Average measured daily discharge by the DWER over the period of 2000-2020 of the three major SMD streams (Serpentine River, Big Brook, 39 Mile Brook) are shown in Figure 4. No major streams in the SDD catchment have been gauged over the past 20 years, only two small tributaries (Del Park and Gordon Catchment with maximum average daily discharges of 0.06 and 0.04 m^3/s, respectively). Over the longest stream measurement record, namely Big Brook, peak winter discharge during the verification period (1 July 2017 to 1 October 2019) during 2017 and 2018 were near/at the maximum over the past 20 years. In contrast, the peak winter discharge of 2019 was near/at the minimum over the 20 years.

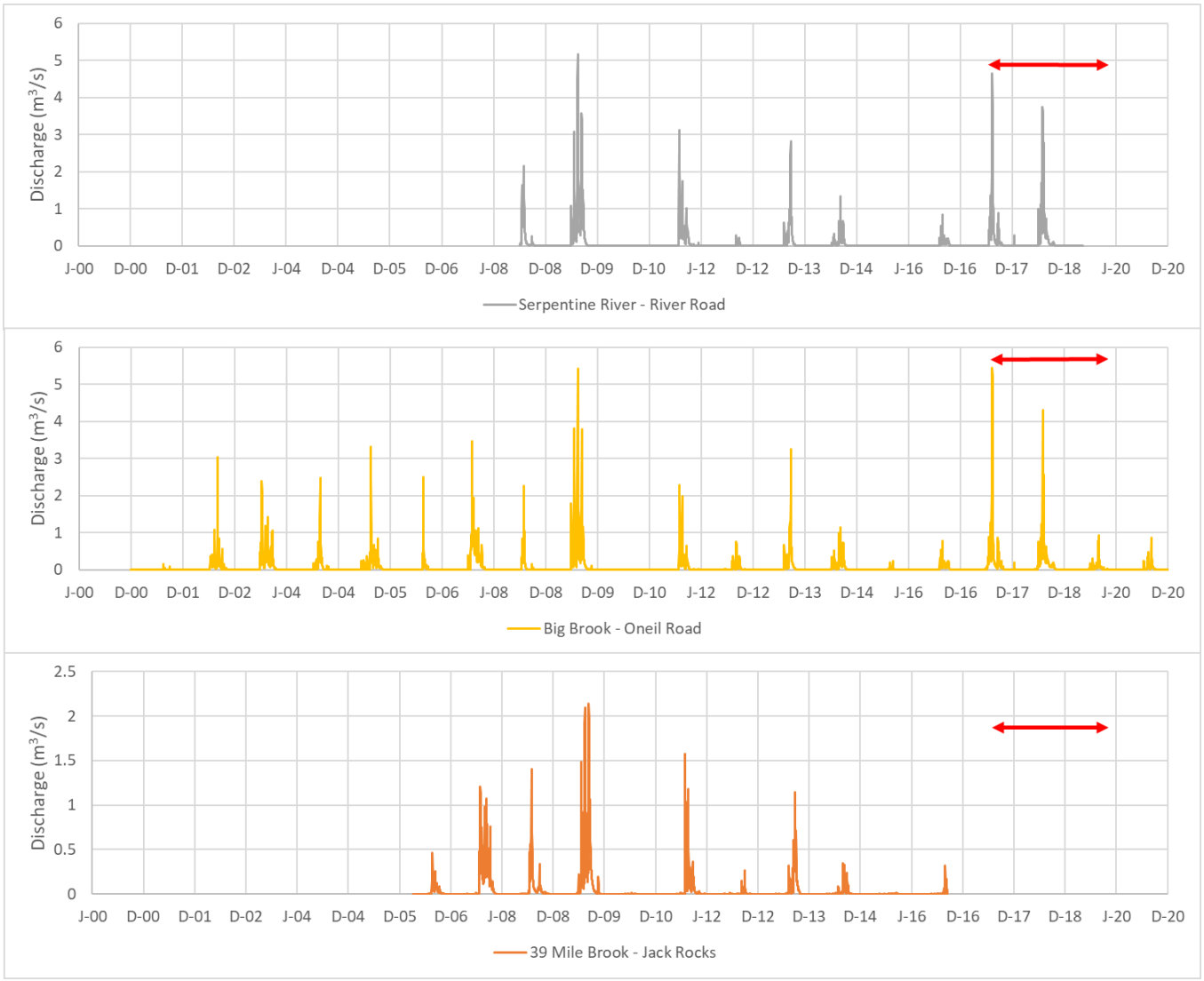


Figure 4 ***Daily average Department of Water and Environmental Regulation (DWER) discharge measurements from 2000-2020 of the Serpentine River, Big Brook and 39 Mile Brook in the SMD catchment. Red arrow shows selected model verification period.***

Monthly (Figure 5) and daily (Figure 6) Big Brook and 39 Mile Brook discharge are highly correlated with the Serpentine River.

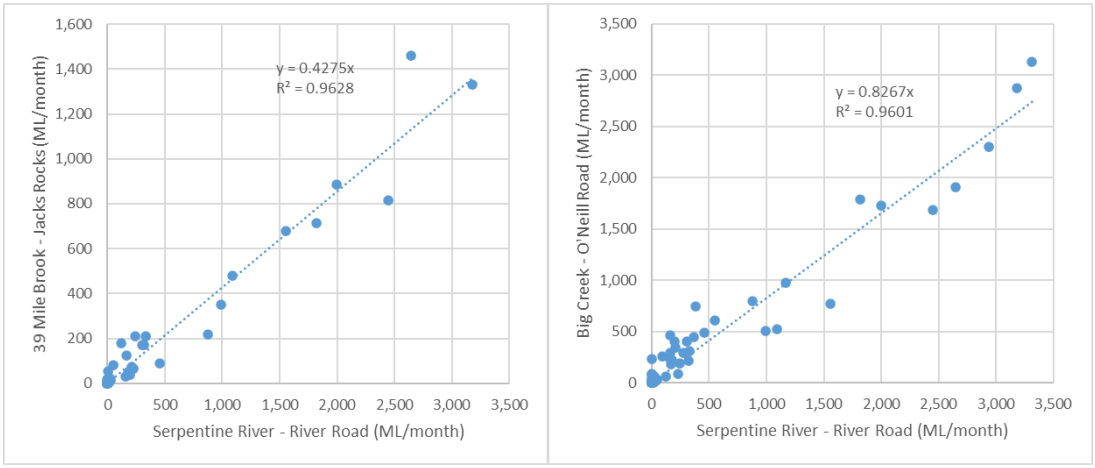


Figure 5 ***Linear regressions between monthly Department of Water and Environmental Regulation (DWER) Serpentine River discharge measurements and those of Big Brook and 39 Mile Brook.***

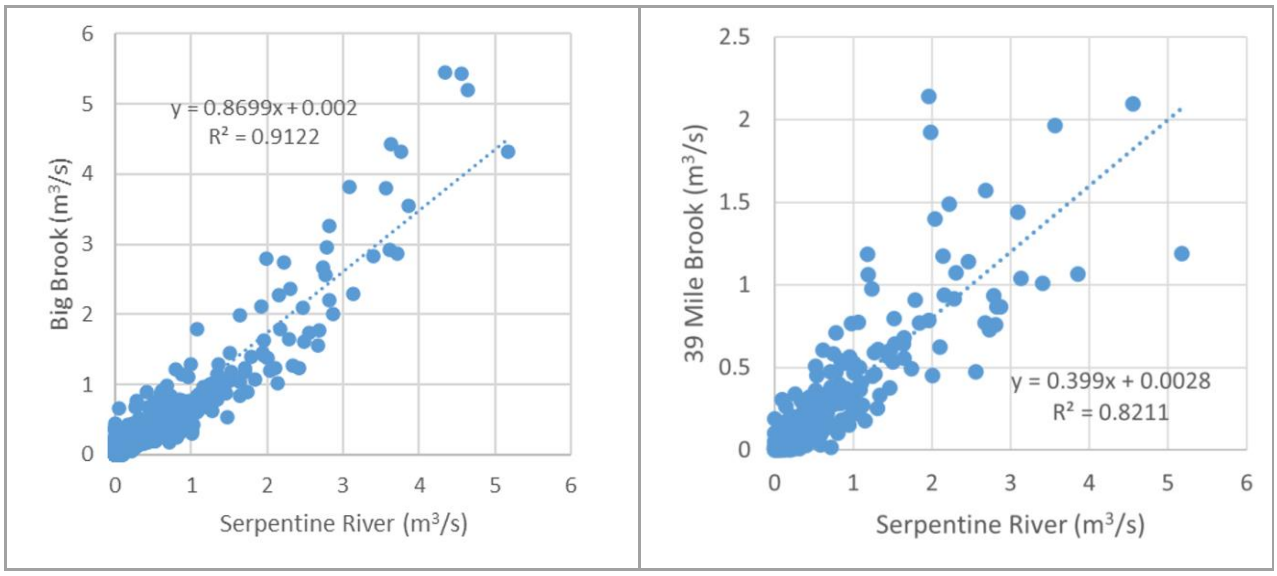


Figure 6 *Linear regressions between daily Department of Water and Environmental Regulation (DWER) Serpentine River discharge measurement and those of Big Brook and 39 Mile Brook.*

3.2.2 Total Discharge Estimates into Reservoirs

Table 2 summarises the methodology to estimate the total inflows into SMD based on the three gauged streams. The gauged catchment area of these three streams accounts for nearly two-thirds of the SMD's total catchment area where the remaining 1.6% and 31.1% are attributable to the reservoir surface area at FSL and the ungauged catchment area, respectively. Linear regression coefficients of monthly discharge from Big Brook and 39 Mile Brook relative to Serpentine River are 82.7% and 42.8% (Figure 5), respectively. These linear coefficients expressed on a per km^2 basis (see Table 2) are 0.0041, 0.0056 and 0.0079 1/km^2 for the Serpentine River, Big Brook and 39 Mile Brook, respectively. These linear areal coefficients were used to estimate discharge from ungauged portions of the catchments.

Table 2 *Derivation of areal linear coefficients to estimate total stream discharge into Serpentine Main Dam (SMD).*

Stream	Location	Area (km^2)	% of Catchment Area	Linear Regression Coefficient relative to Gauged Serpentine River	R^2	Linear Coefficient per km^2	Coarse Estimate of Ungauged Catchment Area (km^2)	Total Catchment Area (km^2)	Linear Coefficient for Total Stream Catchment relative to Gauged Serpentine River
Serpentine River	River Road 614035	243	36.6%	1	1	0.00412	112.1	355.1	1.462
Big Brook	O'Neill Road 614037	149	22.4%	0.827	0.96	0.00555	68.8	217.8	1.209
39 Mile Brook	Jack Rocks 614031	55	8.3%	0.428	0.96	0.00778	25.4	80.4	0.626
	Reservoir @ FSL	10.7	1.6%					10.7	
	Ungauged Catchment	206.3	31.1%	1.375		0.00582			
	Total	664	100.0%				206.3	664.0	

A comparison of the monthly inflow estimates into SMD between Water Corporation's monthly water balance relative to the areal coefficient estimates in Figure 7 are in reasonable agreement.

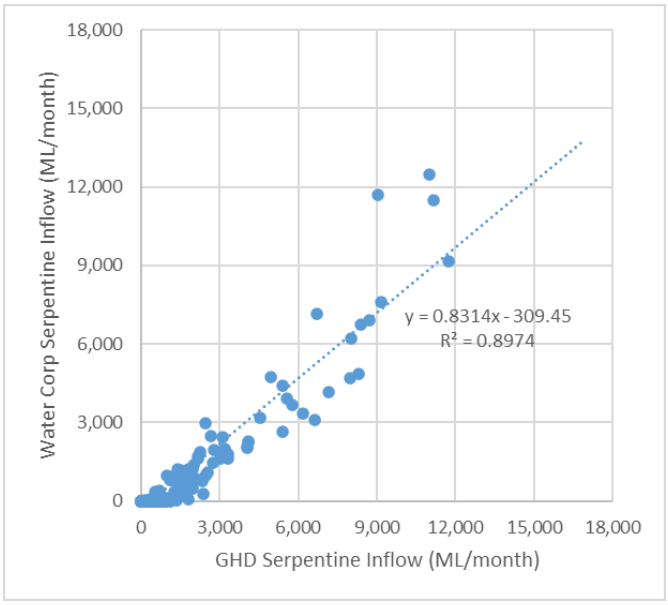


Figure 7 ***Comparison of total Serpentine Main Dam (SMD) catchment inflows via areal coefficient estimates and Water Corporation's monthly water balance.***

For SDD there are no discharge measurements of the major stream (South Dandalup River) over the past 20 years. The average coefficient per square kilometre of the three gauged streams from the proximal SMD catchment of 0.00582/km^2 (Table 2) was used to estimate total SDD catchment inflow as summarised in Table 3.

Table 3 ***Catchment coefficient estimate for South Dandalup Dam (SDD) inflows.***

Stream	Location	Area (km^2)	% of Catchment Area	Linear Coefficient per km^2	Linear Coefficient for Total Stream Catchment relative to Gauged Serpentine River
South Dandalup River		295.2	94.9%	0.00582	1.717
	Reservoir @ FSL	15.8	5.1%		
	Total	311	100.0%		

3.2.3 Stream Temperatures

Figure 8 summarises the stream temperatures of Big Brook from 1 July 2001 through 2000, where during winter, when most high flow events occur, they are in the range of ~5-15°C.

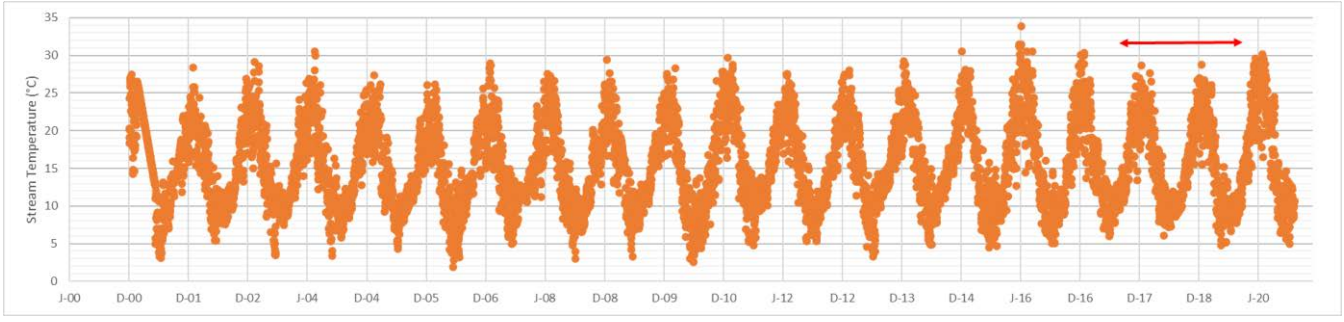


Figure 8 ***Daily Department of Water and Environmental Regulation (DWER) average stream temperature measurements from 2000-2020 of Big Brook (red arrow denotes model verification period).***

3.3 Measurements of Reservoir Water Temperatures and Turbidity near the Dam Walls

Water Corporation provided measurements of turbidity from 2000-2020 near the dam walls of SMD, SDD and SPD at least on a quarterly basis, but at times as frequently as weekly. However, available water temperature measurements only span from 2000-2008.

3.3.1 Serpentine Main Dam

Temperature and turbidity measurements in SMD at the dam wall are illustrated in Figure 9 where:

– Temperatures range from 12-13°C in winter to 25-26°C in summer, noting that measurements cease in 2008.
– Except for elevated turbidity in 2002, levels were generally below 1 NTU. Over the model verification period turbidity was generally below 1 NTU and generally ~0.5 NTU.

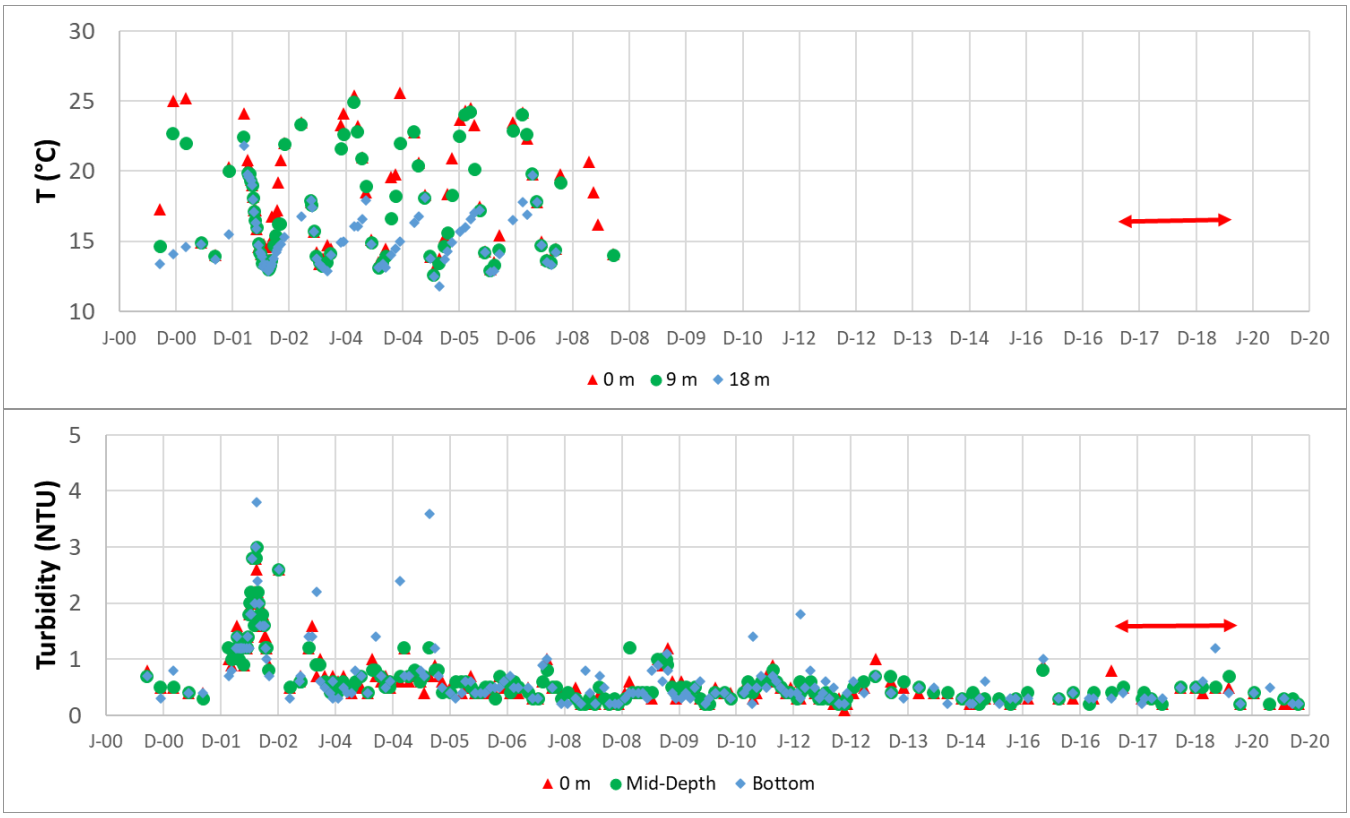


Figure 9 ***Surface (0 m), mid-depth and near-bottom Water Corporation measurements of temperature (T, upper) and turbidity (lower) of the water column at the dam wall from 2000-2020 in Serpentine Main dam (SMD) (red arrow model verification period).***

3.3.2 South Dandalup Dam

Temperature and turbidity measurements in SDD at the dam wall are illustrated in Figure 10 where:

– Temperatures range from 12-13°C in winter to 25-26°C in summer, noting that measurements cease in 2008.
– Except for high levels in the 2011 and 2016 winters, turbidity was generally at or below 1 NTU throughout the 20 years. The 2016 winter was relatively dry with the lowest water level over the past 20 years (Figure 2), Hence it is unlikely that elevated turbidity during these periods was due to catchment inflow, but rather another source such as transfers into SDD.

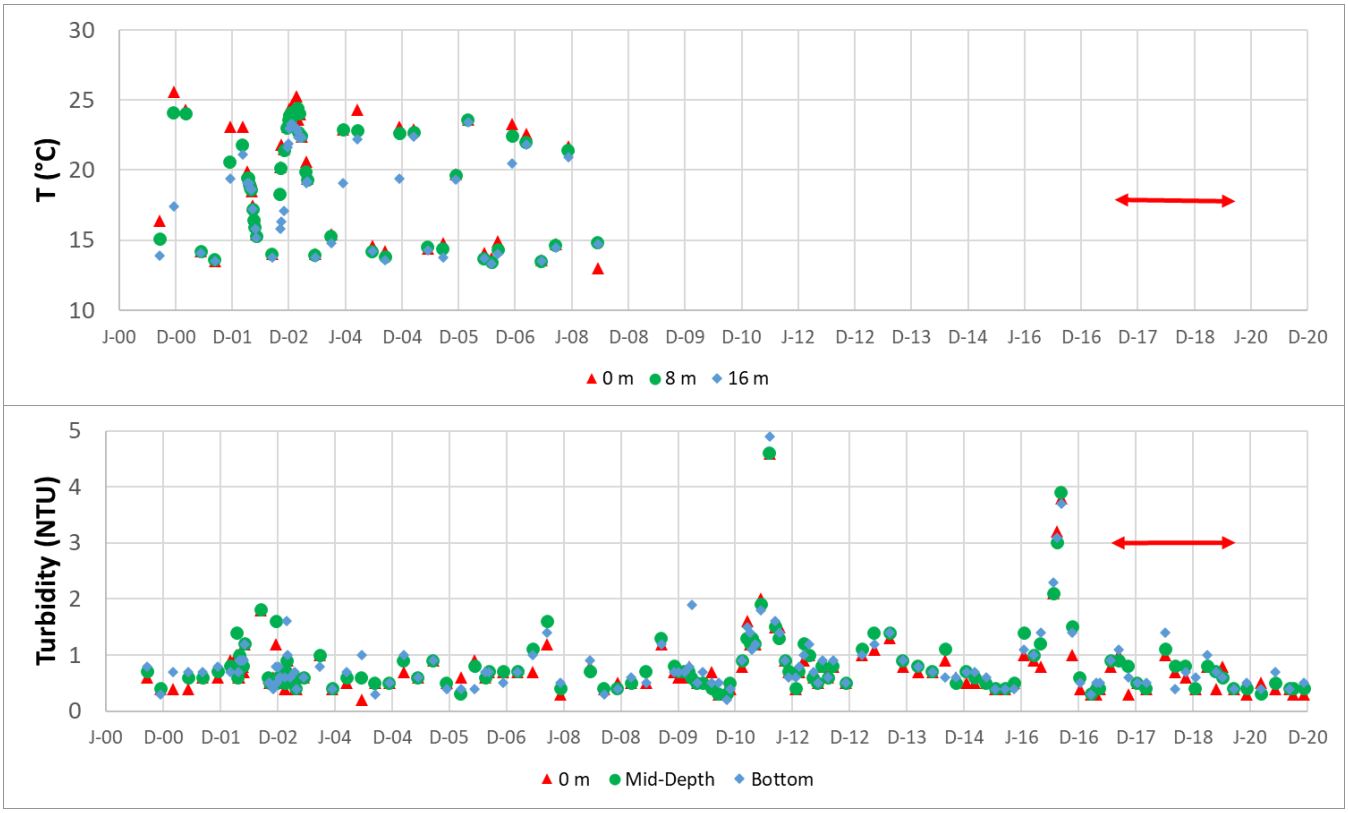


Figure 10 ***Surface (0 m), mid-depth and near-bottom Water Corporation measurements of temperature (T, upper) and turbidity (lower) of the water column at the dam wall from 2000-2020 in South Dandalup Dam (SDD) (red arrow model verification period).***

3.3.3 Serpentine Pipehead Dam

Temperature and turbidity measurements in SPD at the dam wall are illustrated in Figure 10 where:

– Temperatures range from 12-13°C in winter to 25-26°C in summer, noting that measurements cease in 2008.

– Except for elevated turbidity in the winter of 2012, levels were generally at or below 1 NTU throughout the most of the 20 year record. Over the model verification period turbidity was generally below 1 NTU and generally ~0.3-0.5 NTU.

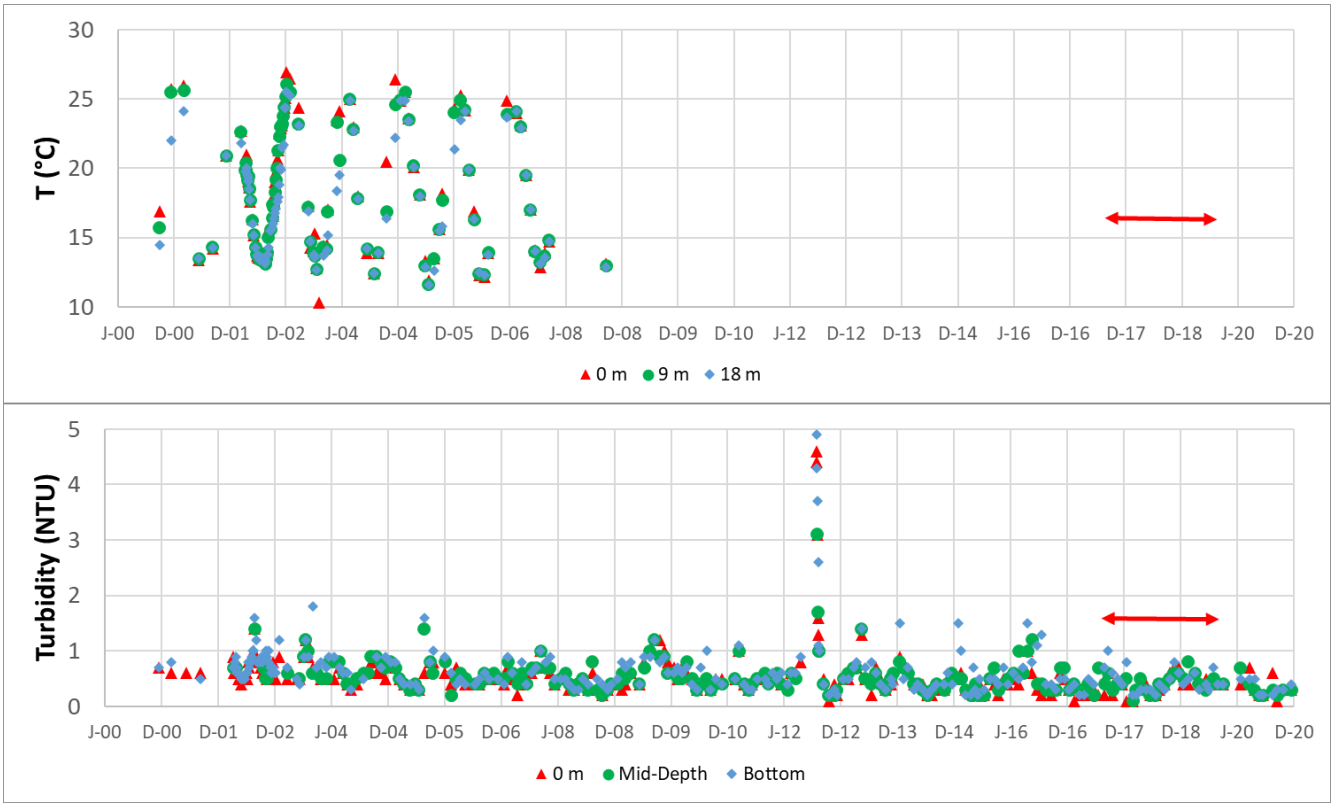


Figure 11 ***Surface (0 m), mid-depth and near-bottom Water Corporation measurements of temperature (T, upper) and turbidity (lower) of the water column at the dam wall from 2000-2020 in Serpentine Pipehead Dam (SPD) (red arrow model verification period).***

3.4 Meteorology

Hourly meteorological inputs were sourced from the National Centers for Environmental Prediction's (NCEP's) Climate Forecast System, version 2 (CFSv2) (Suranjana *et al.* 2014) grid cell nearest to the reservoirs. Figure 12 illustrates the hourly CFSv2 meteorology data that served as inputs to the model.



Figure 12 ***Hourly CFSv2 meteorology from 1 May 2017 to 1 October 2019 of shortwave and incoming longwave radiation (top), air temperature (upper middle), relative humidity (middle), wind speed and direction (lower middle) and rainfall (lower).***

4. Model Establishment and Verification

4.1 Model Inputs

4.1.1 Model Verification Period

A continuous multi-year simulation period for model verification was selected on the following basis:

– Turbidity data was available from Water Corporation from 2000-2020.
– CFSv2 meteorology available from 2015-2020.
– Reliable stream hydrology measurements were available for SMD from 2000-2020. SDD and SPD catchment inflows (no discharge measurements of any large streams from 2000-2020) were estimated from relations of the proximal SMD catchment (see Section 3.2.2).
– Occurrence of at least one substantive inflow event.
– A low reservoir level with reduced volumetric dilution capacity.

On the basis of these criteria the period from 1 July 2017 to 1 October 2019 was selected as the verification modelling period.

4.1.2 Bathymetry of Reservoirs

Spatial data suitable to construct a 3D bathymetry file of each of the three reservoirs was not available. Therefore, the bathymetry of the reservoirs was developed from historical topographic data prior to the construction of the dams and the use of GIS interpolation algorithms to develop digital elevation models. The digital elevation models were then parsed into 100 m by 100 m grids for SMD and SDD, and 50 m by 50 m grids for SPD to serve as bathymetric inputs for the reservoir modelling, which are illustrated in Figure 13, Figure 14 and Figure 15, respectively. The simulated locations of the reservoir confluences of the major streams and smaller catchments are also shown in these figures along with the intake towers (for water supply extraction) and estimates of external transfer locations.

The accuracy of the reservoir volumes at Full Supply Level (FSL) as summarised in Table 4 are considered sufficient for the objectives of this investigation. Though the volume discrepancy is relatively sizeable for SPD (~10%), given the relatively low water age of this reservoir (see Figure 65), this is considered acceptable.

Table 4 ***Comparison of volumes and surface areas at Full Supply Level (FSL) of Serpentine Man Dam (SMD), Serpentine Pipehead Dam (SPD) and South Dandalup Dam (SDD) between modelling inputs and Water Corporation website.***

Reservoir	FSL Level (m AHD)	Water Corp Volume (GL)	Model Volume (GL)	Volume Discrepancy
Serpentine Main	212.4	137.7	143.0	3.9%
Serpentine Pipehead	165.5	3.14	2.83	-11.8%
South Dandalup	252.8	138.0	144.8	4.9%

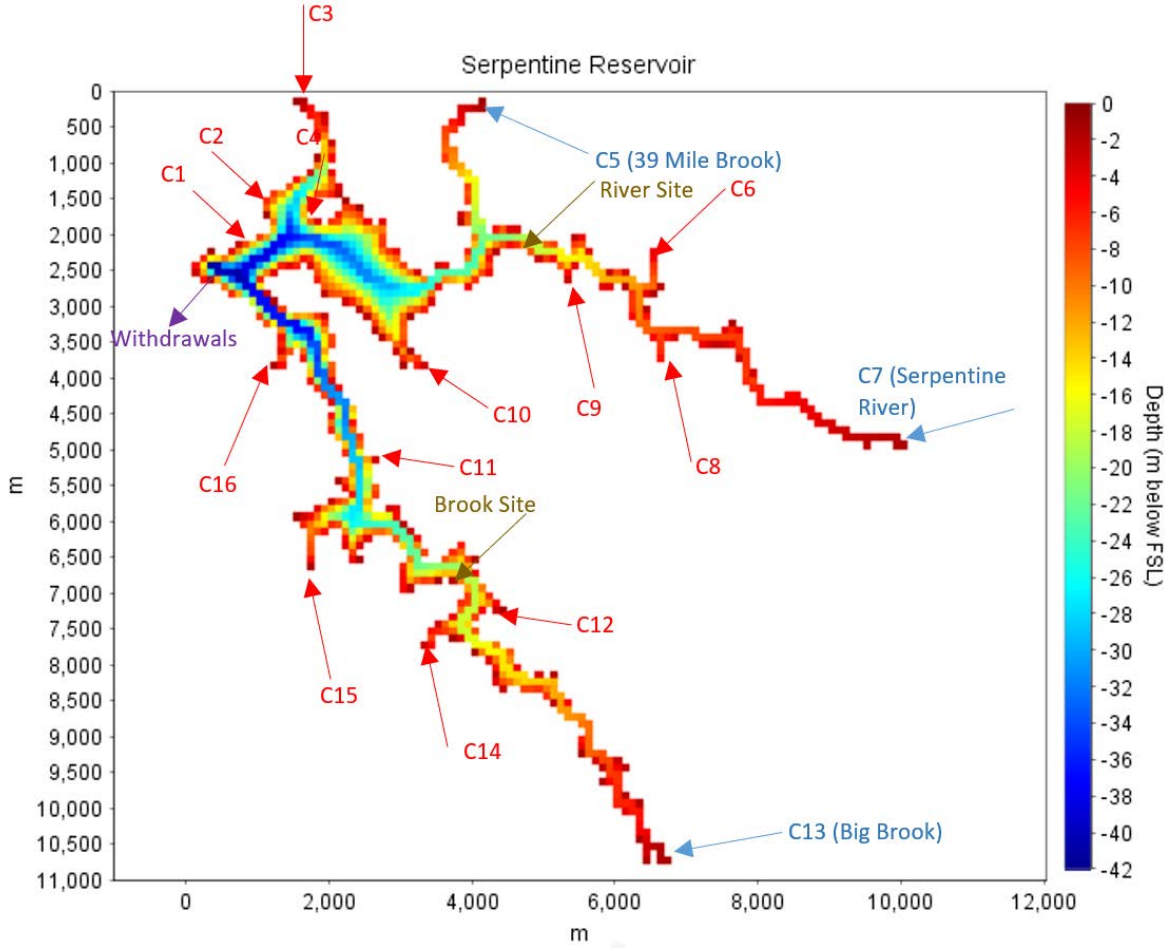


Figure 13 ***Serpentine Main Dam (SMD) bathymetry along with three Department of Water and Environmental Regulation (DWER) gauged major streams (blue), intake tower (purple), 13 other catchments (red) and assessment sites (gold).***

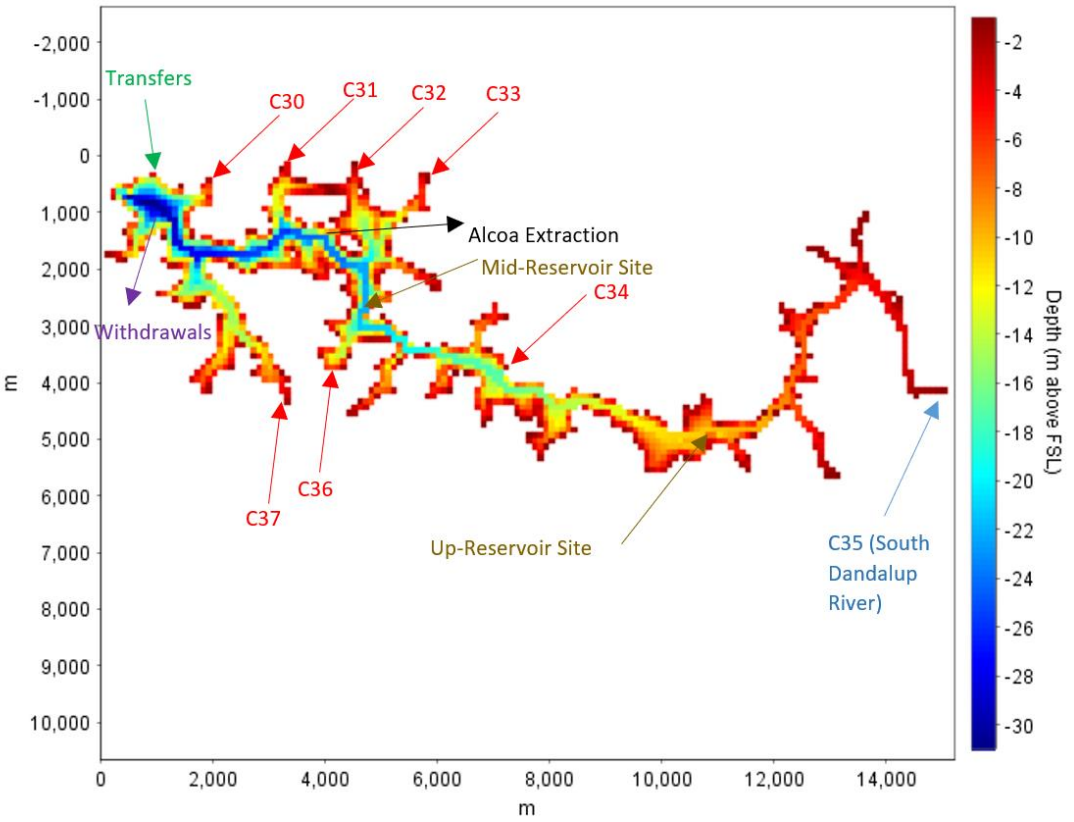


Figure 14 ***South Dandalup Dam (SDD) bathymetry along with the major stream, 7 other catchments, external transfers from Lower South Dandalup (green), Alcoa extractions (black) and assessment sites (gold).***

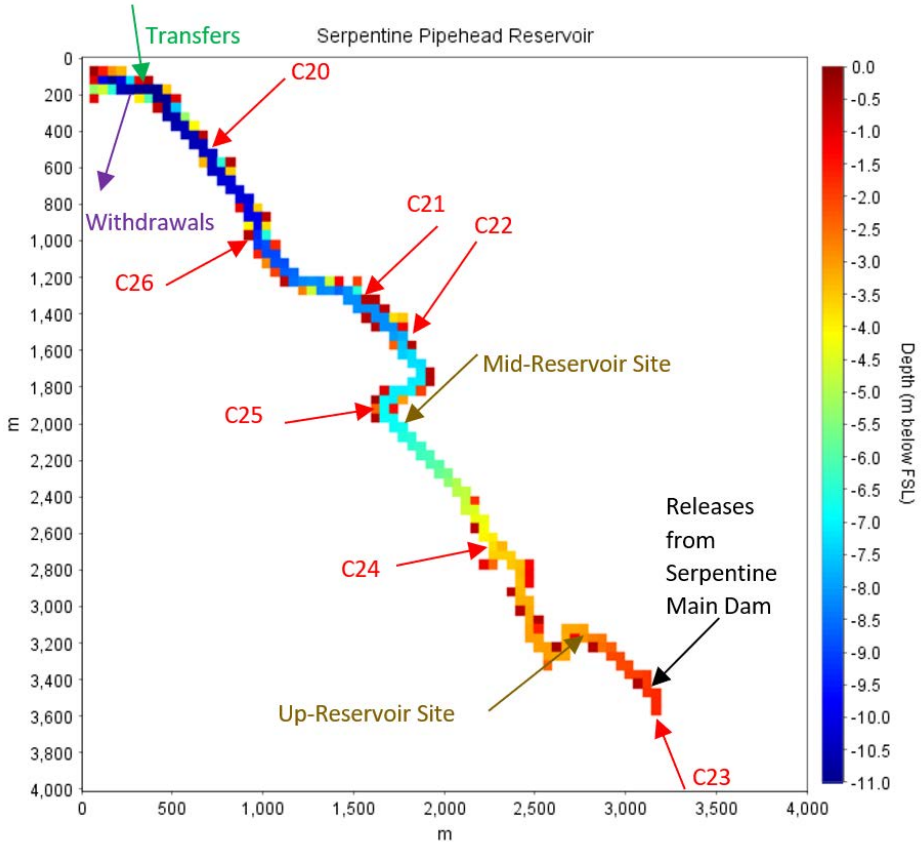


Figure 15 ***Serpentine Pipehead Dam (SPD) bathymetry along with 7 catchments, external transfer (green), Serpentine Main Dam (SMD) releases (black) and assessment sites (gold).***

4.1.3 Meteorology

Refer to Section 3.4 for a description of the meteorological inputs that were applied to the reservoir model.

4.1.4 Catchment Inflows

Total daily catchment discharge estimates into the three reservoirs from the regression relations in Section 3.2.2 served as inputs to the 2017-2019 verification simulations, which are illustrated in Figure 16. The amount of the total daily discharge that was allocated to each of the simulated streams was the percentage of each of the catchment areas to the total reservoir catchment area. Big Brook stream temperatures that served as model inputs for all stream temperatures (Figure 8).

4.1.5 External Transfers

SDD and SPD external transfers were assumed to occur in proximity to the dam wall (Figure 14 and Figure 15) via inspection of Google Earth images. The external transfers were based on the monthly water balance information from the Water Corporation (Section 3.1).

4.1.6 Withdrawal Discharge from and Locations in Reservoirs

No explicit draw (withdrawal) data (i.e. draw volume per day and depth of draw from reservoir through intake tower) was available for SMD.[3] For the purposes of the 2017-2019 SMD verification simulation were as estimated from the revised monthly water balance (Section 3.1). Model inputs for the SDD draws were as provided in the monthly water balance by Water Corporation (Section 3.1).

The SPD water balance is dominated by external transfers and draws. Model inputs for external transfers into SPD were as provided in the monthly water balance by Water Corporation (Section 3.1). However, the draws were configured as a dynamic outflow boundary condition dependent on surface water level height on the basis of the following piece-wise linear relations:

- -2 m below FSL or lower than draw is 0 m^3/s.
- -1.5 m below FSL than draw is 0.25 m^3/s.
- -1 m below FSL than draw is 1 m^3/s.
- -0.5 m below FSL than draw is 1.75 m^3/s.
- 0 m below FSL than draw is 3 m^3/s.

[3] For their monthly water balance Water Corporation does not calculate the draw from SMD.

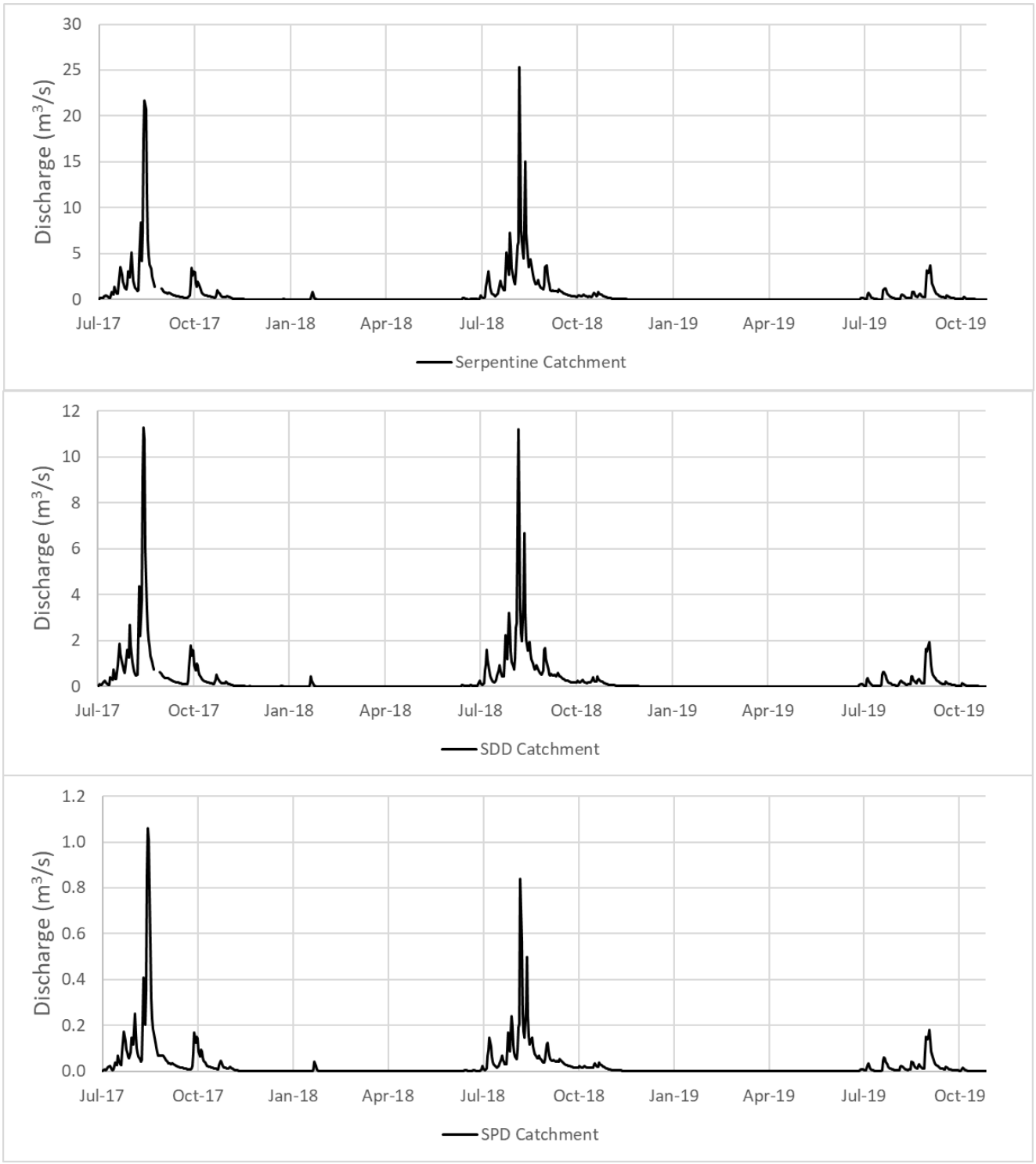


Figure 16 ***Daily modelled stream discharge into Serpentine Main Dam (SMD) (top), South Dandalup Dam (SDD) (middle) and Serpentine Pipehead Dam (SPD) (bottom).***

4.1.7 Suspended Solids

Two particle types were configured to simulate the inorganic suspended solids (SS) concentrations from inputs into the reservoirs, namely clay (SS_{clay}) and silt (SS_{silt}). The model was configured with the following SS parameters:

– Particle density of 2,650 kg/m^3.

– Particle diameters of 1 and 5 µm for SS_{clay} and SS_{silt}, respectively. Clay is defined as particle diameters of 1-4 µm. Silt is defined as particle diameters of 4-63 µm. Very fine silt is defined as particle diameters of 4-8 µm.

Hence, the characteristic diameters configured here are conservative in that they both represent the smallest particle diameters for SS_{clay} and SS_{silt}.

– Application of stokes settling, which yields characteristic settling velocities of 1×10^{-6} m/s and 1×10^{-5} m/s for SS_{clay} and SS_{silt}, respectively.

There were no available reliable measurements of stream turbidity or suspended solids, so estimates were determined. The clay and silt components of SS were set to constant concentrations of:

– SS_{clay} as 5 mg/L.
– SS_{silt} as 15 mg/L.

SS_{clay} of 5 mg/L was based on a sensitivity analysis over a range of concentrations that yielded reasonable simulated SS levels when compared to turbidity measurements at the dam wall over the 2017-2019 verification period for all three reservoirs (see Section 4.2.3). The silt concentration of 15 mg/L was based on particle size distribution measurements of natural streambed sediments (see Table 10), which indicates 20% and 60% of the material is clay and silt, respectively. On this basis SS_{silt} was estimated as a three-fold increase of SS_{clay}. Though these constant clay and silt concentrations are overestimates during low flow periods, volumetrically most of the catchment loads into the reservoirs occur during winter inflow events when these SS levels are reasonable. The following inorganic SS concentrations for the SDD and SPD external transfers (note there are no external transfers into SMD) were fixed based on a sensitivity analysis over a range of concentrations, which yielded reasonable simulated SS when compared to turbidity measurements over the 2017-2019 verification period:

– SDD external transfers had SS_{clay} and SS_{silt} concentrations of 3.0 mg/L and 0.5 mg/L, respectively.
– SPD external transfers had SS_{clay} and SS_{silt} concentrations of 0.45 mg/L and 0.05 mg/L, respectively.
– SMD releases to SPD had SS_{clay} and SS_{silt} concentrations of 0.95 and 0.05 mg/L, respectively. Because of the small volume of SMD releases to SPD over the 2017-2019 verification period, these silt and clay concentrations do not have any meaningful effect on the simulations.

These data gaps in stream turbidity and/or SS measurements yield the highest degree of uncertainty in this investigation.

4.2 Model Verification

4.2.1 Reservoir Surface Levels

Model verification of reservoir surface levels of the three reservoirs was on the basis of comparisons between simulations and those of the monthly water balance.

Initially the simulated SMD water levels matched well with those of the monthly water balance for the 2017 winter, but the 2018 winter levels were underestimated. A ~50% increase to the estimated inflows over the 2018 winter high discharge period (i.e. 14 July-2 September 2018) reproduced the Water Corporation's monthly water levels (Figure 17).

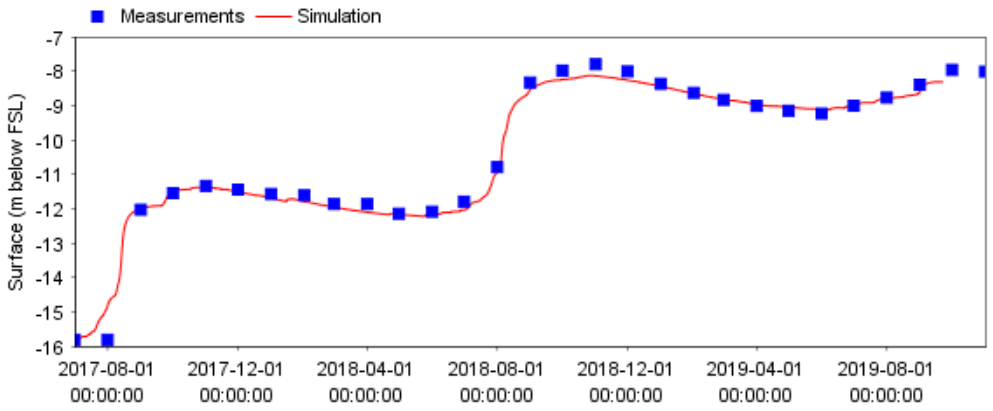


Figure 17 ***Comparison of measured and simulated Serpentine Main Dam (SMD) surface levels on the 1st of the month from July 2017 to June 2019.***

The simulated SDD water levels matched well with those of the Water Corporation's monthly water balance model for the 2017 winter, but the 2018 winter levels were underestimated. A ~25% increase to the estimated inflows over the high winter 2018 discharge period (i.e. 14 July-2 September 2018) reproduced the Water Corporation's monthly water levels (Figure 18).

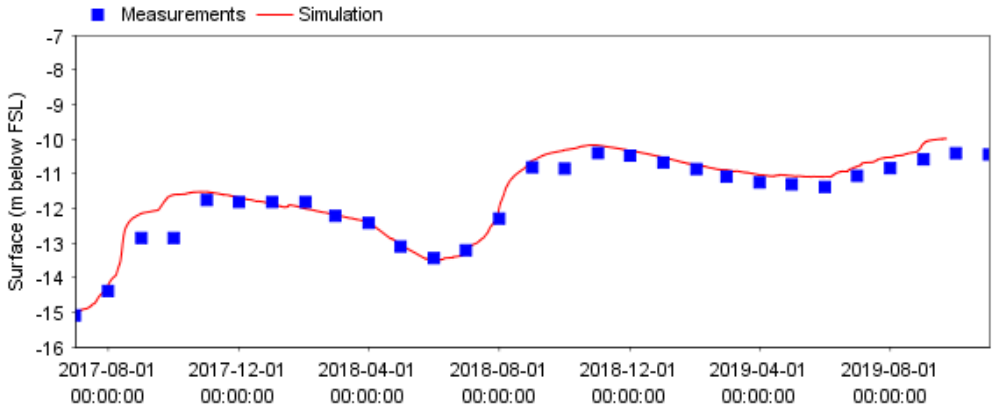


Figure 18 ***Comparison of measured and simulated South Dandalup Dam (SDD) surface levels on the 1st of the month from July 2017 to June 2019.***

The simulated SPD water levels were within the range of the Water Corporation's monthly water balance model over the simulation period (Figure 19) with application of the outflow (withdrawal) dynamic boundary condition as described in Section 4.1.6. Further, the simulated withdrawals with the dynamic outflow boundary condition matched well with the monthly water balance model (Figure 20).

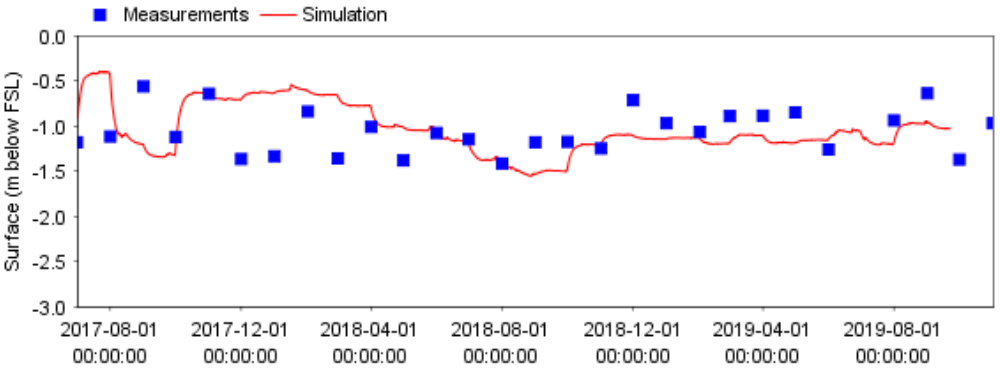


Figure 19 ***Comparison of measured and simulated Serpentine Pipehead Dam (SPD) surface levels on the 1st of the month from July 2017 to June 2019.***

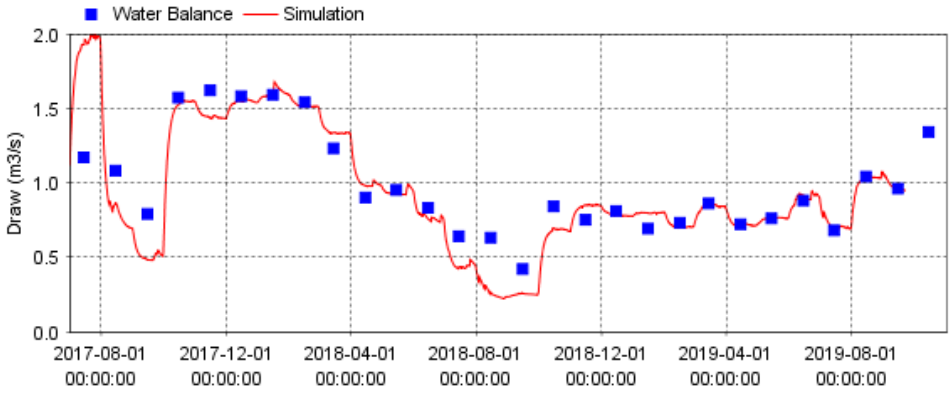


Figure 20 ***Comparison between average monthly water balance and simulated sub-daily Serpentine Pipehead Dam (SPD) draws.***

4.2.2 Temperature

As described in Section 3.3, water temperature measurements of the three reservoirs were only available until 2008. Selection of appropriate periods from the available 2000-2008 temperature measurements to compare to the 2017-2019 verification simulation was based primarily on similarities in the water balance components (i.e. water levels, catchment inflows, draws and transfers) (see Figure 3 of Section 3.1).

Comparison of simulated (2017-18) and measured (SMD 2002-3, SDD 2003-4, SPD 2006-7) water temperatures show a reasonable degree of similarity given the coarse similarity in monthly water balance terms for SMD (Figure 21), SDD (Figure 22) and SPD (Figure 23), respectively. These comparisons demonstrate the following:

– The surface heat balance was modelled well as the simulated surface water temperatures are in reasonable agreement with measurements from the selected comparative year of each reservoir. Hence, the CFSv2 meteorological inputs are acceptable. Note that there was not calibration of meteorological inputs.
– The bottom water temperatures are simulated reasonably well in terms of the rate of hypolimnetic heating and the duration of seasonal stratification for SMD and SDD.

On the basis of these comparisons, the model adequately simulates water temperatures and patterns of thermal stratification in all three reservoirs. Further discussion on the thermal stratification dynamics of the reservoirs is provided in Section 4.3.1.

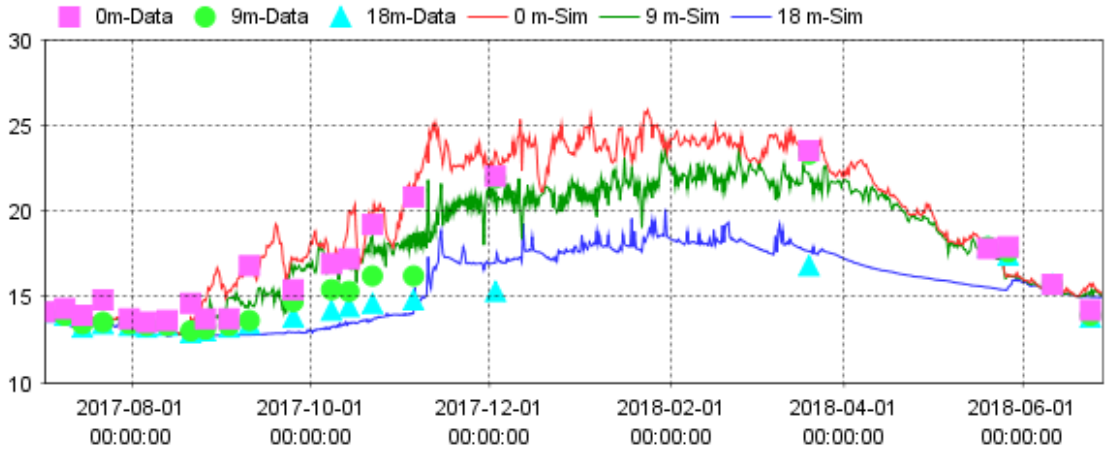


Figure 21 ***Comparison of the Serpentine Main Dam (SMD) 2017-2018 simulated (lines) and 2002-2003 measured (symbols) temperatures at the surface, mid-depth and deep water column near the dam wall from July to June.***

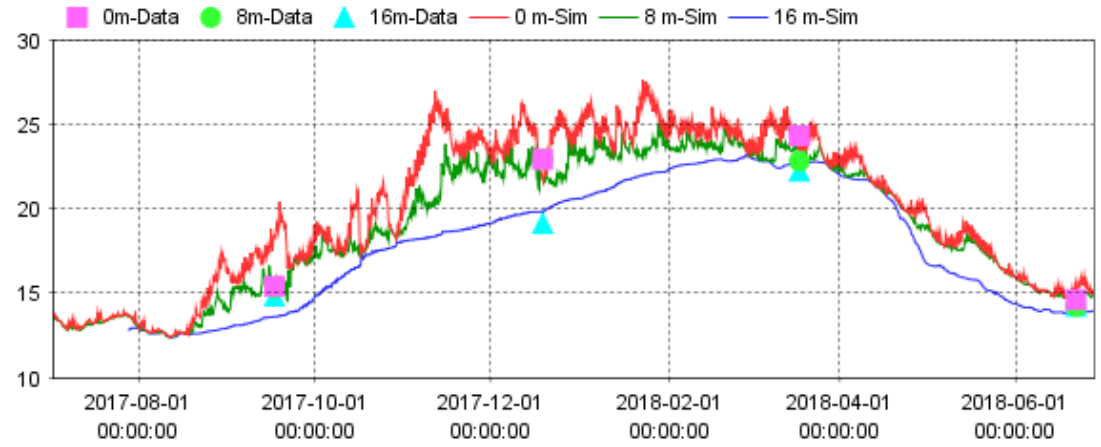


Figure 22 ***Comparison of the South Dandalup Dam (SDD) 2017-2018 simulated (lines) and 2003-2004 measured (symbols) temperatures at the surface, mid-depth and deep water column near the dam wall from July to June.***

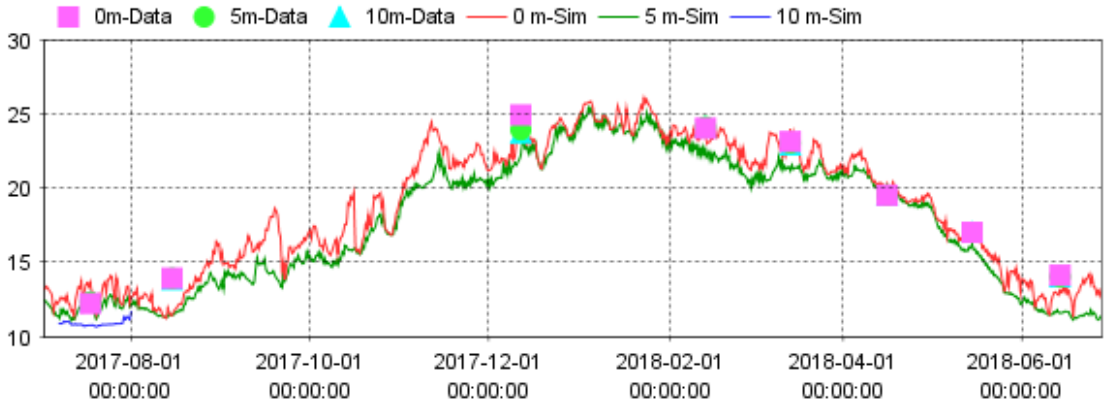


Figure 23 ***Comparison of the Serpentine Pipehead Dam (SPD) 2017-2018 simulated (lines) and 2006-2007 measured (symbols) temperatures at the surface, mid-depth and deep water column near the dam wall from July to June.***

4.2.3 Simulated Inorganic Suspended Solids (SS) and Turbidity Measurements

A comparison of the simulated SS_{clay} in the surface, mid-depth and deeper water column with the available turbidity measurements at the dam wall of the three reservoirs from 2017-2019 is shown in Figure 24. SS_{clay} comprises most of the suspended inorganic particles present in water near the dam wall (refer to Section 4.3.2). The simulated clay component of SS is in reasonable agreement with measurements assuming a SS:turbidity ratio of 1:1, which is applicable at these low concentrations (Section 1.5). The following is noted:

- The simulated SMD SS_{clay} is overestimated during the 2017 winter and underestimated during both the 2017 and 2018 summers. The simulated overestimate in winter 2017 SS_{clay} is ~2-fold greater than measurements, however the simulated 2018 winter levels are similar to turbidity observations. The simulated summer underestimates may be due to a larger proportion of organic SS (e.g. phytoplankton), which is not simulated here.
- The simulated SDD SS_{clay} matches reasonably well during both the 2017 and 2018 winters, but is underestimated during both 2017 and 2018 summers. As with SMD, the summer underestimates may be due to a larger proportion of organic SS (e.g. phytoplankton), which is not simulated here.
- SPD SS_{clay} is simulated well throughout the model verification period.

Given the uncertainty in SS from catchment inputs and external transfers, along with the inability to apply the AEM3D model's biogeochemical modules to simulate organic particle dynamics (e.g. phytoplankton, nutrient and organic carbon) due to a lack of data, the simulated SS_{clay} reproduces reasonably well the measured winter turbidity at the dam walls of the three reservoirs in response to sizeable inflow events. One of the key risks from the proposed mining transition is increased reservoir turbidity due to high inorganic particle loads from mined catchments. The model verification of SS here with available turbidity measurements at the dam wall indicates that the model can adequately quantify the relative effect on inorganic SS of withdrawal near the dam wall across a range of winter inorganic particle loading scenario.

Further discussion on the seasonal and interannual SS patterns in the reservoirs is provided in Section 4.3.2.

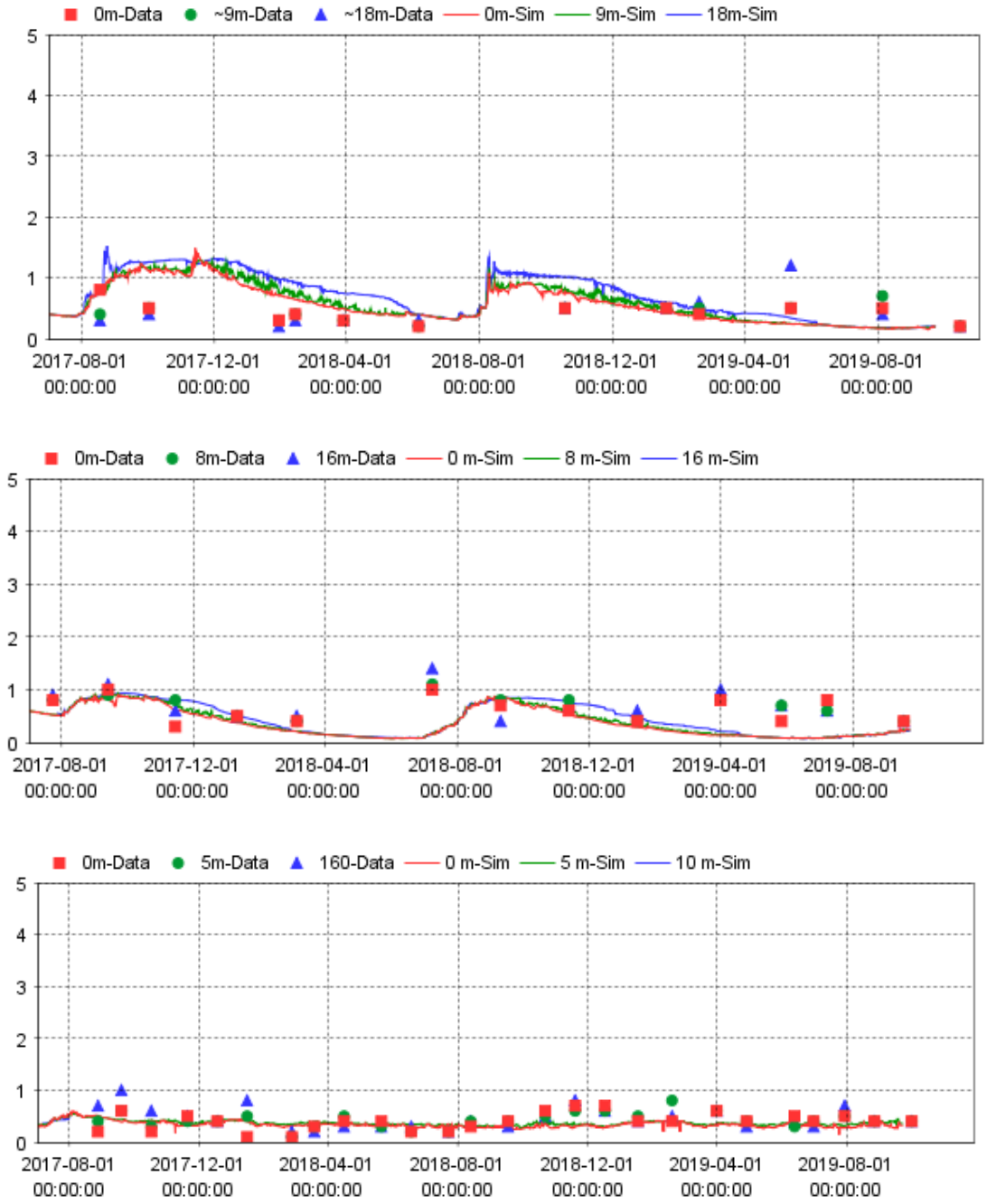


Figure 24 ***Comparison of the simulated clay component of inorganic suspended solids (SS_{clay} in mg/L) and measured turbidity (NTU) at the surface, mid-depth and deeper water column from July 2017 to October 2019 for Serpentine Main Dam (SMD) (top), South Dandalup Dam (SDD) (middle) and Serpentine Pipehead Dam (SPD) (bottom).***

4.3 Key Reservoir Processes during Model Verification Period

4.3.1 Seasonal Patterns of Thermal Stratification

Figure 13, Figure 14 and Figure 15 show the three assessment sites in each reservoir (i.e. near dam wall near the intake towers and two up-reservoir sites) that are used to illustrate seasonal patterns of thermal stratification in SMD, SDD and SPD, respectively. The simulated water levels, patterns of thermal stratification (as isotherms through the water column with time at each assessment site), and withdrawal temperatures at the three assessment sites for each reservoir are shown in Figure 25, Figure 26 and Figure 27 for SMD, SDD and SPD, respectively,. In SMD and SDD the simulated thermal stratification patterns include:

– Seasonal thermal stratification is maintained at the up-reservoir sites, but more so with the substantially cooler hypolimnetic temperatures at the dam site.
– The several meter increase in water levels during the 2018 winter resulted in seasonal thermal stratification that was more pronounced in the up-reservoir sites than the previous season at lower water levels.
– Short-term (~1 day) fluctuations in hypolimnetic temperatures are simulated at the dam sites over the thermally stratified period. These fluctuations are caused by sustained high wind events that induce internal waves via tilting of the thermocline at the dam wall. During such events higher rates of vertical mixing occur.

In SPD seasonal thermal stratification was not maintained, but brief periods (days to weeks) of intermittent thermal stratification were simulated.

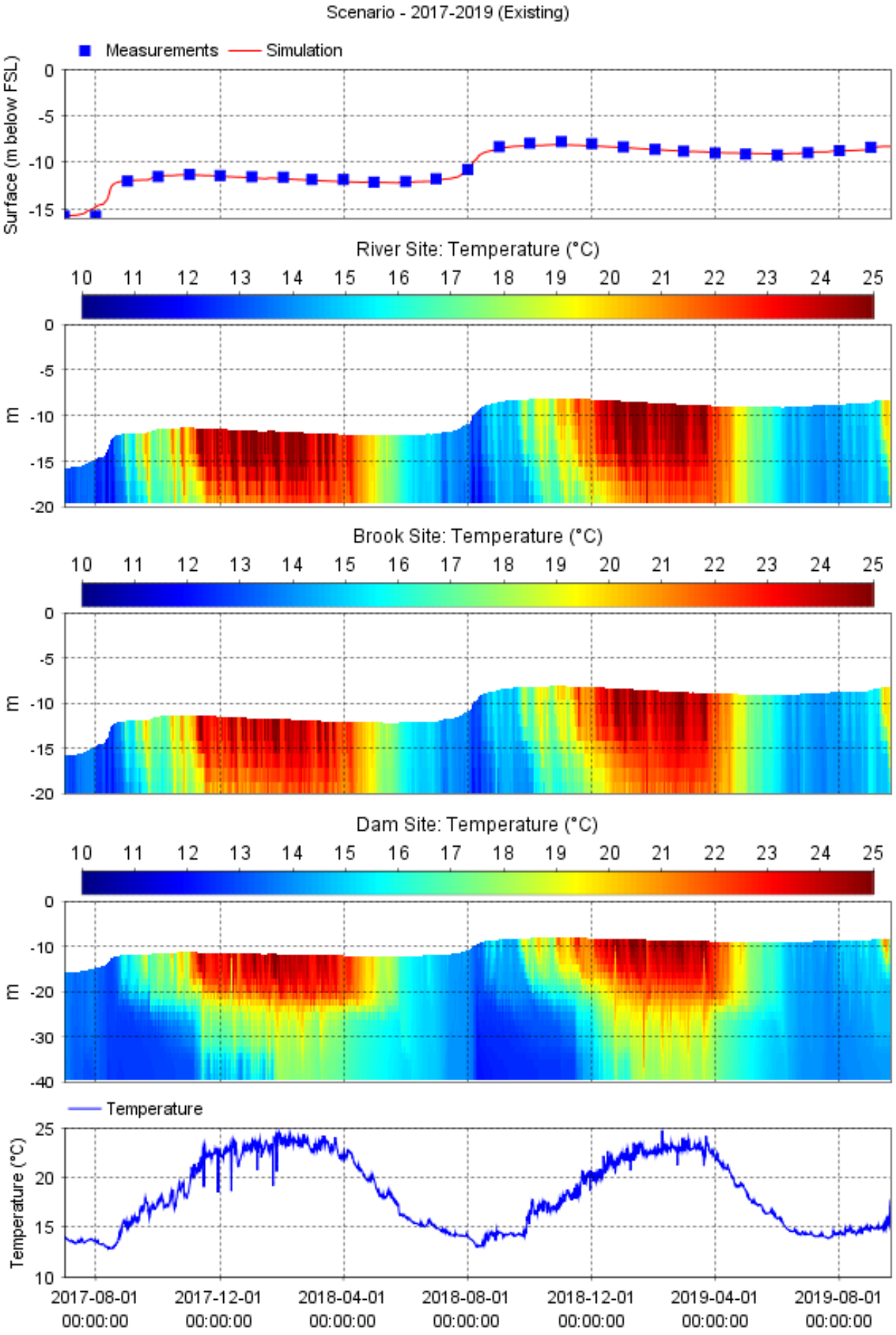


Figure 25 ***Simulated and measured Serpentine Main Dam (SMD) water levels (top), and simulated isotherms at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated withdrawal temperatures (bottom).***

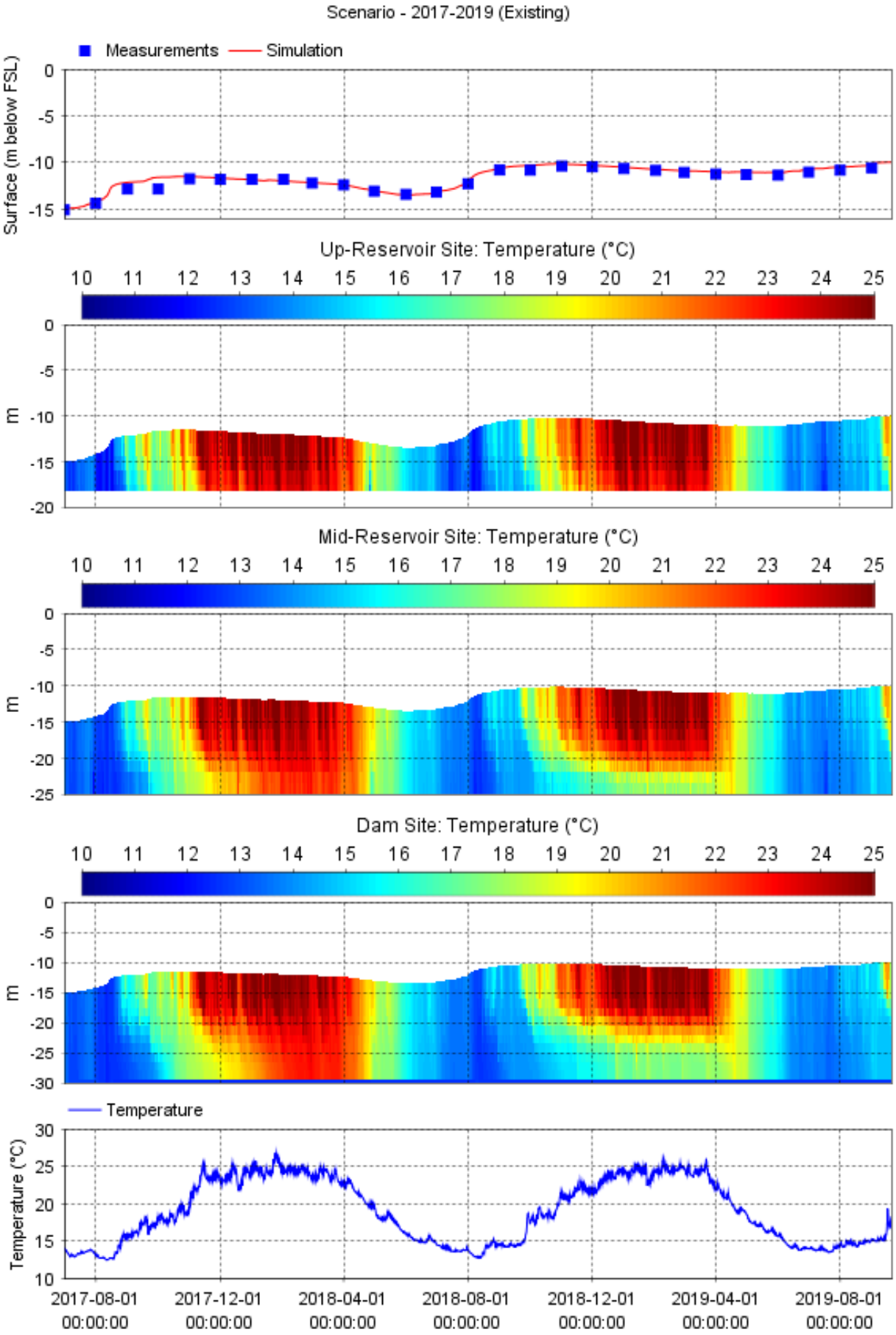


Figure 26 ***Simulated and measured South Dandalup Dam (SDD) water levels (top), and simulated isotherms at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated withdrawal temperatures (bottom).***

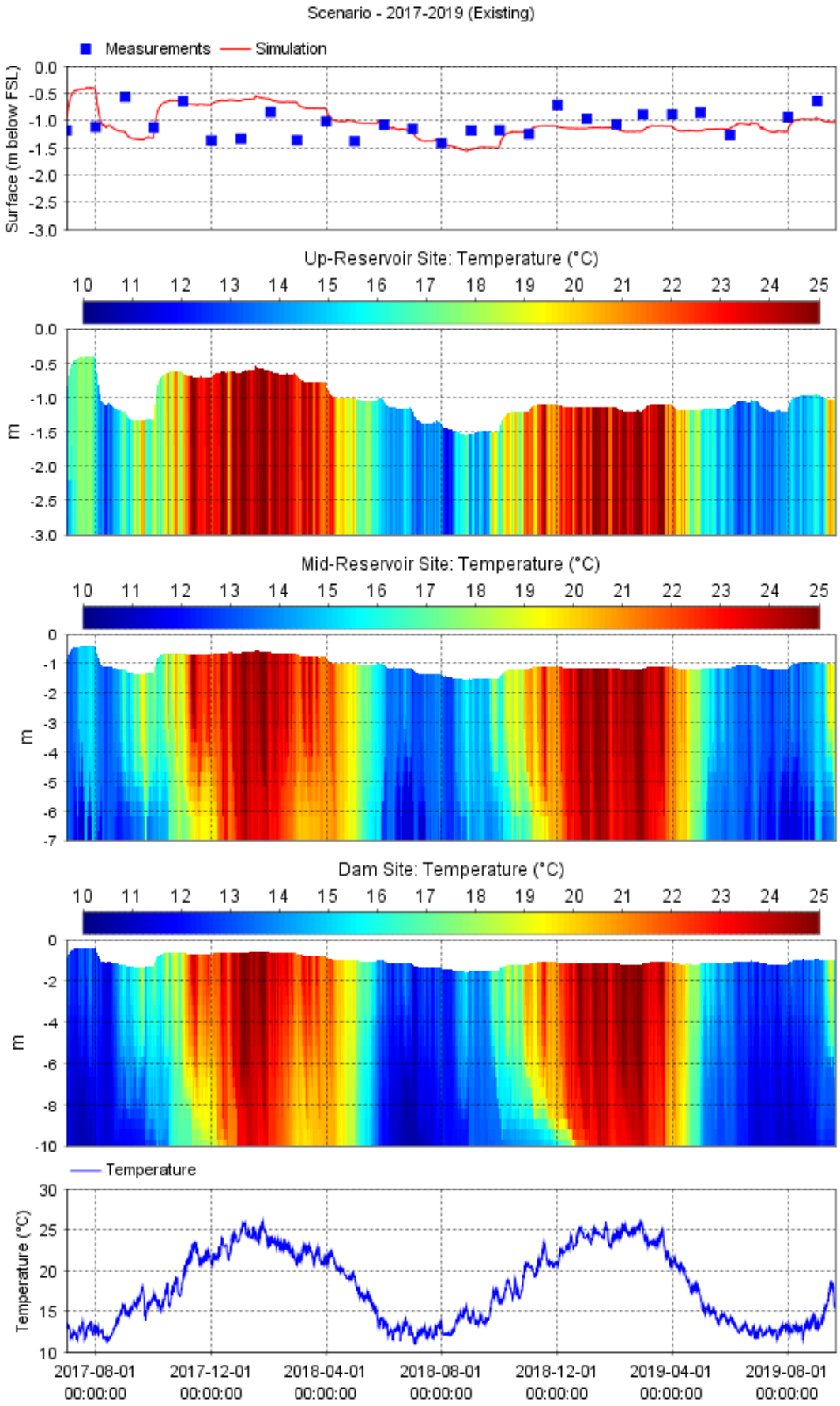


Figure 27 ***Simulated and measured Serpentine Pipehead Dam (SPD) water levels (top), and simulated isotherms at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated withdrawal temperatures (bottom).***

4.3.2 Spatial Patterns of Inorganic Suspended Solids (SS) during the 2017 and 2018 Inflow Events

Spatial snapshots of the simulated SS_{Clay} every 2 weeks during the 2017 and 2018 inflow events along the thalwegs of SMD (Serpentine River arm), SDD and SPD are provided in Figure 28, Figure 29 and Figure 30, respectively.

Elevated SS_{clay} levels typically are simulated in the upstream portions of SMD and SDD because these particles tend to remain in suspension due to their very low settling velocities. These elevated levels in SMD and SDD typically are transported down the reservoir bed slope towards the dam as turbid underflows. Hence, substantially lower SS_{clay} occurs in the upper half of the water column in proximity to the dam walls.

In contrast, SS_{clay} is much lower in SPD relative to the other two reservoirs for several reasons:

– Relatively low SS catchment loads occur into SPD because of the small catchment area.
– External transfers into SPD have high discharge and low SS, which dilutes SS from catchment inflow events.

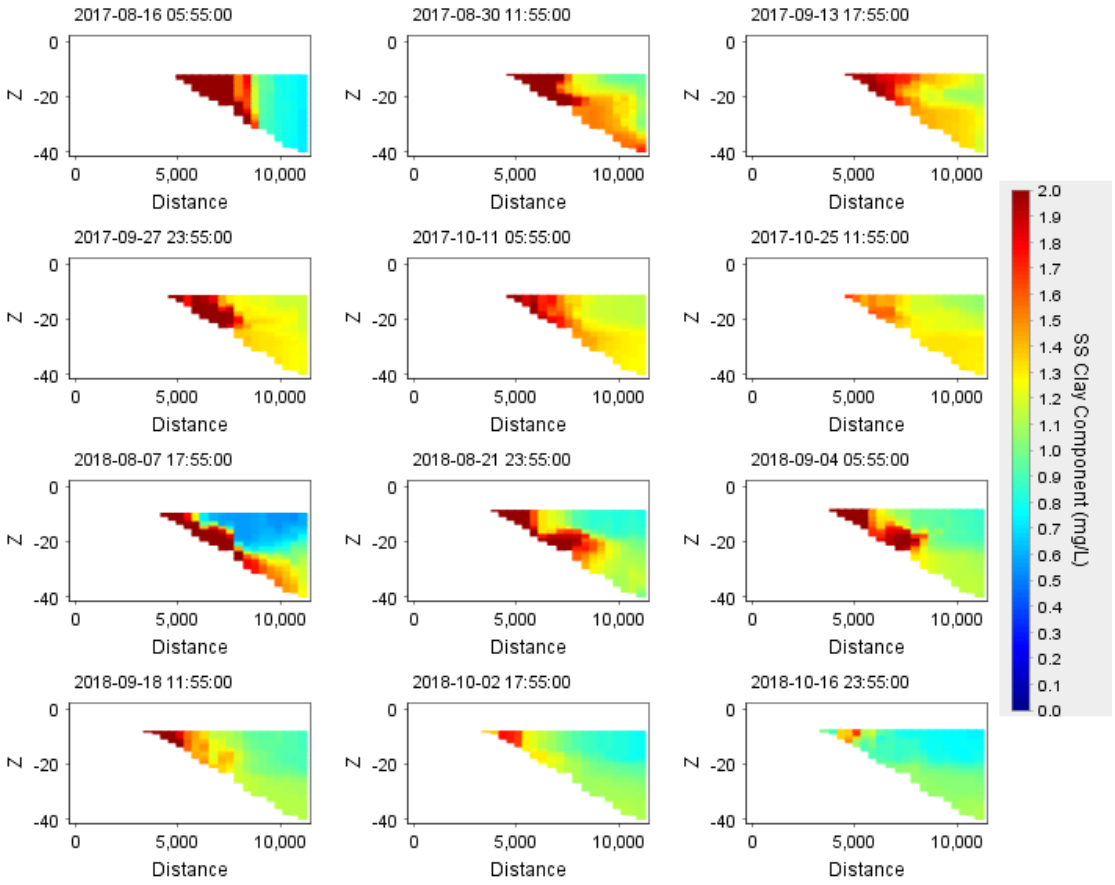


Figure 28 ***Spatial snapshots of the simulated Serpentine Main Dam (SMD) clay component of inorganic suspened solids (SS_{clay}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the Serpentine River thalweg.***

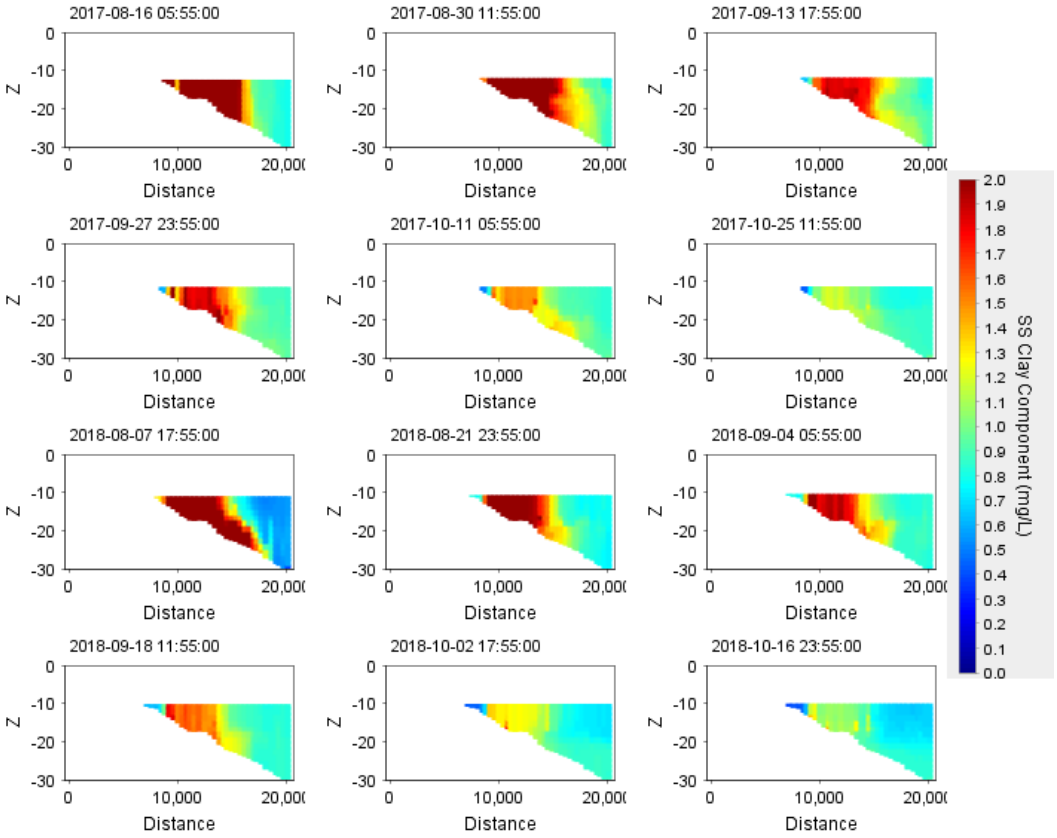


Figure 29 ***Spatial snapshots of the simulated South Dandalup Dam (SDD) clay component of inorganic suspened solids (SS_{clay}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the South Dandalup River thalweg.***

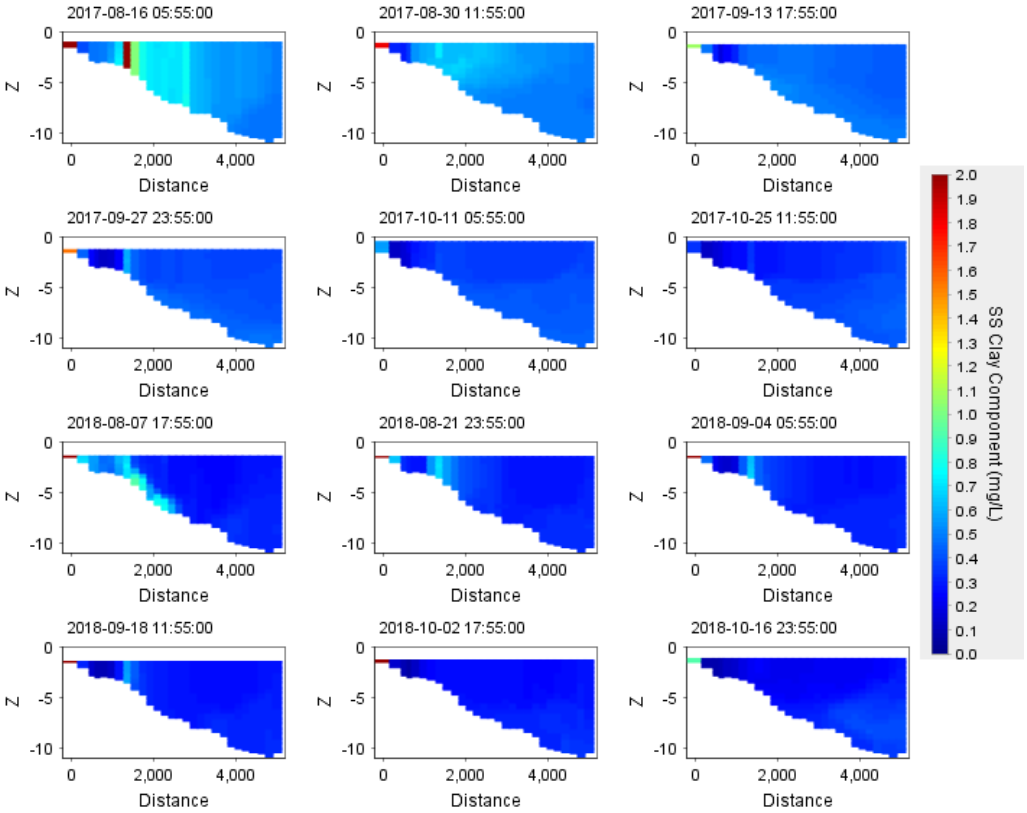


Figure 30 ***Spatial snapshots of the simulated Serpentine Pipehead Dam (SPD) clay component of inorganic suspened solids (SS_{clay}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the Serpentine River thalweg.***

Spatial snapshots of SS_{silt} every 2 weeks during the 2017 and 2018 inflow events along the thalwegs of SMD, SDD and SPD are provided in Figure 31, Figure 32 and Figure 33, respectively. This shows that elevated SS_{silt} levels are short-lived relative to SS_{clay} because of their higher settling velocities. During the period that silt remains in suspension, as with clay it tends to be transported down the reservoir bed slope within turbid underflows. Because of the relatively small catchment inputs, silt levels in SPD are simulated to be very low.

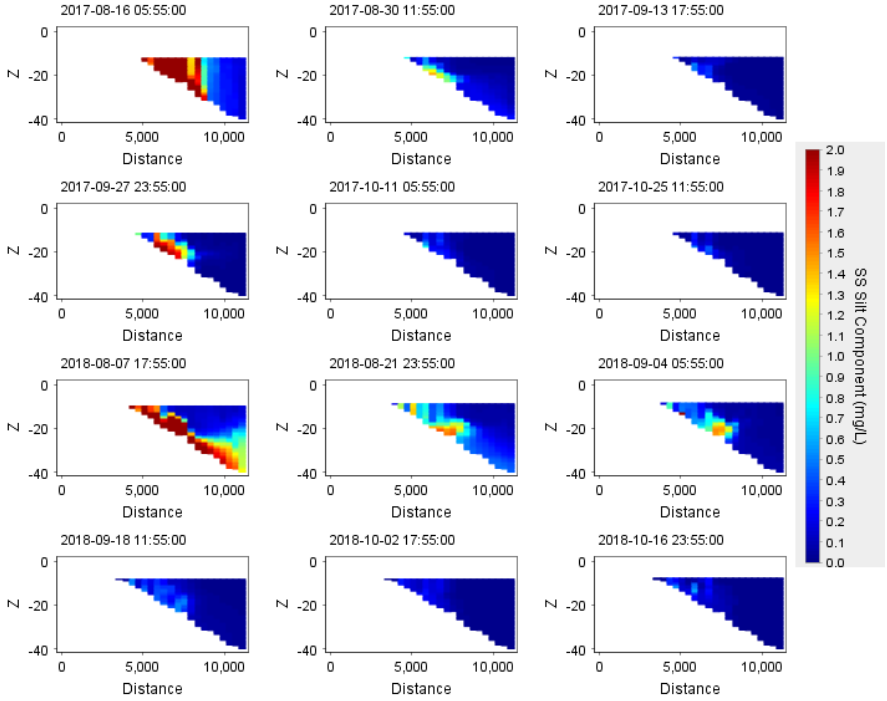


Figure 31 ***Spatial snapshots of simulated Serpentine Main Dam (SMD) silt component of inorganic suspened solids (SS_{silt}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the Serpentine River thalweg.***

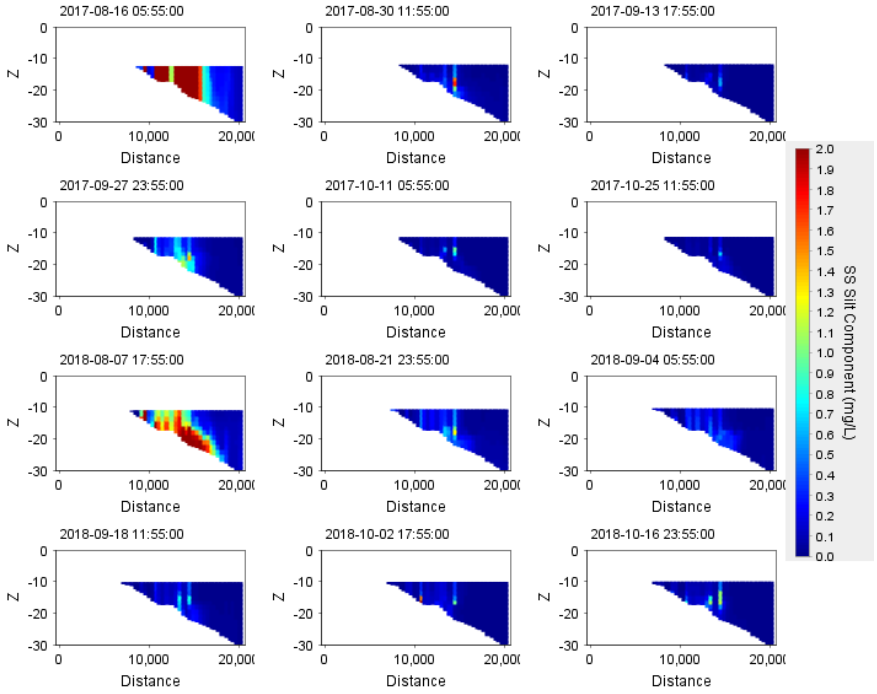


Figure 32 ***Spatial snapshots of simulated South Dandalup Dam (SDD) silt component of inorganic suspened solids (SS_{silt}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the South Dandalup River thalweg.***

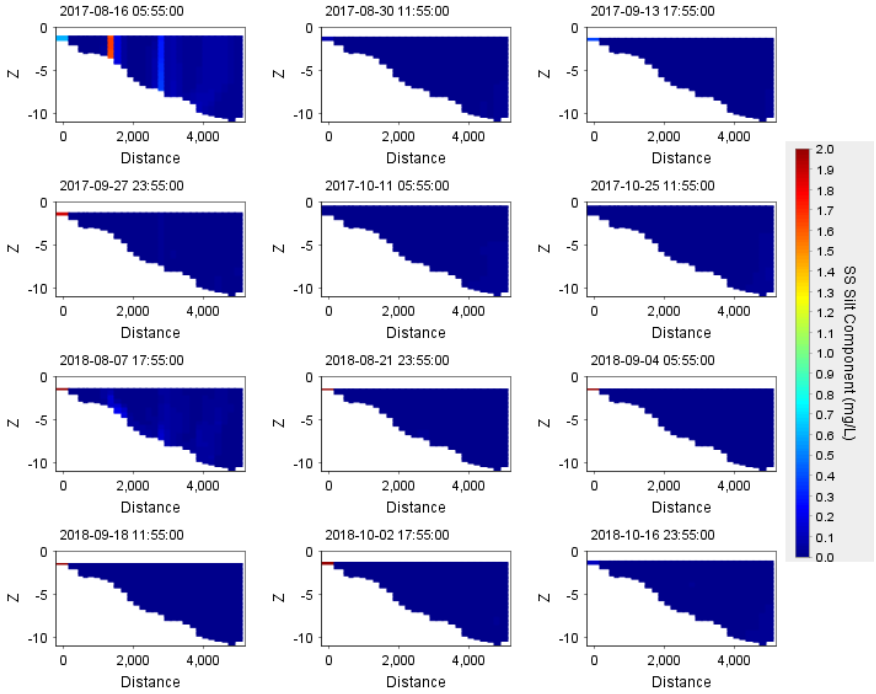


Figure 33 ***Spatial snapshots of simulated Serpentine Pipehead Dam (SPD) silt component of inorganic suspened solids (SS_{silt}) every 2 weeks during the 2017 (upper half) and 2018 (lower half) winter inflow events along the Serpentine River thalweg.***

Figure 13, Figure 14 and Figure 15 show the three assessment sites in each reservoir (i.e. near dam wall near the intake towers and two up-reservoir sites) that are used to illustrate seasonal patterns of SS in SMD, SDD and SPD, respectively. The simulated water levels, spatial and temporal patterns of SS_{clay} and SS_{silt} (as isopleths through the water column with time at each assessment site), and withdrawal SS_{clay} and SS_{silt} are shown in Figure 34 to Figure 39 for the three reservoirs. Simulated spatial patterns of SS include:

– There is a considerable decrease due to dispersion and settling of SS from the upstream portion of the reservoirs to the dams.
– Simulated elevated levels of SS_{Clay} are relatively short-lived. For SMD and SDD as clay particles are transported as turbid underflows and are not readily vertically transported back into the mixed layer. This is primarily due to the establishment of a winter thermocline due to the inputs of cool winter inflows that act as a barrier to upwards vertical transport of these particles.
– For SMD and SDD the winter 2017 inflow event caused higher SS_{clay} in the mixed layer for a longer period than the winter 2018 event. Inspection of the spatial pattern of SS_{clay} on 13 September 2017 shows that a simulated mechanism led to the rapid transport of high clay content waters to the dam wall in the near surface waters.
– For SMD and SDD, much lower levels of elevated SS_{silt} were simulated near the intake tower (typically <0.5 mg/L) for a very short duration. As described previously, the higher settling velocity of silt relative to clay yields considerably lower concentrations and substantially shorter durations of suspension in the water column for the 2017 and 2018 winter inflow events.
– Generally, simulated SPD SS levels were very low in response to the 2017 and 2018 winter inflow events relative to those of SMD and SDD.

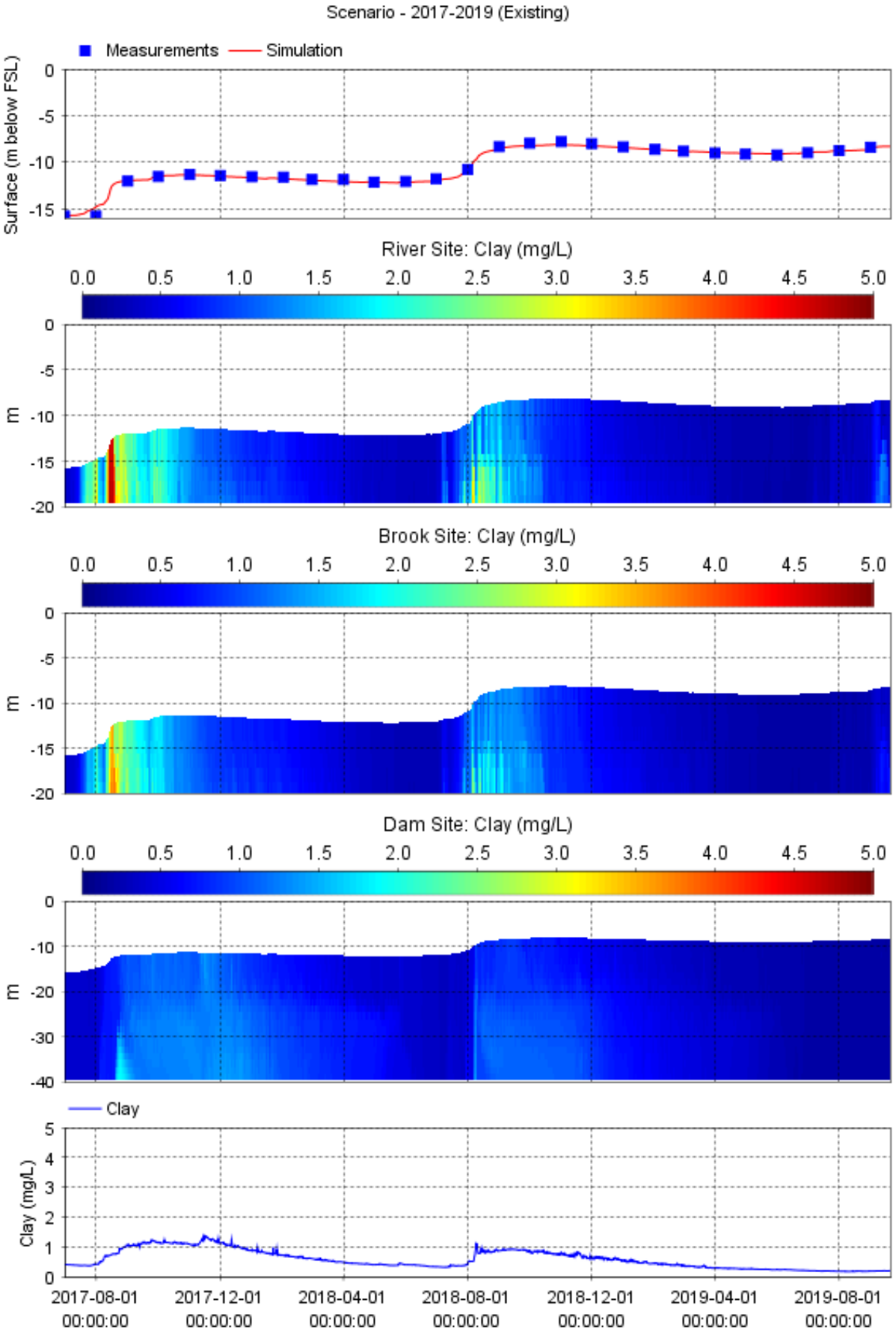


Figure 34 ***Simulated and measured Serpentine Main Dam (SMD) water levels (top), simulated isopleths of the clay component of inorganic suspened solids (SS_{clay}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{clay} of the withdrawals (bottom).***

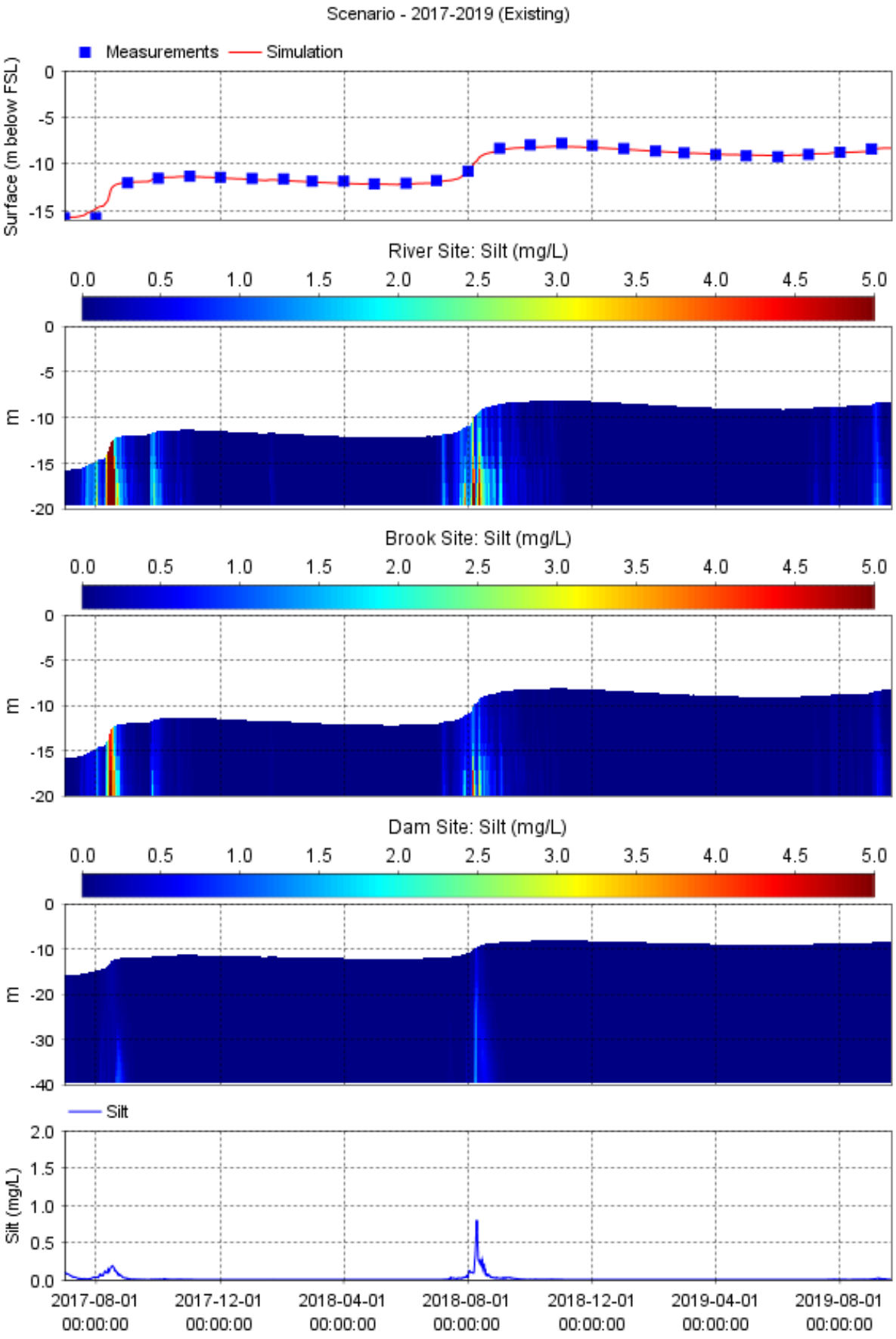


Figure 35 ***Simulated and measured Serpentine Main Dam (SMD) water levels (top), simulated isopleths of silt component of inorganic suspened solids (SS_{silt}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{silt} of the withdrawals (bottom)***

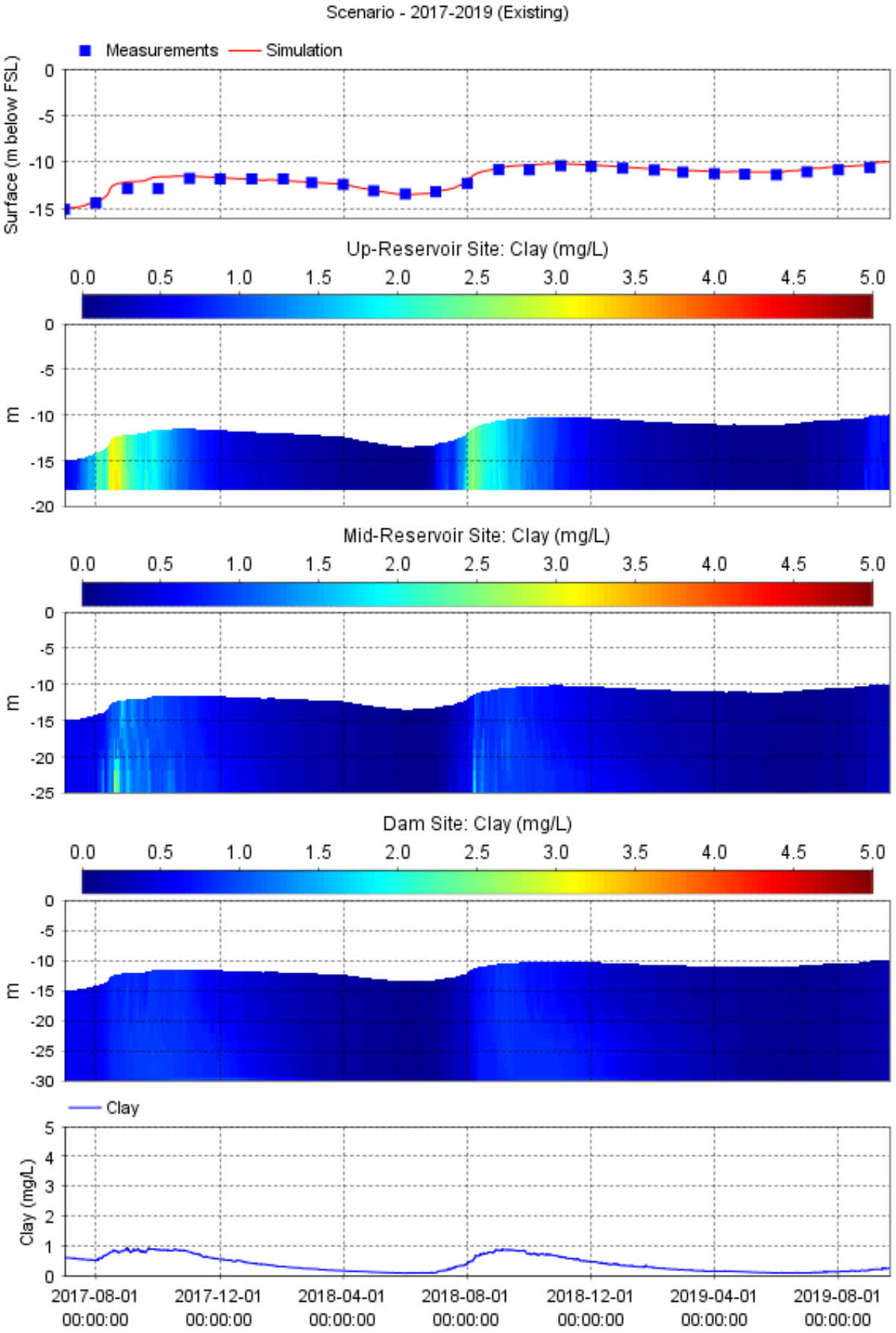


Figure 36 ***Simulated and measured South Dandalup Dam (SDD) water levels (top), simulated isopleths of clay component of inorganic suspened solids (SS_{clay}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{clay} of the withdrawals (bottom).***

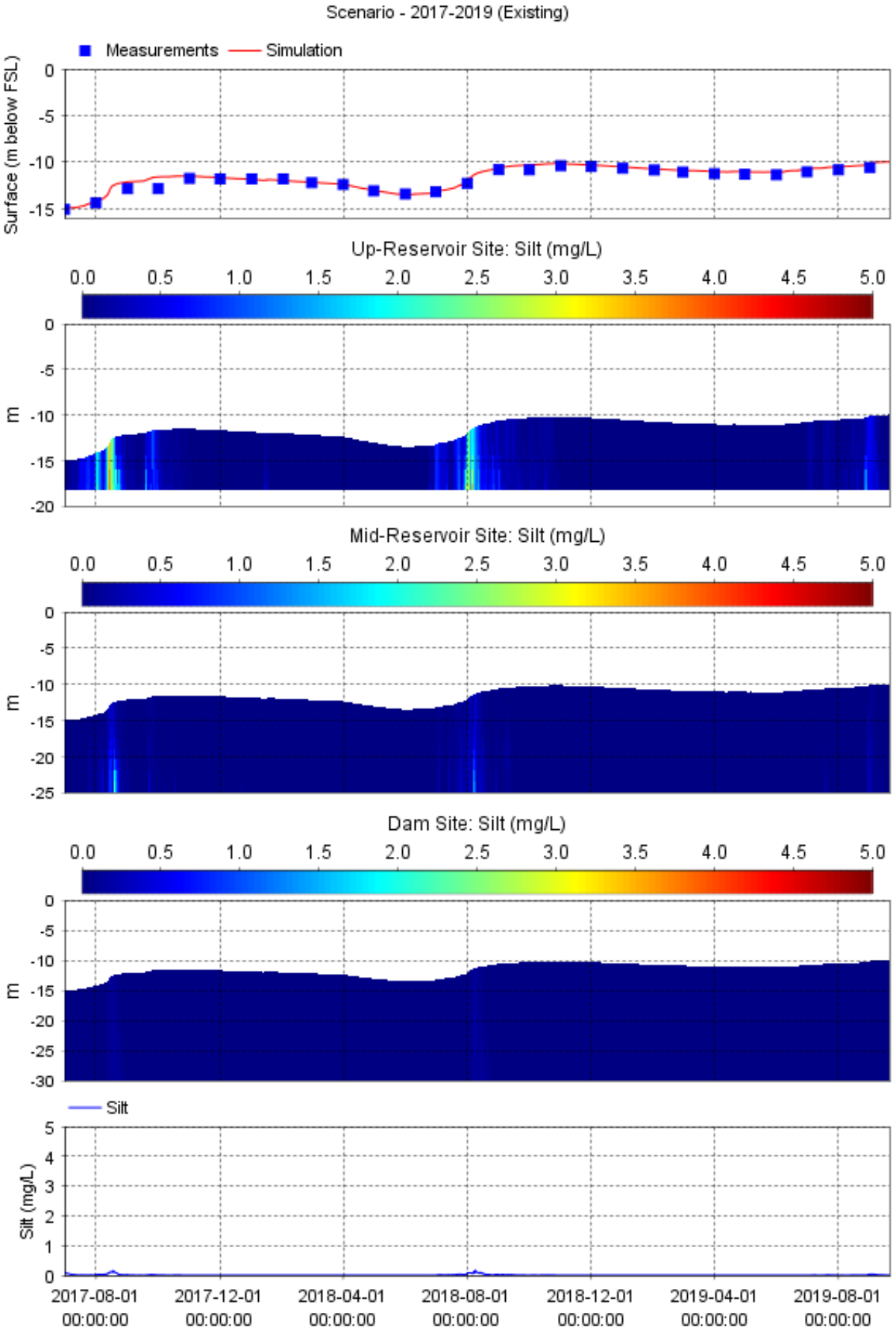


Figure 37 ***Simulated and measured South Dandalup Dam (SDD) water levels (top), simulated isopleths of silt component of inorganic suspened solids (SS_{silt}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{silt} of the withdrawals (bottom).***

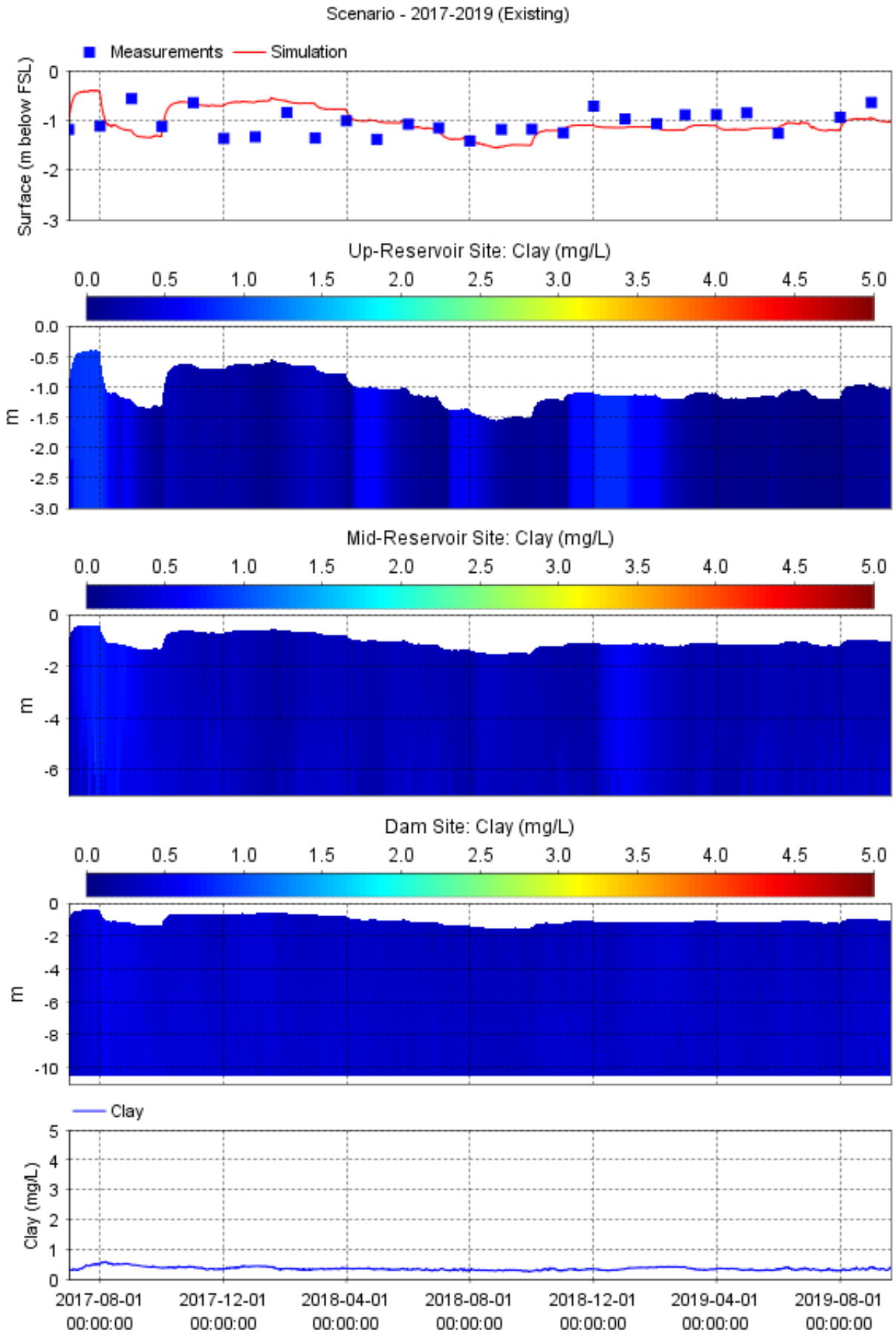


Figure 38 ***Simulated and measured Serpentine Pipehead Dam (SPD) water levels (top), simulated isopleths of clay component of inorganic suspened solids (SS_{clay}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{clay} of the withdrawals (bottom).***

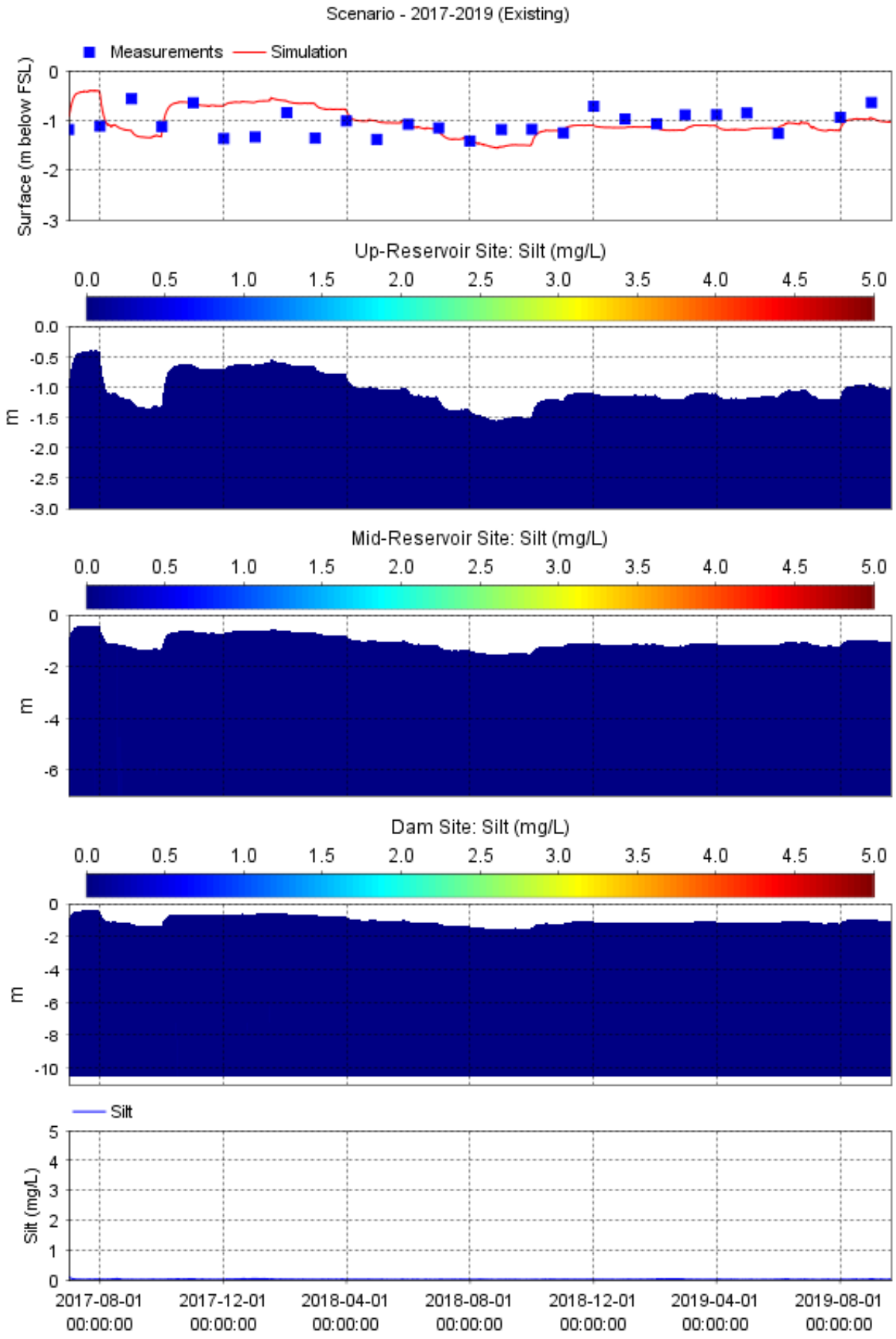


Figure 39 ***Simulated and measured Serpentine Pipehead Dam (SPD) water levels (top), simulated isopleths of silt component of inorganic suspened solids (SS_{silt}) at the dam (upper middle), river (middle) and brook (lower middle) assessment sites, and simulated SS_{silt} of the withdrawals (bottom).***

5. Scenarios

5.1 Inputs

5.1.1 Initial Dam Water Level

The initial dam water level for all scenarios was -15.8 m FSL (196.6 m AHD). This is 0.5 m lower than the 20th percentile over the 1985-2020 period of 197.1 m AHD.

5.1.2 Cryptosporidium and Diesel Spill Incidents

The 1 July 2017 to 1 October 2019 verification simulation period was used to characterise the effects of cryptosporidium and diesel spill incidents for the primary beneficial use of water supply (i.e. drinking water quality). The hydrological model inputs are described in sections 4.1.4 to 4.1.6. Cryptosporidium is evaluated in this assessment because it is a chlorine-treatment resistant pathogen, and the reliance of the downstream treatment system on chlorination for disinfection. The pathogen component of the modelling assessment considered four hazard types as described in GHD (2021a) and summarised in Table 5.

Table 5 Cryptosporidium hazards and scenario definitions.

Hazard	Source	Pathway	Receptor	Duration
1: STP raw sewage overflow	Raw sewage overflow at some point in STP 18 m3/day sewage @ 2,000 oocysts/L = 36 million oocysts/day	Overflow occurs during wet catchment conditions and heavy rainfall Transport via overland flow and shallow channel flow ~ several hundred metres of Jarrah forest @ 5-10% slope Attenuation ~2 log10	360,000 oocysts/day discharge into creek Creek flowing into reservoir	Two days overflow[4]
2: STP effluent irrigation area washout	Treated effluent accumulates at surface of irrigation area during wet catchment conditions 18 m3/day treated sewage @ 200 oocysts/L[5] = 3.6 million oocysts/day Sustained heavy rainfall causes wash out of accumulated oocysts ~ ten times daily deposition = 36 million oocysts/day	Washout occurs during wet catchment conditions and heavy rainfall Transport via overland flow and shallow channel flow ~ several hundred metres of Jarrah forest @ 5-10% slope Attenuation ~2 log10	360,000 oocysts/day discharge into creek Creek flowing into reservoir	Two days heavy rainfall
3. STP effluent irrigation area subsurface flow	Treated effluent leaches into subsurface during winter/spring when rainfall exceeds evapotranspiration 18 m3/day treated sewage @ 200 oocysts/L = 3.6 million oocysts/day	Oocysts in leachate transported by shallow perched aquifer ~ several hundred metres to creek or downslope seepage face Attenuation ~ 4 log10	360 oocysts/day discharge into creek Creek flowing into reservoir	Three months shallow seepage per year
4. Defecation in the field	Asymptomatic infected staff member defecates in the field, in bushland adjacent to mine pit or rehabilitation area 150 g stool @ 1 million oocysts/g = 150 million oocysts	Stool present/remaining in wet catchment conditions during heavy rainfall event Approximately 10% is washed out and transported via overland flow and shallow channel flow ~ several tens of metres of Jarrah forest @ 5-10% slope	15,000,000 oocysts discharge into creek Creek flowing into reservoir	Following two days of heavy rainfall

[4] Two days is a reasonable period for a 24 hour/day manned site to notice and to manage such an incident.
[5] 1 $\log_{10}$ reduction from raw sewage due to treatment.

Locations of each of these simulated pathogen incidents for the existing and proposed mining cases are summarised in Table 6, which can be cross-referenced spatially with Figure 13.

Table 6 ***Catchments where cryptosporidium hazards simulated in the three reservoirs for the existing and proposed mining scenarios.***

Hazard	SMD		SDD		SPD	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
1: STP raw sewage overflow	Catchment 13	Catchment 5	No existing mining	Catchment 35	No STP in catchment	No STP in catchment
2: STP effluent irrigation area washout	Catchment 13	Catchment 5		Catchment 35		
3. STP effluent irrigation area subsurface flow	Catchment 13	Catchment 5		Catchment 35		
4. Defecation in the field	Catchments 16 (4A), 10 (4B), 9 (4C) Reference: Catchment 1 (4D, Dam recreation area)	Catchments 3 (4A), 5 (4B), 7 (4C) Reference: Catchment 1 (4D, Dam recreation area)	Catchments 35 (4A), 34 (4B), 33(4C) Reference: Catchment 30 (4D, Dam recreation area)	Catchments 35 (4A), 34 (4B), 33(4C) Reference: Catchment 30 (4D, Dam recreation area)	Catchments 23 (4A), 24 (4B), only two mining catchments so no 4C Reference: Catchment 20 (4D, Dam recreation area)	As existing case

A diesel spill incident is assumed to occur under typical winter conditions, where there is sufficient baseflow in streams to convey the fuel to the reservoir. It has been assumed that Alcoa transports diesel in tanks with capacities up to 15,000 litres. The model inputs for a diesel spill incident were defined conservatively as:

– The diesel spill occurs on a haul road stream crossing within an existing or proposed mining catchment.
– At the time of the incident the fuel truck is full and spills its entire load of diesel.
– The spill occurs directly into a stream with sufficient discharge to transport all of the diesel to the reservoir.

The spill duration into the reservoir is assumed to be 4 hours with a linear increase/decrease to/from a peak concentration at 2 hours. As a conservative measure the entire 15 m^3 of spilled diesel is assumed to be transported and discharged into the reservoir with no losses due to volatilisation, degradation, and adsorption and settling in the stream or in the reservoir. Hence, the only processes that decrease spilled diesel concentrations are river dilution, reservoir mixing and dispersion, and withdrawals from the dams.

Diesel spill incidents were simulated in the existing and proposed mining catchments (i.e. those with haul road stream crossings) as summarised in Table 7, which can be cross-referenced spatially with Figure 13 to Figure 15.

Table 7 ***Catchments with diesel spill incidents for existing and proposed mining activity scenarios.***

Incident	SMD		SDD		SPD	
	Existing	Proposed	Existing	Proposed	Existing	Proposed
Diesel Spill (15 m3)	Catchments 8, 13, 16	Catchments 3, 5, 6	Non, no existing mining	Catchments 35, 36	Catchments 23, 24	Catchments 23, 24

It is highly unlikely that Alcoa will transport any fuel during a large storm event. Hence, it was assumed that the spill incident occurs after peak stream discharge during the winter 2017 inflow event during moderately low stream flow. Further, it was assumed that diesel entered the reservoirs over a period of 4 hours from 1000 to 1400 on 24 August 2017.

5.1.3 Inorganic Suspended Solids (SS) Assessment

A summary of the catchments in SMD, SDD and SPD (refer to Figure 13 to Figure 15) that are defined as those with existing and proposed (existing[6] and proposed mining areas) mining activity is provided in Table 8. All remaining catchments were considered to be un-mined or fully rehabilitated historical mining areas with baseline SS loads.

Table 8 Existing and proposed mining catchments.

Reservoir	Existing Mining Catchments	Proposed Mining Catchments
SMD	4, 7-16	1-16
SDD	No existing mining, all historical mining assumed to be fully rehabilitated	23, 24
SPD	23, 24	23, 24 (same as existing)

Scenario inputs to evaluate the effect of winter and summer inflow events on reservoir and withdrawal SS levels used the GHD (2021a) hydrology estimates over 2 weeks and hourly intervals of the 1% and 10% annual exceedance periods [AEP] for baseline (no mining), and existing and proposed mining scenarios as summarised in Table 9. GHD (2021a) also estimated the 1 exceedance per year (E.Y.) for the baseline, existing and proposed mining activities, but these flows were too small to have any material effect on the SS climate of the reservoirs, and thereby were not evaluated. Though there are a total of 18 potential scenarios per reservoir (i.e. 3 flow events [1% and 10% AEP, 1 E.Y.] x 2 seasons [winter, summer] x 3 mining cases [baseline, existing, proposed]), only a subset were evaluated for each of the reservoirs, namely:

– No 1 E.Y. flow events were simulated for any of the three reservoirs.
– For SMD, 12 scenarios were evaluated assuming effective SS management of mining areas (see Appendix A for inputs). An additional 8 scenarios were also evaluated assuming ineffective SS management of mining areas with substantial increases in drainage failure SS concentrations (see Appendix C for inputs).
– For SDD, there has not been recent mining activity in the catchment (historical mining activity is assumed to be fully rehabilitated), so 8 scenarios were evaluated assuming effective SS management of mining areas (see Appendix E for inputs). An additional 4 scenarios were also evaluated assuming ineffective SS management of mining areas (see Appendix G for inputs).
– For SPD, the catchments with proposed mining activity are the same as the existing mining catchments, so 8 scenarios were evaluated assuming effective SS management of mining areas (see Appendix I for inputs). An additional 4 scenarios were also evaluated assuming ineffective SS management of mining areas (see Appendix K for inputs).

[6] In this assessment, the proposed catchments include both the existing and proposed mining catchments. It is conservatively assumed that rehabilitation of existing catchments will not be completed over the timescale of implementation of the proposal.

Table 9 Overview of inorganic suspended solids (SS) scenarios.

Scenario ID	Catchment clearing	Starting level	Synthetic flow event season	Synthetic Storm event and drainage failure rate[7]	SMD Simulated	SDD Simulated	SPD Simulated
E	Existing	1 July 2017	Not applicable, actual 2017-2019 hydrology	Not applicable, no drainage failures	Diesel and cryptosporidium incidents in **existing** and **proposed** mining catchments	No **existing** mining in catchments	Diesel and crypto incidents in **existing** mining catchments
P	Proposed					Diesel and cryptosporidium incidents in **proposed** mining catchments	Same catchments for **proposed** mining catchments as **existing** mining catchments
01	Baseline (No mining effects on SS)		2017 Summer	1% AEP with no drainage failures	Yes, baseline for increased SS assessments of **existing** and **proposed** mining activities	Yes, baseline for increased SS assessments of **proposed** mining activities	Yes, baseline for increased SS assessments of **existing** mining activities
02				10% AEP with no drainage failures			
03				1 E.Y. with no drainage failures	No, negligible SS increase from small inflow events with no drainage failures		
04			2018 Winter	1% AEP with no drainage failures	Yes, baseline for increased SS assessments of **existing** and **proposed** mining activities	Yes, baseline for increased SS assessments of proposed mining activities	Yes, baseline for increased SS assessments of **existing** mining activities
05				10% AEP with no drainage failures			
06				1 E.Y. with no drainage failures	No, negligible SS increase from small inflow events with no drainage failures		
07	Existing		2017 Summer	1% AEP with 75% drainage failures	Yes, to assess increased SS of **existing** mining activities	No existing mining in catchments	Yes, to assess increased SS of **existing** mining activities
08				10% AEP with 30% drainage failures			
09				1 E.Y. with 5% drainage failures	No, negligible SS increase from small inflow events with no drainage failures		
10			2018 Winter	1% AEP with 75% drainage failures	Yes, to assess increased SS of **existing** mining activities	No existing mining in catchments	Yes, to assess increased SS of **existing** mining activities
11				10% AEP with 30% drainage failures			
12				1 E.Y. with 5% drainage failures	No, negligible SS increase from small inflow events with no drainage failures		
13	Proposed		2017 Summer	1% AEP with 75% drainage failures	Yes, to assess increased SS of **proposed** mining activities		No, same catchments for **proposed** mining catchments

[7] Zero drainage failure for areas with existing mining activity in all baseline scenarios.

14				10% AEP with 30% drainage failures		as **existing** mining catchments
15				1 E.Y. with 5% drainage failures	No, negligible turbidity increase from small inflow events with no drainage failures	
16			2018 Winter	1% AEP with 75% drainage failures	Yes, to assess increased SS of **proposed** mining activities	No, same catchments for **proposed** mining catchments as existing mining catchments
17				10% AEP with 30% drainage failures		
18				1 E.Y. with 5% drainage failures	No, negligible turbidity increase from small inflow events with no drainage failures	

GHD (2021a) assumed these 7-day 1% and 10% AEP inflow events resulted in the following drainage failures in mining areas, which are adopted here:

– A 30% drainage failure rate for the 10% AEP inflow event for the existing and proposed scenarios. For the proposed scenarios, both the existing and proposed mining areas are assumed to have a 30% drainage failure rate, as it is conservatively assumed that existing mining areas will not be rehabilitated over the timescale of the proposed mining activity.
– A 75% drainage failure rate for the 1% AEP inflow event for the existing and proposed mining scenarios.

Variations in catchment discharge due to drainage failures generally did not have a major effect in terms of the overall water budgets of the reservoirs. However, drainage failures have a more substantive increase on stream SS_{clay} and SS_{silt}, which is described next.

The model configuration of SS_{clay} and SS_{silt} for baseline (non-mined or fully rehabilitated) mining areas is described in section 4.1.7. In this section the configuration of SS associated with drainage failures is outlined.

Turbidity is an optical measure of total suspended solids (TSS). In the absence of reliable continuous turbidity (and/or TSS) monitoring for mined and un-mined catchments, soil sampling of three natural streams and three mining sumps were collected and relations between TSS and turbidity for these samples in suspension were determined by Murdoch University's Marine and Freshwater Research Laboratory (MAFRL). The results of this investigation are illustrated in Figure 40, which indicates the SS of natural catchments and sumps are approximately a factor of 1.42 and 0.63 of the turbidity, respectively. However, over the range of interest (up to 60-70 NTU) a 1:1 relation is a good approximation, and is utilised here.

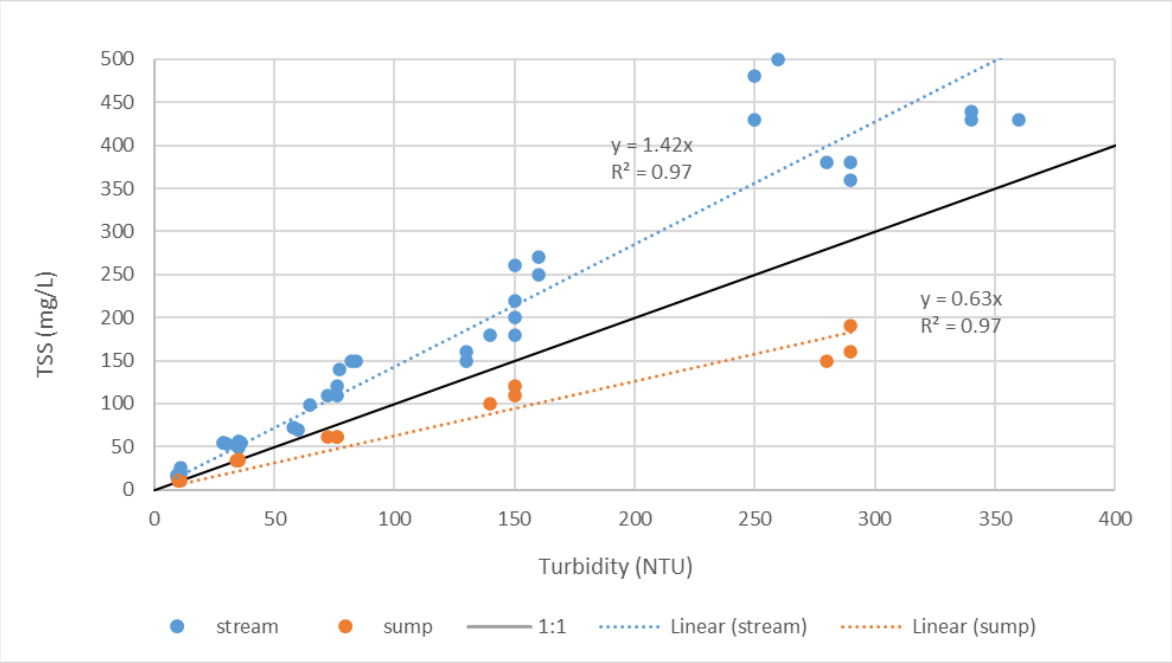


Figure 40 Relation between turbidity and TSS.

TSS is made up of a range or particle diameters. Particle size distribution (PSD) analyses were carried out by MAFRL on the soil samples from the natural streambeds and mining sumps and the proportion of clay, silt and sand is summarised in Table 10 for both soil types. These findings were used to determine the proportion of SS that was allocated to SS_{clay} and SS_{silt} from drainage failures. Note the natural streambed clay:silt ratio of 1:3 is used for both the model verification simulations and the baseline scenarios (section 4.1.7).

Table 10 PSD of un-mined and mined streambed soil samples.

Streambed Type	Clay	Silt	Sand
Mined	40%	50%	10%
Unmined	20%	60%	20%

SS_{clay} of 5 mg/L was established as a reasonable constant value for non-mined and mined catchments with no drainage failures (i.e. as used during verification of the hydrodynamic model in section 4.2.3). A SS_{silt} of 15 mg/L was adopted on the basis of the PSD ratio between clay and silt PSD measurements for these catchment conditions in Table 10. These baseline SS_{clay} and SS_{silt} concentrations are assumed to be constant throughout the catchments regardless of the magnitude of stream discharge except for occurrences of mining drainage failures. In fact, these levels are representative of concentrations during elevated flow events, but not low or moderate flows. However, as the SS load during low inflow periods do not have a material effect on most of the reservoir volume, this simplification is apt for the purposes of this investigation.

The reliability of available turbidity measurements of drainage failure events is suspect. Hence, a constant drainage failure turbidity of 31.5 NTU or 31.5 mg SS/L (assuming a 1:1 SS:turbidity ratio) was assumed in the case of effective drainage turbidity management, which equates to 12.6 mg/L and 15.8 mg/L for SS_{clay} and SS_{silt}, respectively. This is conservative in terms of the current operational stream limit in mined catchments of 25 NTU for no more than 1 hour. For the case of ineffective drainage turbidity management, the continuous SS (or turbidity) concentration during drainage failures was doubled to 63 NTU or 63 mg SS/L, which equates to 25.2 mg/L and 31.5 mg/L of SS_{clay} and SS_{silt}, respectively.

Each catchment into the reservoirs incorporated these SS concentrations in combination with discharge from the mined and un-mined (and rehabilitated) areas as follows:

– Zero surface runoff (and thereby no SS loads) for mining areas within catchments.
– Baseline SS_{clay} and SS_{silt} of 5 and 15 mg/L, respectively, for un-mined and fully rehabilitated areas within catchments.
– Drainage failure SS_{clay} and SS_{silt} of 12.6 mg/L and 15.8 mg/L, respectively, for mined areas of catchments with drainage failures and an effective drainage turbidity management.
– Drainage failure SS_{clay} and SS_{silt} of 25.2 mg/L and 31.5 mg/L, respectively, for mined areas of catchments with drainage failures and an ineffective drainage turbidity management.

Large particles (i.e. sand) that enter the reservoirs will not be transported a material distance down-reservoir due to rapid settling.

5.2 Serpentine Main Dam (SMD)

5.2.1 Existing and Proposed 2017-2019 Scenarios (Cryptosporidium and Hydrocarbon Spill Assessment)

Suspended Solids

Patterns of suspended inorganic solids (SS) in SMD are described in Section 4.3.2 for these scenarios.

Cryptosporidium

Simulated cryptosporidium concentrations along a transect of the Serpentine River arm at 4 day intervals over the first 3 weeks of reference hazard 4D (i.e. mobilisation of infected human stool from catchment 1 closest to the dam wall) is illustrative of the potential risk from this pathogen (Figure 41). Spatial patterns of simulated cryptosporidium levels of this hazard varied between the 2017 and 2018 winter inflow events where:

– Elevated levels during the 2017 winter event tended to remain in the upper water column.
– Cryptosporidium concentrations during the 2018 winter had greater vertical mixing and dispersion throughout the water column.

Isopleths of cryptosporidium concentration near the dam for hazards 1, 2, 3, 4A and 4D for the existing and proposed mining scenarios over the 2017-2019 simulation period are summarised in Figure 42 and Figure 43, respectively. These figures illustrate the relative magnitude and duration of cryptosporidium risks from infected human stool and STP-related incidents. For example, hazards 1 (STP overflow), 2 (STP irrigation area washout) and 3 (STP irrigation area subsurface drainage) are predicted to yield relatively low cryptosporidium levels at the dam (~<1×10^{-5} oocysts/L) in comparison to concentrations from loading of an infected human stool (~<5×10^{-4}

oocysts/L) from existing and proposed mining catchments (hazard 4A) and the reference un-mined catchment closest to the dam wall (hazard 4D). Characteristics of simulated cryptosporidium incidents include:

– The typical timescale of elevated cryptosporidium levels is ~3-4 months.

– Over these ~3-4 months the oocysts occur throughout the water column.

Simulated cryptosporidium levels in the withdrawals for release to SPD over the 2+ year simulations of the existing and proposed mining scenarios are presented in Figure 44. The only material difference in the pathogen risk is that the proposed STP location will be moved to a catchment with a reservoir confluence closer to the dam wall (and intake tower) than the existing STP location. Further, the proposed STP catchment has a lower discharge than the existing STP catchment with concomitant lower stream dilution of cryptosporidium prior to entry into the reservoir for hazards 1-3. Both of these factors result in a ~2 fold increase in peak cryptosporidium concentrations, which are still very low relative to simulated levels for hazards 4A -4D. The higher concentrations for hazards 4A-4D are similar for the existing and proposed mining scenarios over the 2017-2019 simulation period used to characterise pathogen risks in this study.

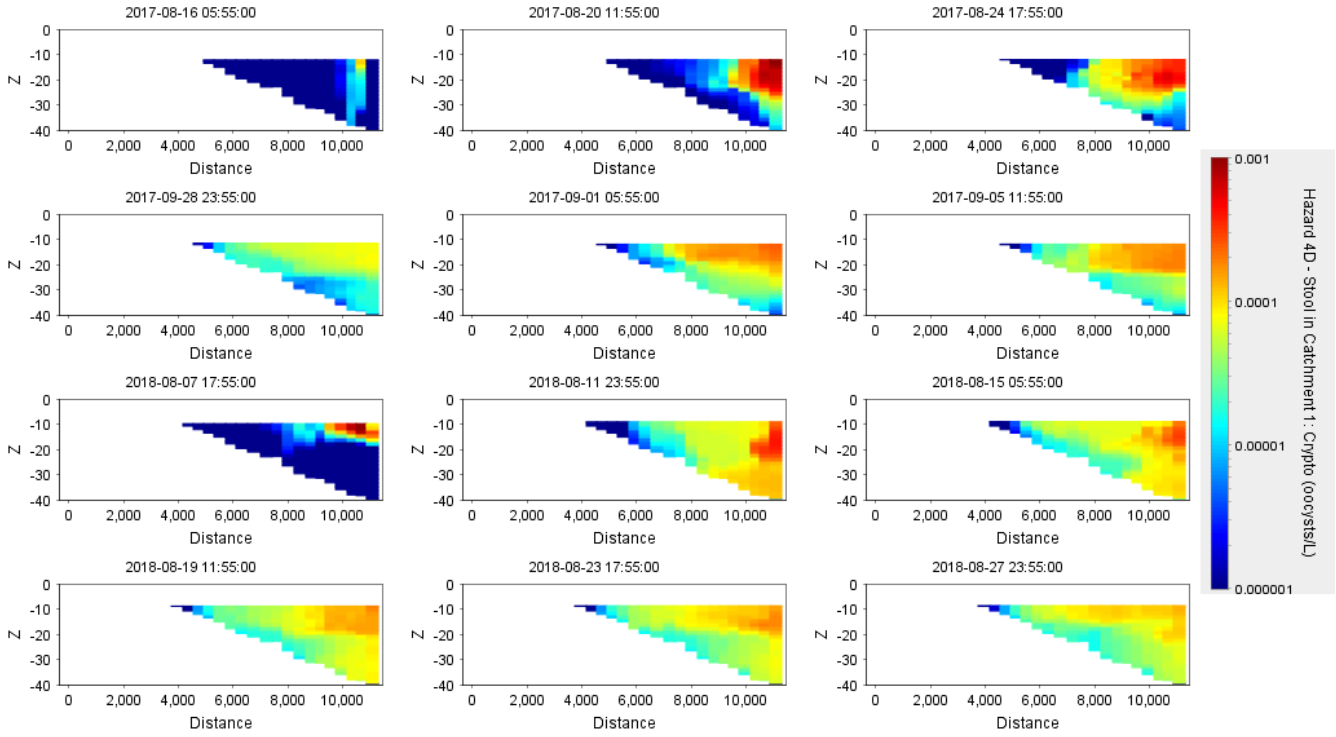


Figure 41 ***Cryptosporidium along the Serpentine River arm of Serpentine Main Dam (SMD) over 4 day intervals at the onset of hazard 4D during the 2017 (top 2 panels) and 2018 (bottom 2 panels) winter inflow events for hazard 4D.***

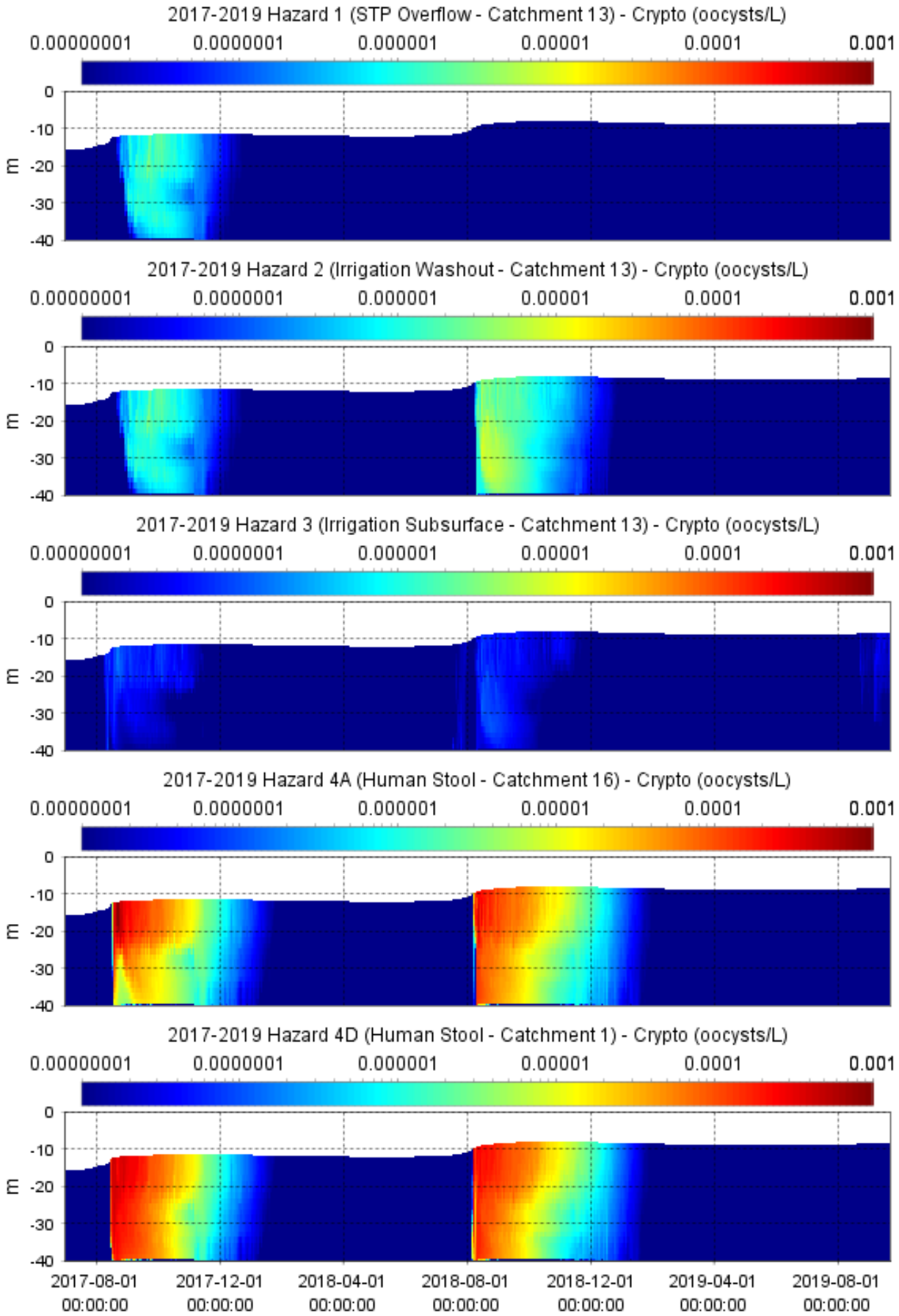


Figure 42 ***Isopleths of cryptosporidium concentration near the Serpentine Main Dam (SMD) dam wall for selected hazards for the existing mining scenario over the 2017-2019 simulation period.***

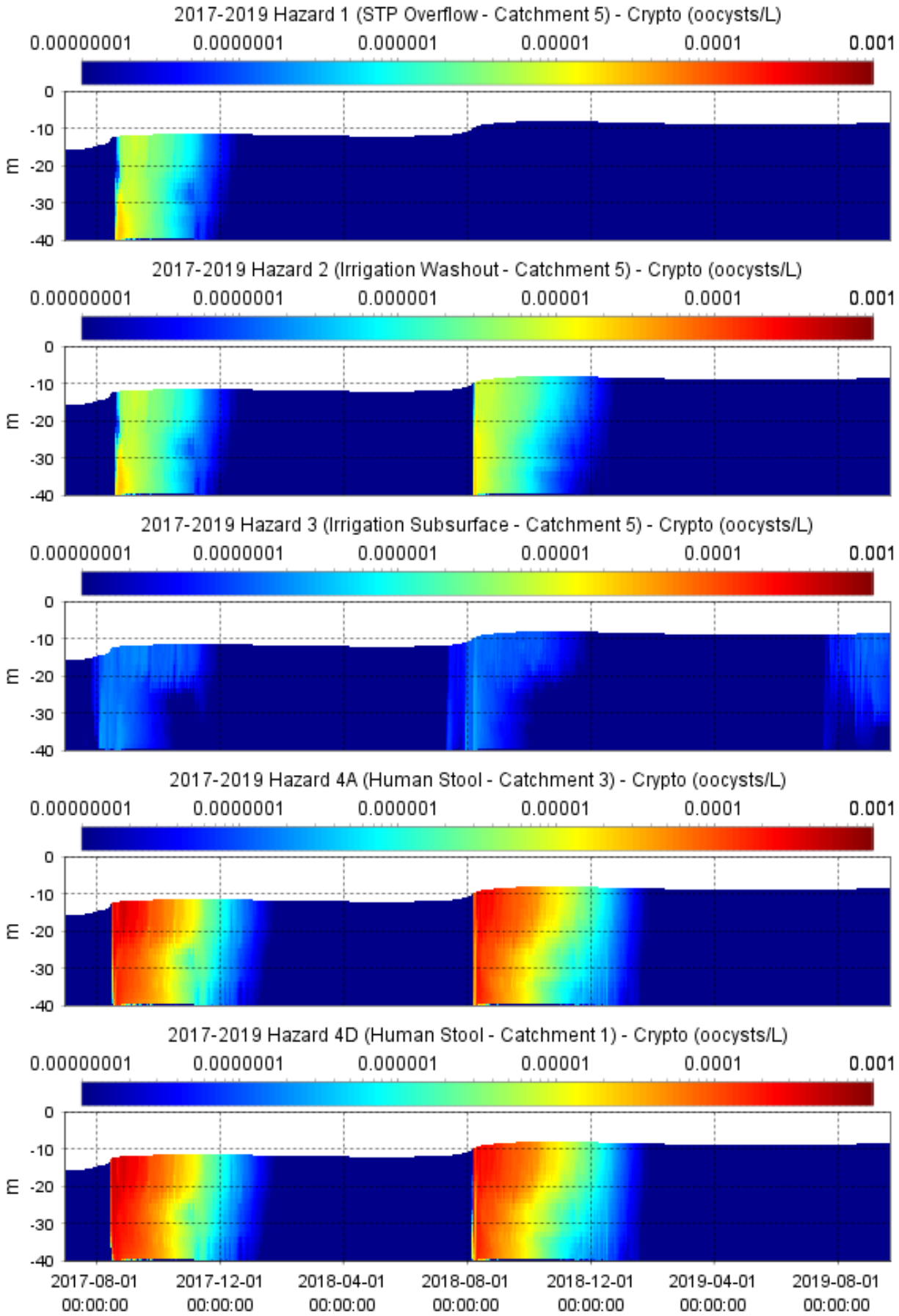


Figure 43 ***Isopleths of cryptosporidium concentration near the Serpentine Main Dam (SMD) dam wall for selected hazards for the proposed mining scenario over the 2017-2019 simulation period.***

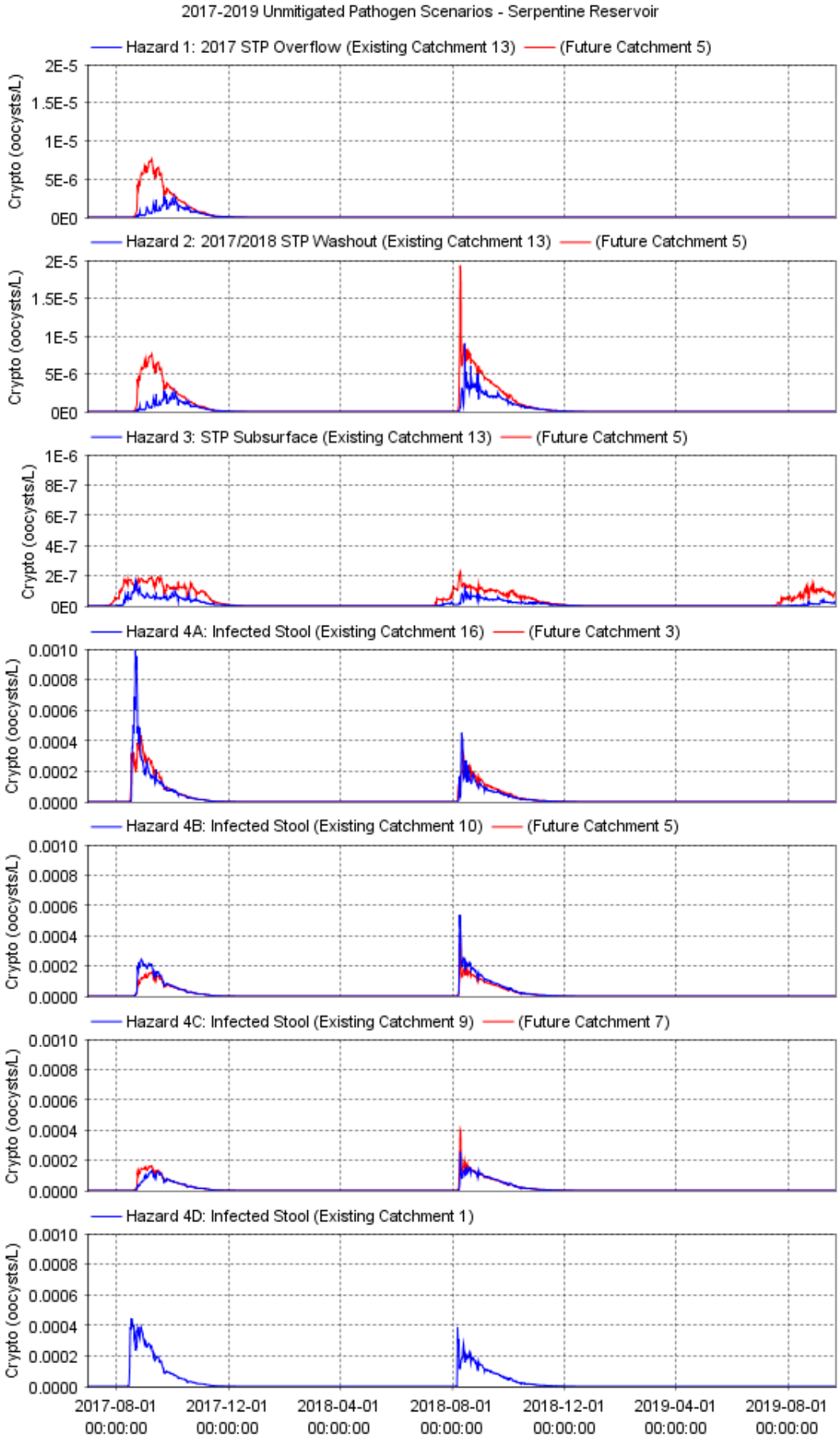


Figure 44 ***Comparison of simulated cyrptosporidium concentration of Serpentine Main Dam (SMD) withdrawals of the seven hazards for existing and proposed mining scenarios over the 2017-2019 simulation period.***

Diesel Spill

Diesel concentrations at the dam wall and in the withdrawals from spills in the selected existing and proposed SMD mining catchments (i.e. haul roads with stream crossings) had similar patterns (Figure 45 to Figure 48). Peak diesel concentrations of up to 1 µg/L were predicted with all levels below 0.2 µg/L within 6-7 months of the spill. As noted in section 5.1.2, simulated diesel concentrations do not account for any fate losses due to volatilisation, degradation or settling to adhered particles (i.e. diesel modelled as a conservative tracer in the reservoir).

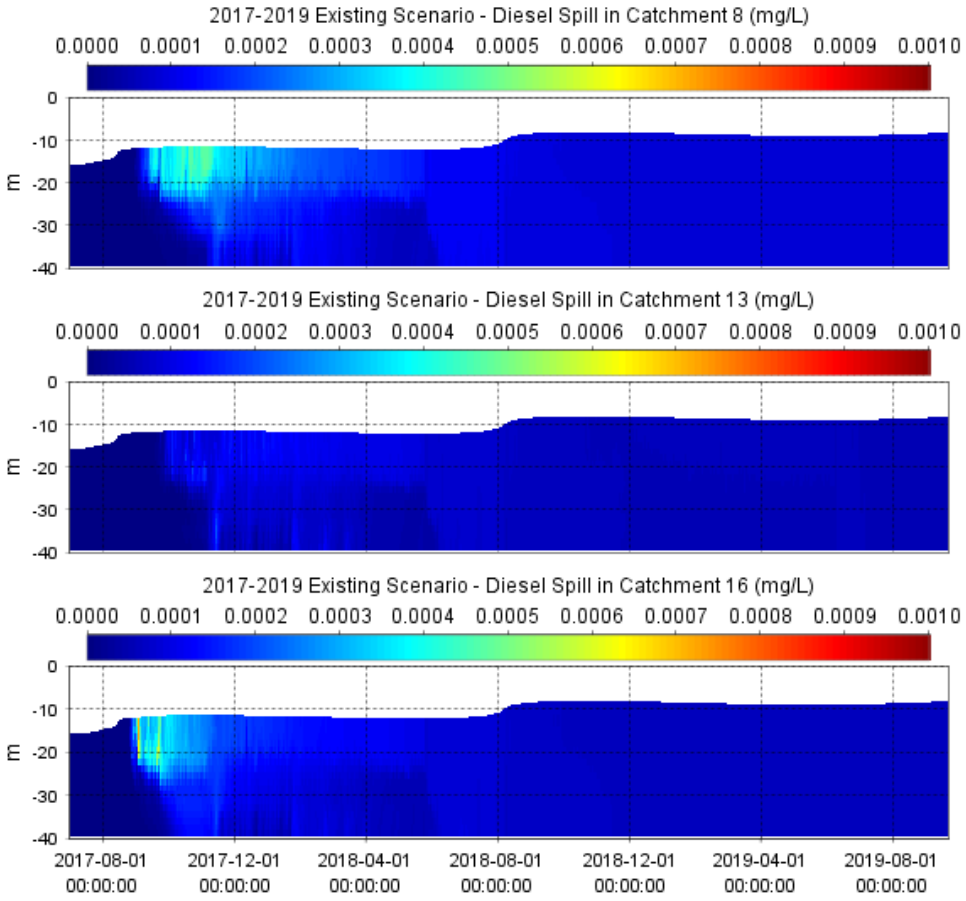


Figure 45 ***Isopleths of diesel concentrations near the Serpentine Main Dam (SMD) dam wall from spills for the existing mining scenario over the 2017-2019 simulation period.***

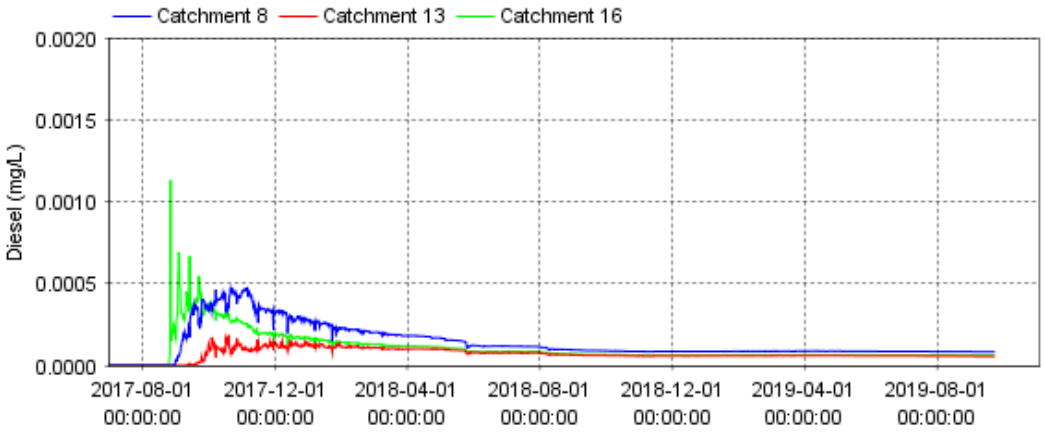


Figure 46 ***Diesel concentrations of Serpentine Main Dam (SMD) withdrawals of spills for the exisiting mining scenario over the 2017-2019 simulation period.***

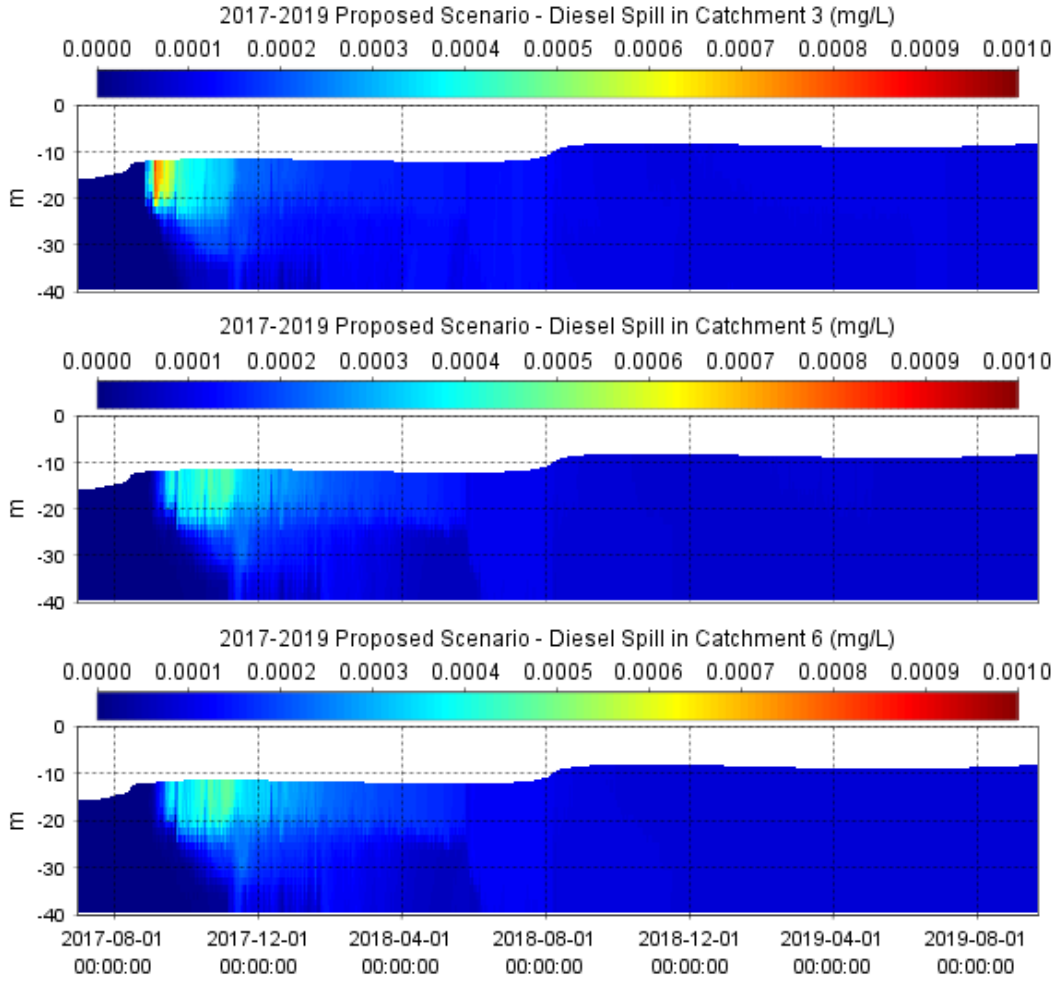


Figure 47 ***Isopleths of diesel concentrations near the Serpentine Main Dam (SMD) dam wall from spills for the proposed mining scenario over the 2017-2019 simulation period.***

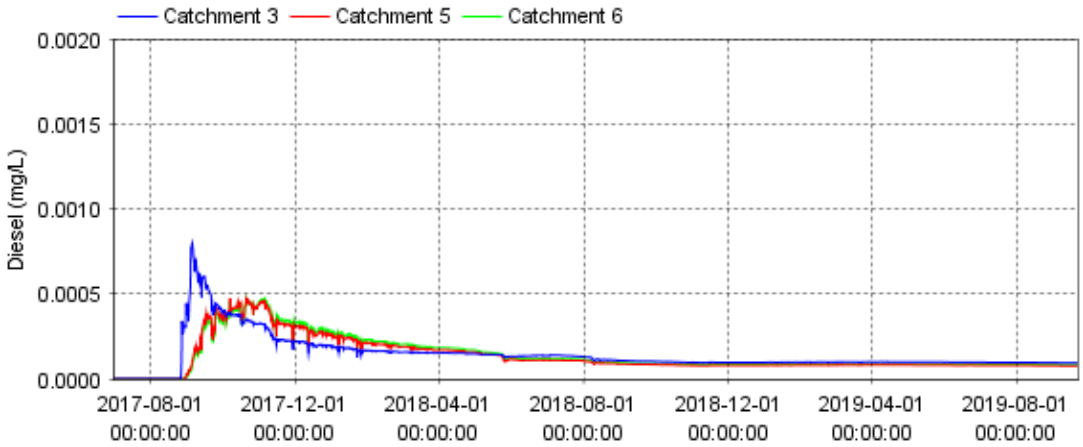


Figure 48 ***Diesel concentrations of Serpentine Main Dam (SMD) withdrawals of spills for the proposed mining scenario over the 2017-2019 simulation period.***

5.2.2 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (Moderate Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix A provides the 1% and 10% 7-day AEP flood event model inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SMD assuming moderate drainage failure SS levels, which can be summarised as:

– The total baseline (i.e. un-mined, fully rehabilitated mining and no drainage failures in mined catchments) discharge over the 14 day inflow events was 28,706 ML and 13,503 ML for the 1% and 10% AEP scenarios, respectively. Both of these volumes are considerably larger than the 2017 and 2018 maximum 14-day totals of 10,245 and 10,291 ML, respectively.
– An additional 2,646 and 4,034 ML of discharge from drainage failures of the 1% AEP inflow event (75% drainage failures) was inputted for the existing and proposed scenarios, respectively. For the 10% AEP inflow event (30% drainage failures) an additional 979 and 1,492 ML of discharge was estimated for the existing and proposed scenarios, respectively.
– All of the baseline (no mining) scenarios had SS_{clay} and SS_{silt} catchment concentrations representative of the natural catchment of 5 and 15 mg/L, respectively, as no drainage failures with associated higher SS levels were assumed.
– Depending on the proportion of the catchment area for the existing and proposed scenarios, the SS_{Clay} catchment concentrations ranged from ~5.5-12.5 mg/L. Generally, the larger catchments (i.e. catchment 5 [39 Mile Brook], catchment 7 [Serpentine River] and catchment 13 [Big Brook]) had lower SS_{clay} concentrations as smaller proportions of the catchments were mined and thereby underwent greater stream dilution of SS prior to the reservoir.

Appendix B presents graphical summaries of the simulated SS_{clay} and SS_{silt} at the dam wall and up-reservoir locations, and in the withdrawals from the intake tower[8], which illustrate the following:

– The 1% and 10% AEP summer inflow events result in elevated concentrations for these rare events. The largest differences in SS throughout the reservoir and the withdrawals between the baseline, existing and proposed scenarios occurred for the summer 1% AEP inflow event. and to a lesser degree for the summer 10% AEP inflow event. Summer thermal stratification promotes higher SS levels in the upper portion of the water column coincident with the assumed 17 m below FSL withdrawal depth, thereby particle trapping above the seasonal thermocline generally leads to increased SS in water supply extractions. In contrast, during the winter there is a greater tendency for catchment inflows to be transported as underflows where elevated SS levels tend to occur deeper in the water column below the assumed withdrawal extraction level.
– Variations in SS between the three scenarios (i.e. baseline, existing and proposed) for the 1% and 10% AEP winter inflow events were very subtle.
– As with the 2017-2019 scenarios, elevated SS_{silt} for all scenarios was of short duration due to relatively rapid settling. The duration of elevated SS was primarily due to clay particles.
– The 10% AEP inflow events did not markedly increase maximum SS_{clay} levels above 1 mg/L. However, the simulated 1% AEP inflow events attained maximum SS_{clay} of ~2 mg/L.

A summary of the simulated total silt and clay SS in the SMD withdrawals is provided as time series in Figure 49 and percentile distributions over two 1 year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 50. The simulated SS (silt + clay) concentrations in the withdrawals are predicted to have minimal variations between the scenarios for the 10% AEP inflow event. Greater variations on the order of ~0.5 mg/L are predicted between the three scenarios for the rare 1% AEP summer inflow events, though the difference is considerably less (~0.2-0-3 mg/L) for the more common 1% AEP winter inflow event. In short, SS variations (and hence also turbidity variations) from mining activity are predicted to not cause large relative changes in SS (or turbidity) between the existing and proposed mining scenarios, even for the 1% AEP inflow events with effective drainage turbidity management.

[8] Appendix B also shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

The relative changes to the baseline SMD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 11. This summary table provides the predicted relative changes to SMD withdrawal SS from the existing and proposed mining scenarios with moderate drainage failure SS levels to inform the GHD (2021a) drinking water risk assessment.

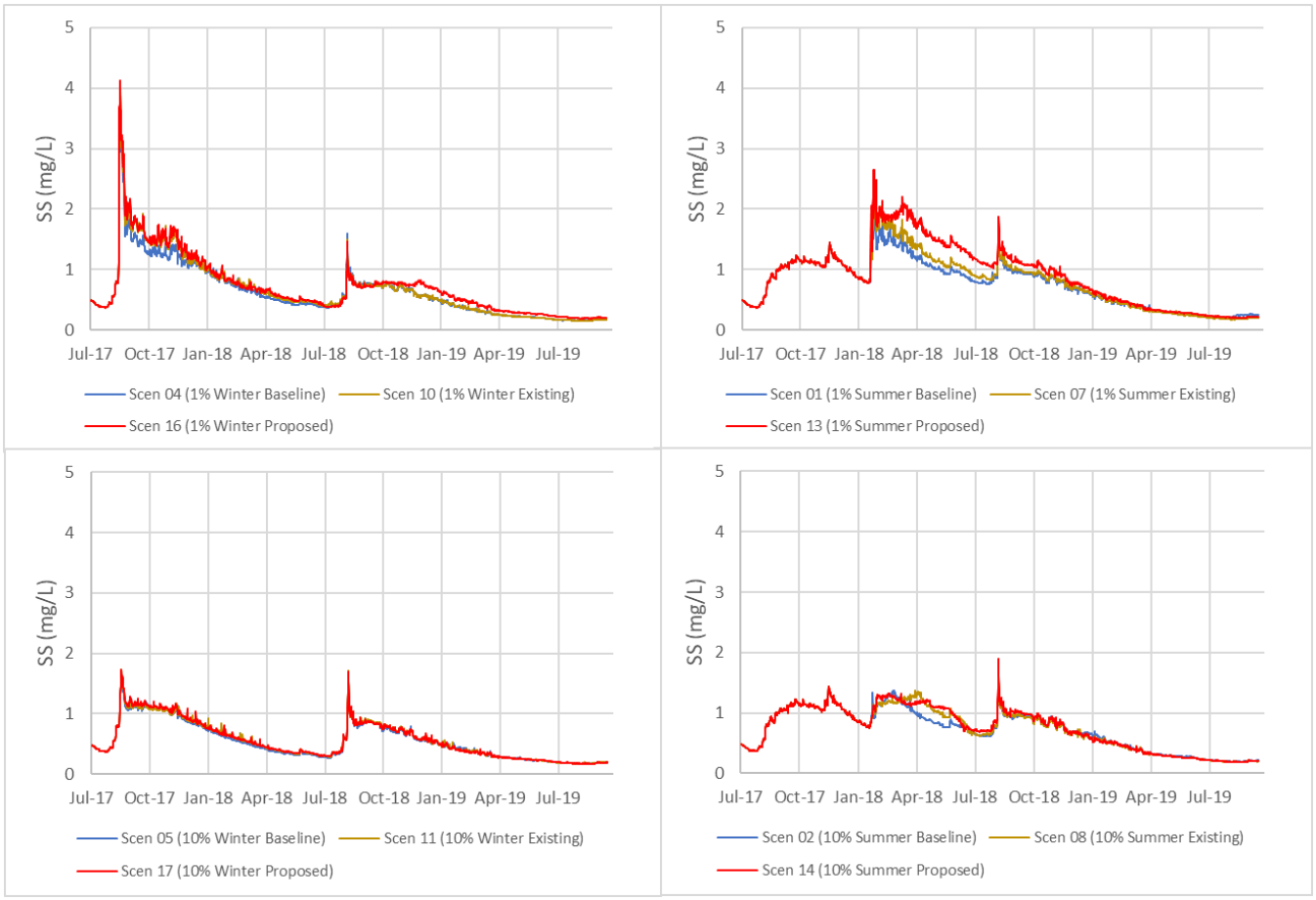


Figure 49 ***Time series of simulated Serpetine Main Dam (SMD) withdrawal inorgnaic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedanc Period (AEP) inflow event scenarios with moderate drainage failure SS levels.***

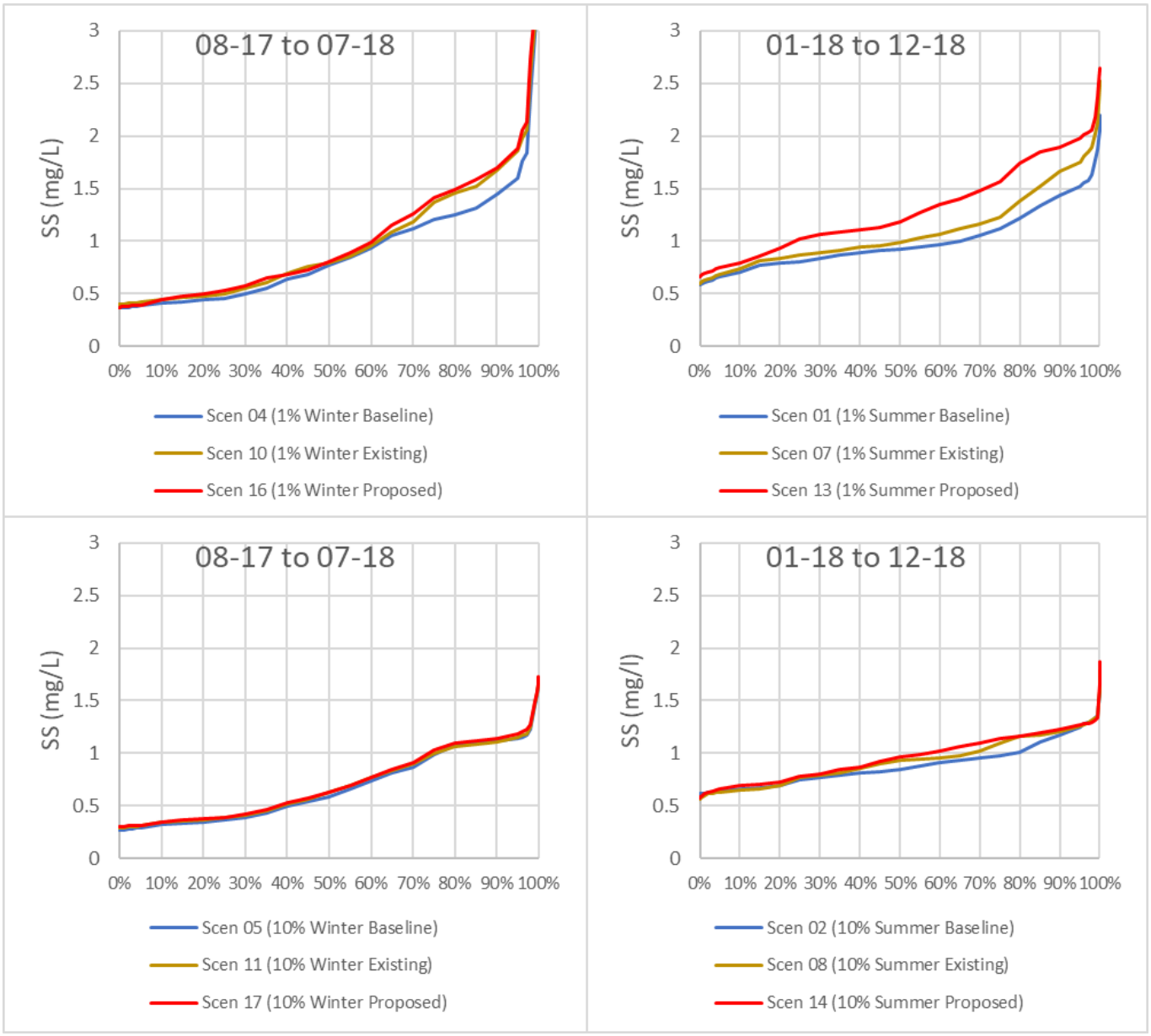


Figure 50 ***Percentile plots of simulated Serpentine Main Dam (SMD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter[9] and summer[10] 1% and 10% Annual Exceedance Period (AEP) inflow event scenarios with moderate drainage failure SS levels.***

[9] Percentiles over 1 year from 1 August 2017 to 31 July 2018.
[10] Percentiles over 1 yar from 1 January to 31 December 2018.

Table 11 ***Summary of simulated increases in Serpentine Main Dam (SMD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

Statistic	1% AEP Summer Existing Scenario	10% AEP Summer Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Summer Proposed Scenario	10% AEP Summer Proposed Scenario	1% AEP Winter Proposed Scenario	1% AEP Winter Proposed Scenario
Maximum	0.54	0.40	0.36	0.20	1.09	0.34	0.56	0.23
99th percentile (~4 cumulative days over 1 year)	0.31	0.32	0.29	0.08	0.64	0.32	0.37	0.10
95th percentile (~20 cumulative days over 1 year)	0.20	0.19	0.22	0.04	0.52	0.25	0.26	0.05
80th percentile (~70 cumulative days over 1 year)	0.10	0.01	0.05	0.03	0.33	0.06	0.14	0.03

5.2.3 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (High Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix C provides the 1% and 10% 7-day AEP flood event model inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SMD assuming high drainage failure SS levels (i.e. higher drainage SS of 63 mg/L rather than 31.5 mg/L for the existing and proposed scenarios). Appendix D presents graphical summaries of the simulated SS_{clay} and SS_{silt} at the dam wall and up-reservoir locations, and in the withdrawals[11] for these four scenarios with high drainage failure SS levels.

A summary of the simulated total silt and clay SS in the SMD withdrawals is provided as time series in Figure 51 and percentile distributions over two one year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 52 for the existing and proposed scenarios with high drainage failure SS levels. The simulated SS (silt + clay) concentrations in the withdrawals have minimal variations between the scenarios for the 10% AEP inflow event. Greater variations on the order of ~1 mg/L are simulated between the three scenarios for the rare 1% AEP summer inflow events, larger than the ~0.5 mg/L predicted with moderate drainage failure SS levels. The 1% AEP winter inflow event was predicted to increase from ~0.2-0.3 mg/L over baseline to ~0.3-0.4 mg/L over baseline for the moderate and high drainage failure SS levels scenarios. Further, a notable increase is also simulated under the high drainage failure SS level scenarios for the 10% AEP summer inflow event, though the differences between scenarios are negligible for the 10% AEP winter inflow event. In short, SS variations of the withdrawals from mining activity are predicted to cause larger relative changes with high drainage failure SS levels than with low drainage failure SS levels (Section 5.2.2), but differences between the existing and proposed scenarios are only substantive (~0.3-0.5 mg/L) for the rare 1% AEP summer inflow events.

The relative changes to the baseline SMD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 12. This summary table provides the

[11] Appendix D also shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

predicted relative changes to SMD withdrawal SS from the existing and proposed mining scenarios with high drainage failure SS levels to inform the GHD (2021a) drinking water risk assessment.

Table 12 ***Summary of simulated increases in Serpentine Main Dam (SMD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

Statistic	1% AEP Summer Existing Scenario	10% AEP Summer Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Summer Proposed Scenario	10% AEP Summer Proposed Scenario	1% AEP Winter Proposed Scenario	1% AEP Winter Proposed Scenario
Maximum	0.92	0.52	1.03	0.31	1.80	0.53	0.79	0.62
99th percentile (~4 cumulative days over 1 year)	0.51	0.43	0.45	0.11	1.04	0.49	0.64	0.19
95th percentile (~20 cumulative days over 1 year)	0.40	0.29	0.37	0.08	0.86	0.43	0.50	0.15
80th percentile (~70 cumulative days over 1 year)	0.22	0.06	0.14	0.06	0.59	0.17	0.21	0.10

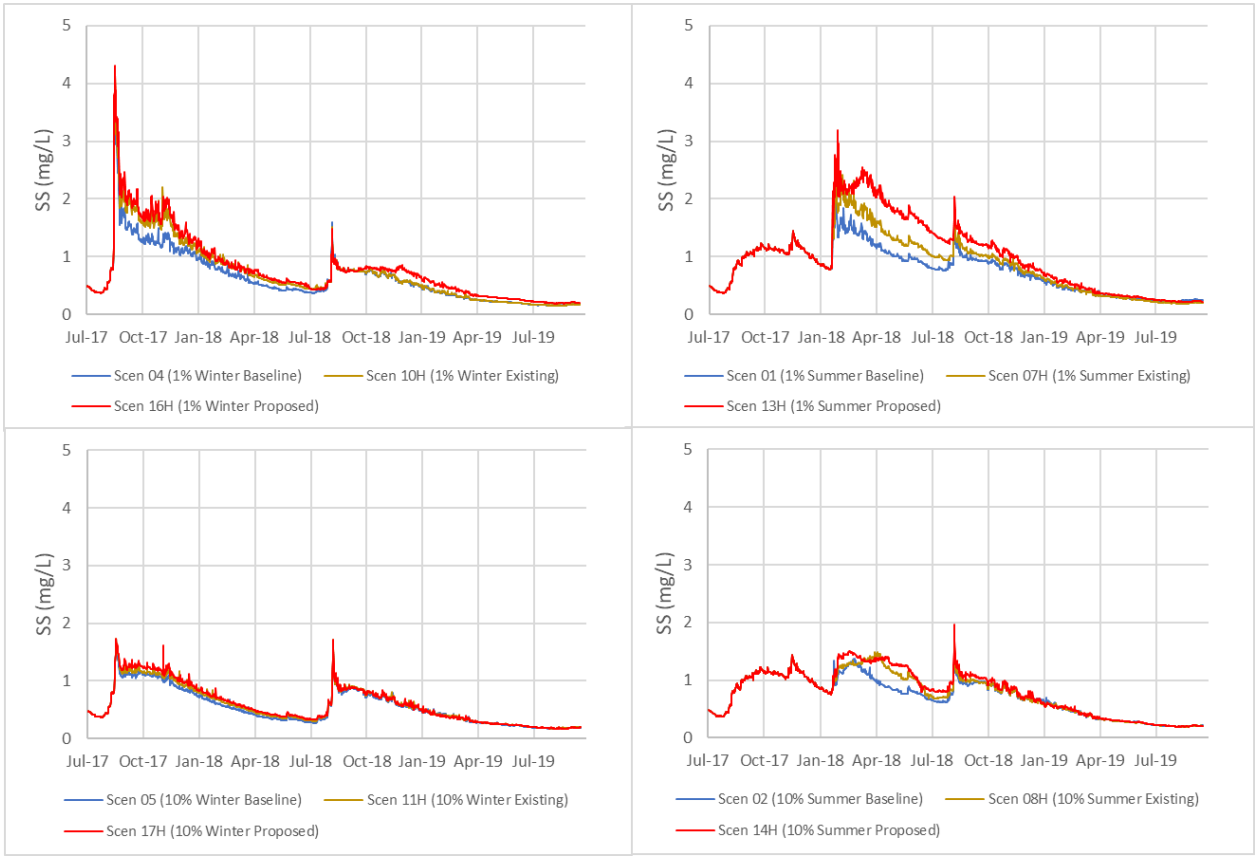


Figure 51 ***Time series of simulated Serpetine Main Dam (SMD) withdrawal inorgnaic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedanc Period (AEP) inflow event scenarios with high drainage failure SS levels.***

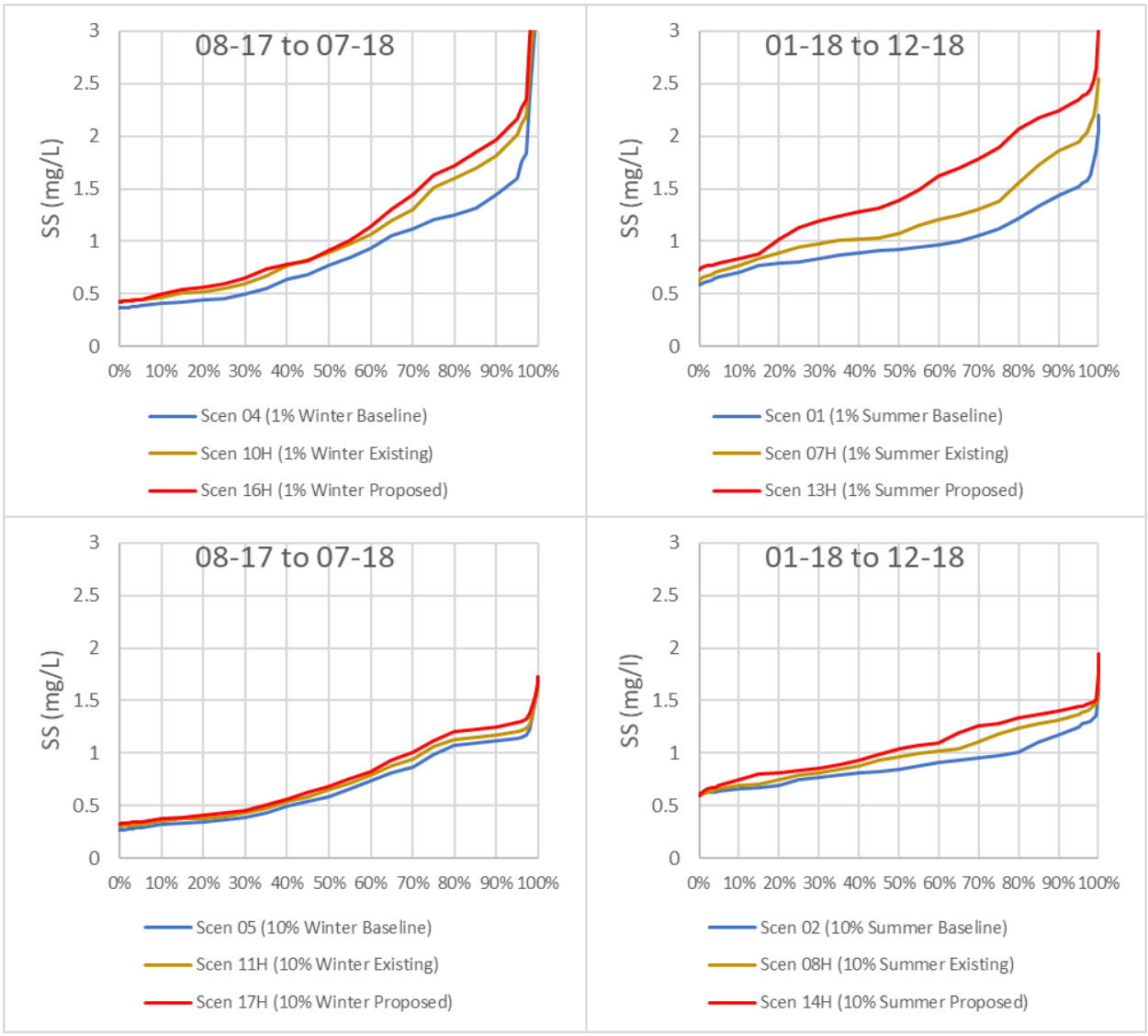


Figure 52 ***Percentile plots of simulated Serpentine Main Dam (SMD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter[12] and summer[13] 1% and 10% Annual Exceedance Period (AEP) inflow event scenarios with high drainage failure SS levels.***

[12] Percentiles over 1 year from 1 August 2017 to 31 July 2018.
[13] Percentiles over 1 yar from 1 January to 31 December 2018.

5.3 South Dandalup Dam (SDD)

5.3.1 Proposed 2017-2019 Scenarios (Cryptosporidium and Hydrocarbon Spill Assessment)

Suspended Solids

Patterns of suspended inorganic solids (SS) in SDD are described in Section 4.3.2 for this scenario.

Cryptosporidium

Simulated cryptosporidium concentrations along the SDD thalweg at 4 day intervals over the first 3 weeks of reference hazard scenario 4D (i.e. mobilisation of infected human stool from catchment 30 closest to the dam wall) is illustrative of the potential risk from this pathogen (Figure 53). Unlike reference hazard 4D for SMD that had variations in the spatial patterns of pathogen between years, spatial patterns of simulated cryptosporidium levels of this hazard scenario for SDD were similar between the 2017 and 2018 inflow events with vertical mixing distributing this pathogen through the water column. However, large scale transport processes did not distribute pathogens to the same degree throughout the up-reservoir volume in SDD as for the SMD simulations, in part due to the smaller inflow to reservoir volume ratio during these hydrological events.

Isopleths of cryptosporidium concentration near the dam of hazards 1, 2, 3, 4A and 4D for the proposed scenario over the 2017-2019 simulation period is summarised in Figure 54. These figures illustrate the relative magnitude and duration of the risks from these incidents. For example, hazards 1 (STP overflow), 2 (STP irrigation area washout) and 3 (STP irrigation area subsurface drainage) are predicted to yield relatively low cryptosporidium levels at the dam (~<3×10^{-6} oocysts/L) similar to the SMD scenarios for loading of an infected stool from proposed mining catchments (hazards 4A-4C) (~<1×10^{-4} oocysts/L) and the reference un-mined catchment closest to the dam (reference hazard 4D) (~<1×10^{-3} oocysts/L). Characteristics of the simulated cryptosporidium incidents include:

– The typical timescale of elevated cryptosporidium levels is ~3-4 months.
– Over these ~3-4 months the oocysts occur throughout the water column.

Simulated cryptosporidium levels in the withdrawals to the IWSS over the 2+ year simulation of the proposed mining scenario are presented in Figure 55. As with the SMD scenarios, there are considerably higher concentrations for infected human stool hazards 4A-4D than those for STP hazards 1-3 for the SDD proposed mining scenario over the 2017-2019 simulation period. Because of the reduced horizontal transport in SDD, withdrawal cryptosporidium concentrations for hazards 4A-4C were ~2-4 fold lower than SMD and those for hazard 4D were ~2 fold greater than SMD.

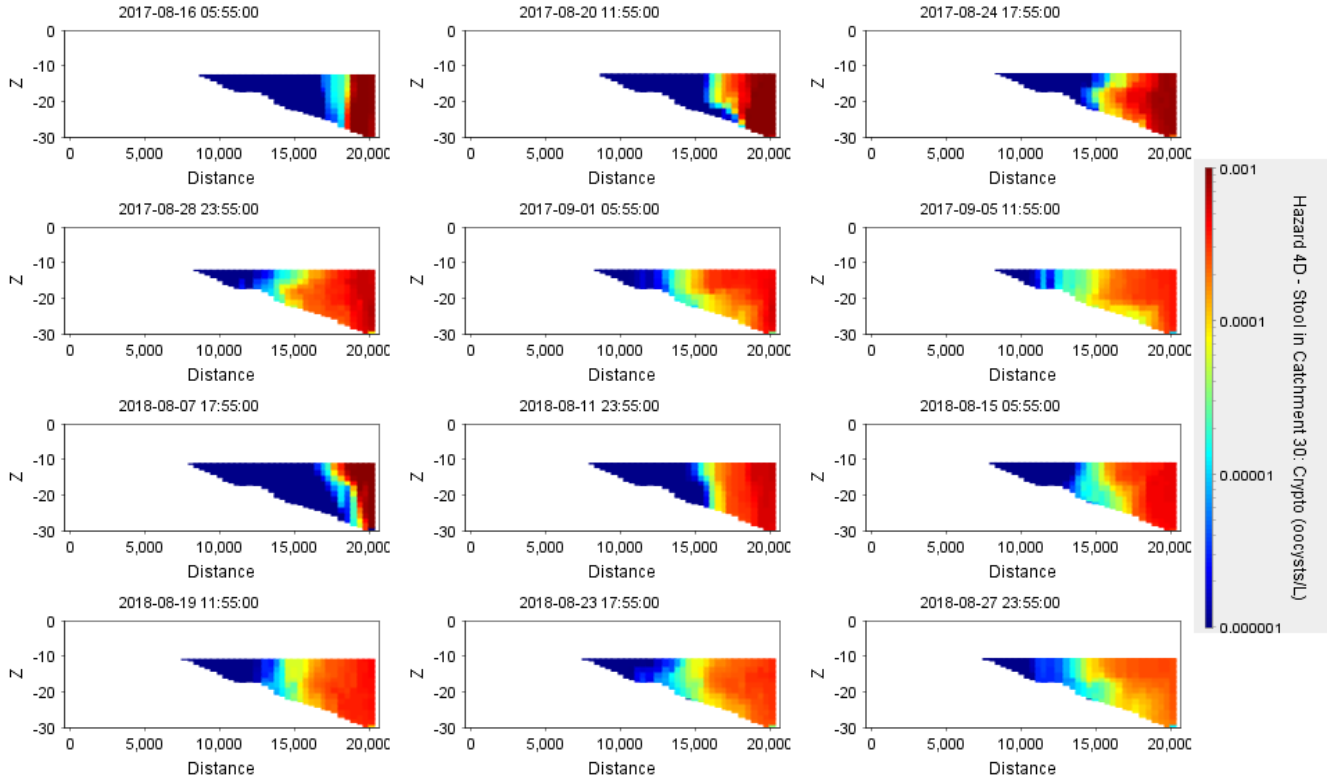


Figure 53 ***Cryptosporidium concentrations along the South Dandalup Dam (SDD) thalweg over 4 day intervals at the onset of hazard 4D during the 2017 (top 2 panels) and 2018 (bottom 2 panels) winter inflow events.***

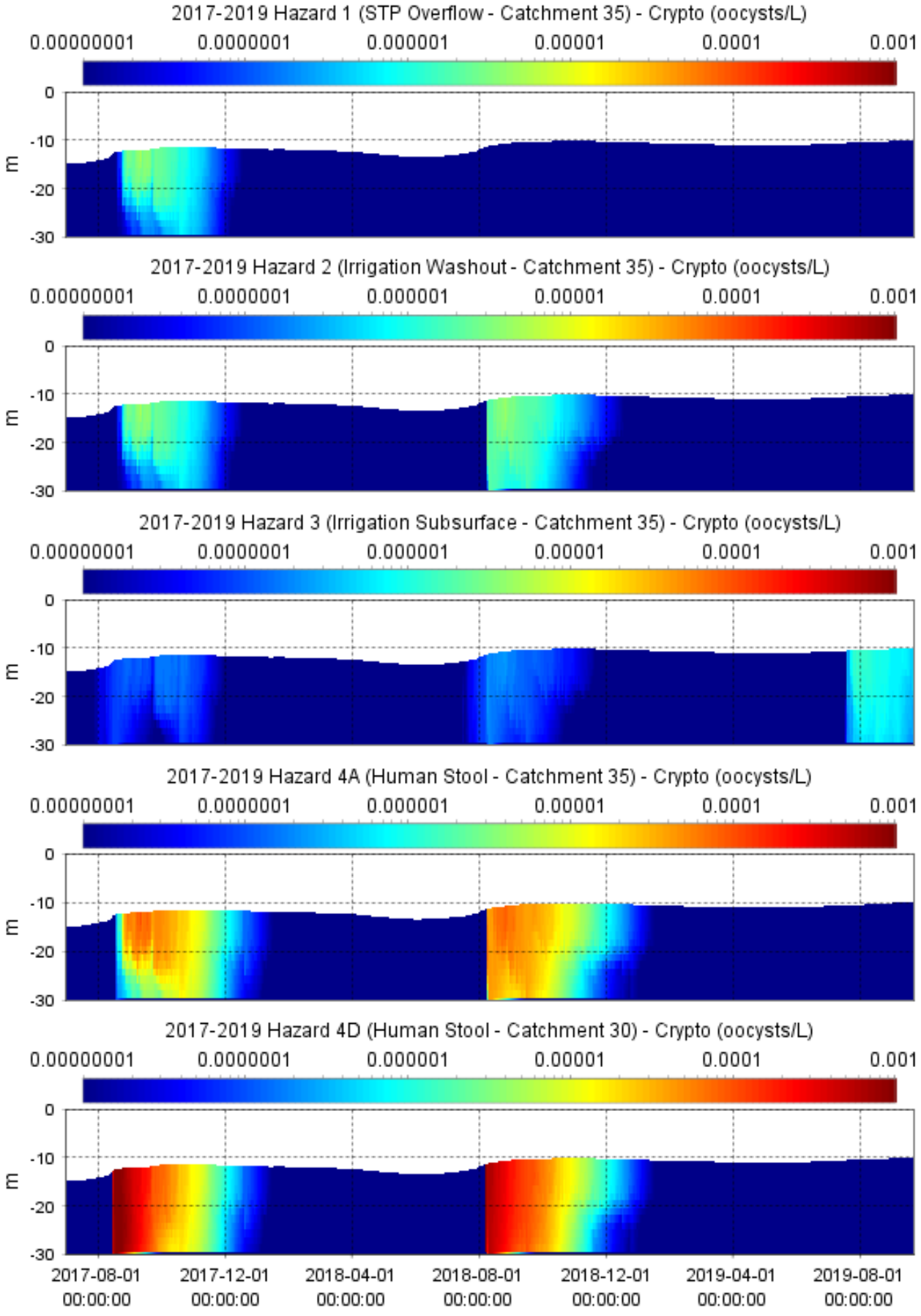
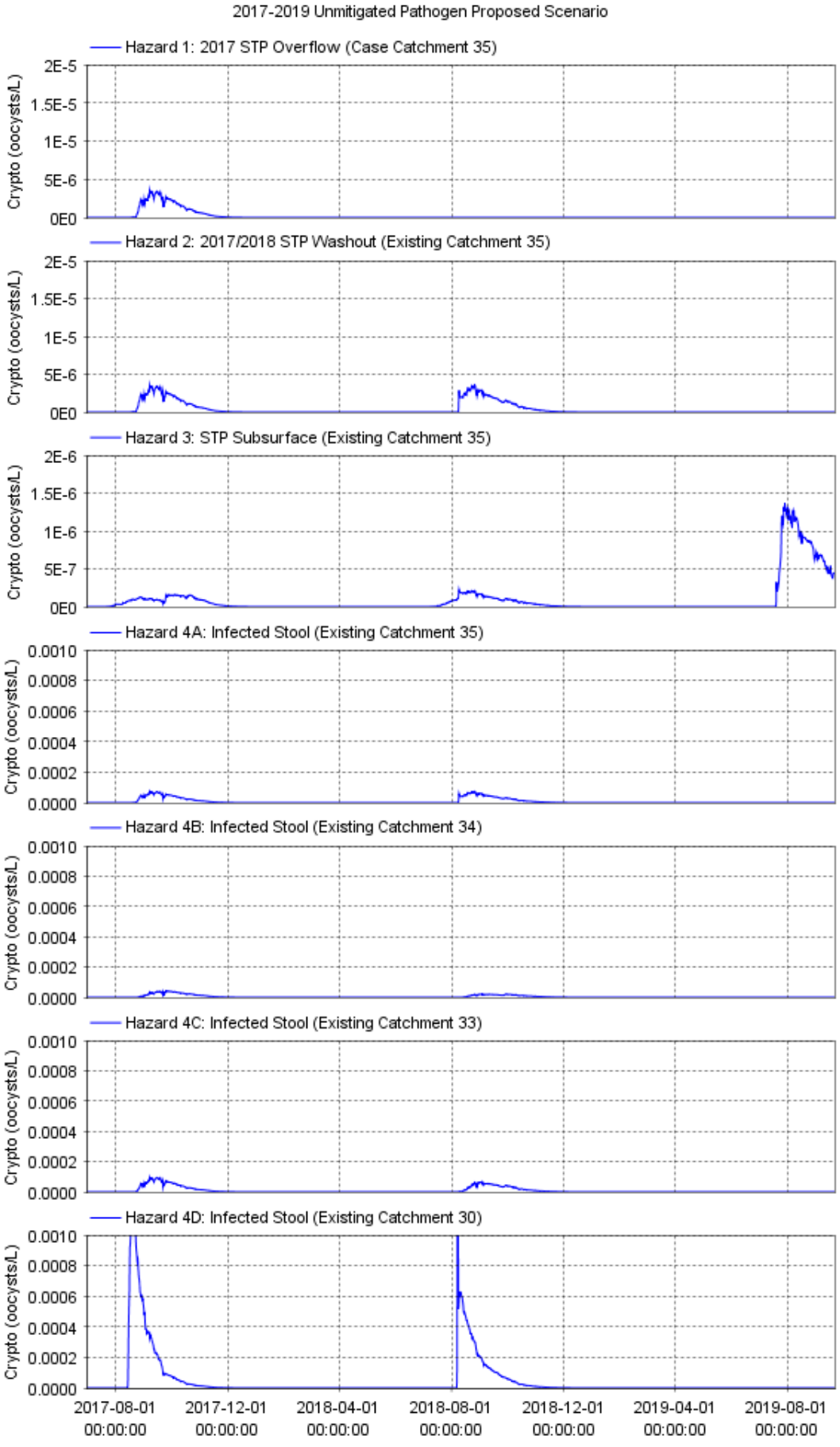


Figure 54 ***Isopleths of cryptosporidium concentrations near the South Dandalup Dam (SDD) dam wall for selected hazards for the proposed mining scenario over the 2017-2019 simulation period.***



1

Figure 55 ***Simulated South Dandalup Dam (SDD) cyrptosporidium withdrawal concentrations of the seven hazards for the proposed mining scenario over the 2017-2019 simulation period.***

Diesel Spill

Diesel concentrations at the dam wall and withdrawals from spills in the selected SDD proposed mining catchments (i.e. haul roads with stream crossings) had similar patterns and concentrations (Figure 56 and Figure 57). As with SMD, peak diesel concentrations of up to 1 µg/L were predicted with all levels below 0.4 µg/L within 6-7 months of the spill. As noted in section 5.1.2, simulated diesel concentrations do not account for any fate losses due to volatilisation, degradation or settling to adhered particles (i.e. diesel modelled as a conservative tracer in the reservoir).

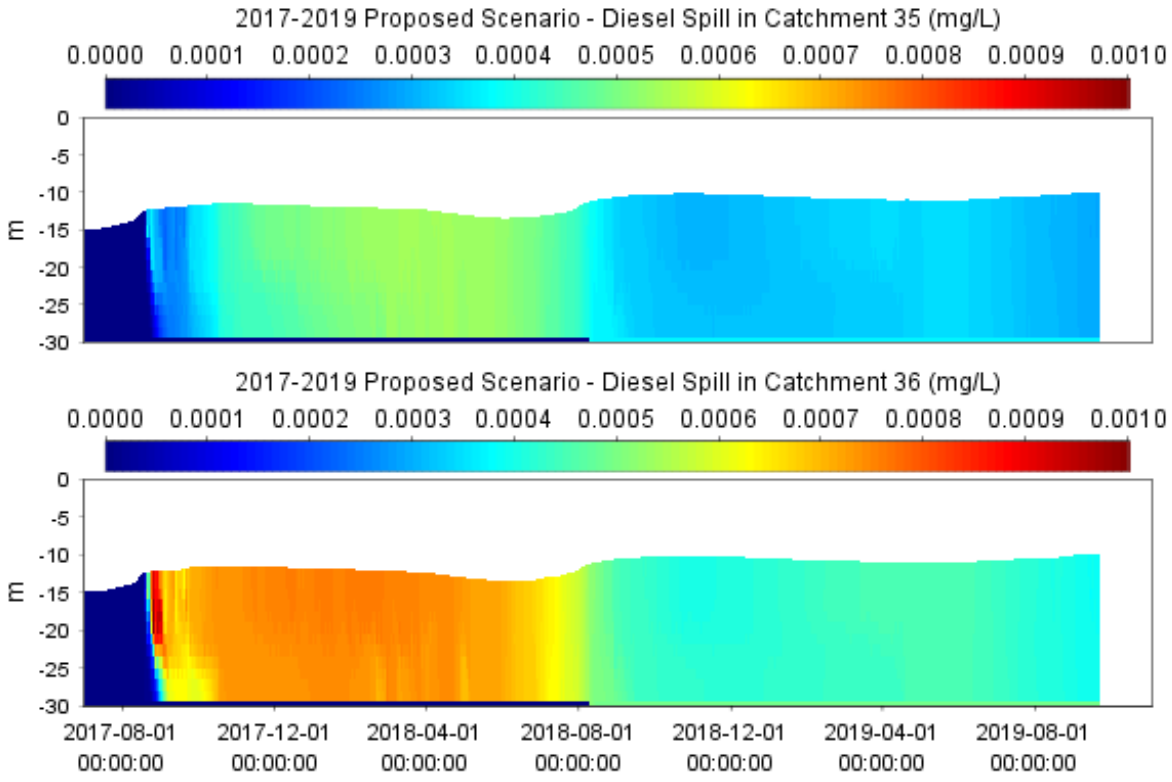


Figure 56 *Isopleths of diesel concentration near the South Dandalup (SDD) dam wall of spills for the proposed mining scenario over the 2017-2019 simulation period.*

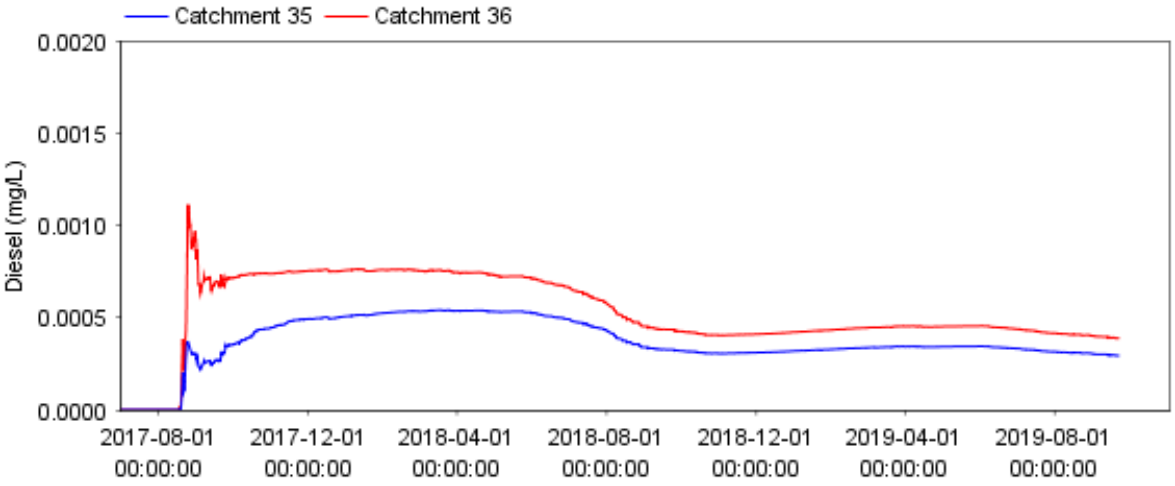


Figure 57 *Diesel concentrations of South Dandalup Dam (SDD) withdrawals of spills for the proposed mining scenario over the 2017-2019 simulation period.*

5.3.2 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (Moderate Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix E provides the 1% and 10% AEP flood event model inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SDD assuming moderate drainage failure SS levels, which can be summarised as:

– The total baseline (i.e. un-mined, fully rehabilitated mining and no drainage failures in mined catchments) discharge over the 14 day inflow events were 13,503 ML and 5,791 ML for the 1% and 10% AEP scenarios, respectively. Both of these volumes are larger than the 2017 and 2018 maximum 14-day totals of 5,335 and 4,500 ML, respectively.
– An additional 864 ML of discharge was inputted from drainage failures of the 1% AEP inflow event (75% drainage failures) for the proposed scenario. For the 10% AEP inflow event (30% drainage failures) an additional 319 ML of discharge was estimated for the proposed scenario.
– All of the baseline (no mining) scenarios had SS_{clay} and SS_{silt} catchment concentrations representative of the natural catchment of 5 and 15 mg/L, respectively, as no drainage failures with associated higher SS levels were assumed.
– Depending on the proportion of the catchment area for the proposed scenario, the SS_{clay} catchment concentrations ranged from ~5.5-10 mg/L. Generally, the larger catchment (i.e. catchment 35 [Serpentine River]) had lower SS_{clay} concentrations as a smaller proportion of the catchment was mined and more substantive discharge caused greater stream dilution of SS prior to reservoir insertion.

Inspection of the scenario simulations at the upper, mid- and near-dam locations in Appendix F[14] illustrate the following:

– Unlike the SMD scenarios, the SDD scenarios did not predict any material differences in the 1% and 10% AEP summer and winter inflow events between the baseline and proposed scenarios (note no existing mining scenario for SDD). The relatively small proportion of the catchment that will undergo mining does not generate sufficient additional SS loads over the baseline (no mining) scenario to cause a substantive increase in SS of the proposed scenarios.
– As with the 2017-2019 scenarios, elevated SS_{silt} for all scenarios was of short duration due to relatively rapid settling. The duration of elevated SS was primarily due to clay particles.

A summary of the simulated total silt and clay SS in the SDD withdrawals is provided as time series in Figure 58 and percentile distributions over two one year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 59. The simulated SS (silt + clay) concentrations in the withdrawals predict minimal variations between the baseline and proposed scenarios for the 1% and 10% AEP inflow events. In short, SS variations from proposed SDD mining activity are predicted to not cause large relative changes between the baseline and proposed scenarios, even for the 1% AEP inflow events. The larger reservoir volume to catchment inflow ratio for SDD provides a greater volumetric barrier to elevated SS relative to SMD, which has a similar volume, but substantially larger catchment discharge.

The relative changes to the baseline SDD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 13. This summary table provides the predicted relative changes to SDD withdrawal SS from the proposed mining scenarios with moderate drainage failure SS levels to inform the GHD (2012a) drinking water risk assessment.

[14] Appendix F shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

Table 13 ***Summary of simulated increases in South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

Statistic	1% AEP Summer Proposed Scenario	10% AEP Summer Proposed Scenario	1% AEP Winter Proposed Scenario	1% AEP Winter Proposed Scenario
Maximum	0.21	0.04	0.11	0.11
99th percentile (~4 cumulative days over 1 year)	0.05	0.02	0.09	0.06
95th percentile (~20 cumulative days over 1 year)	0.03	0.02	0.08	0.05
80th percentile (~70 cumulative days over 1 year)	0.02	0.01	0.04	0.02

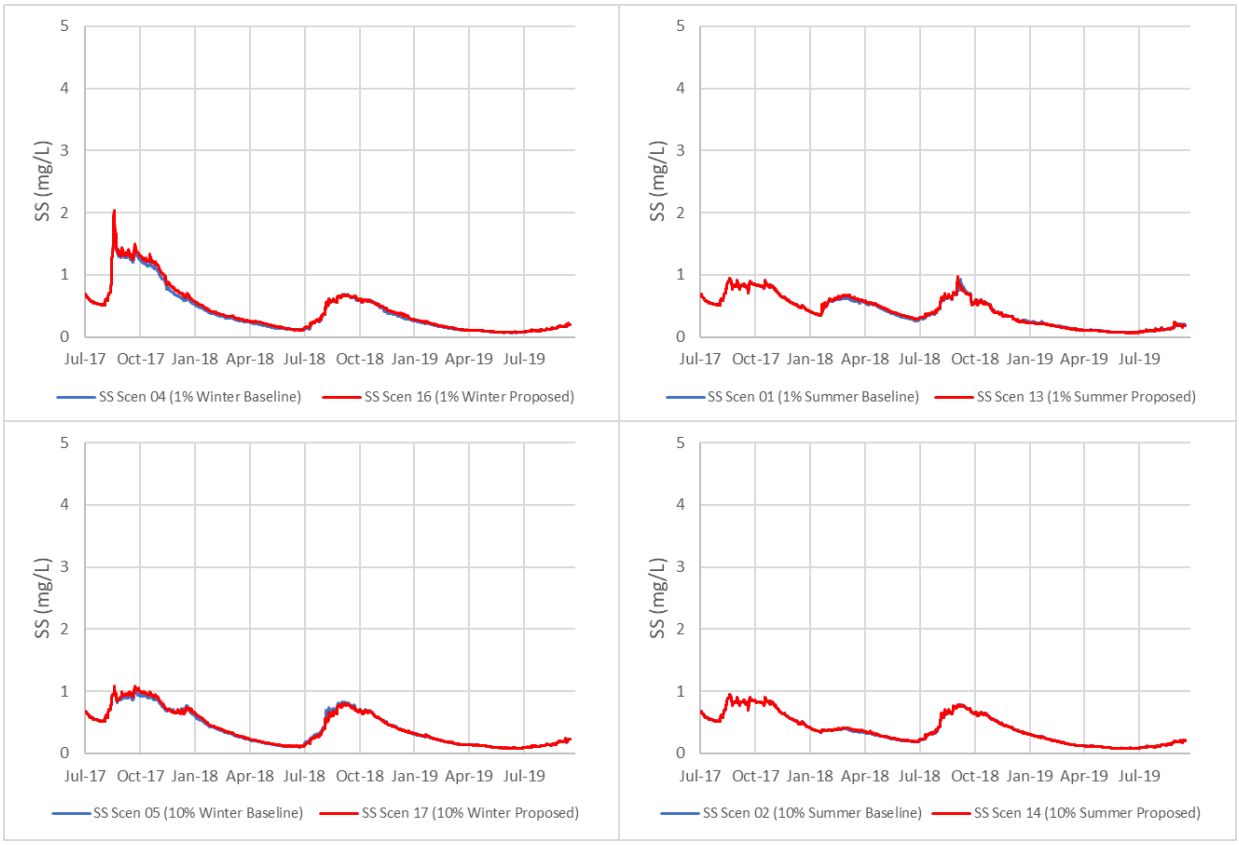


Figure 58 ***Time series of simulated South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

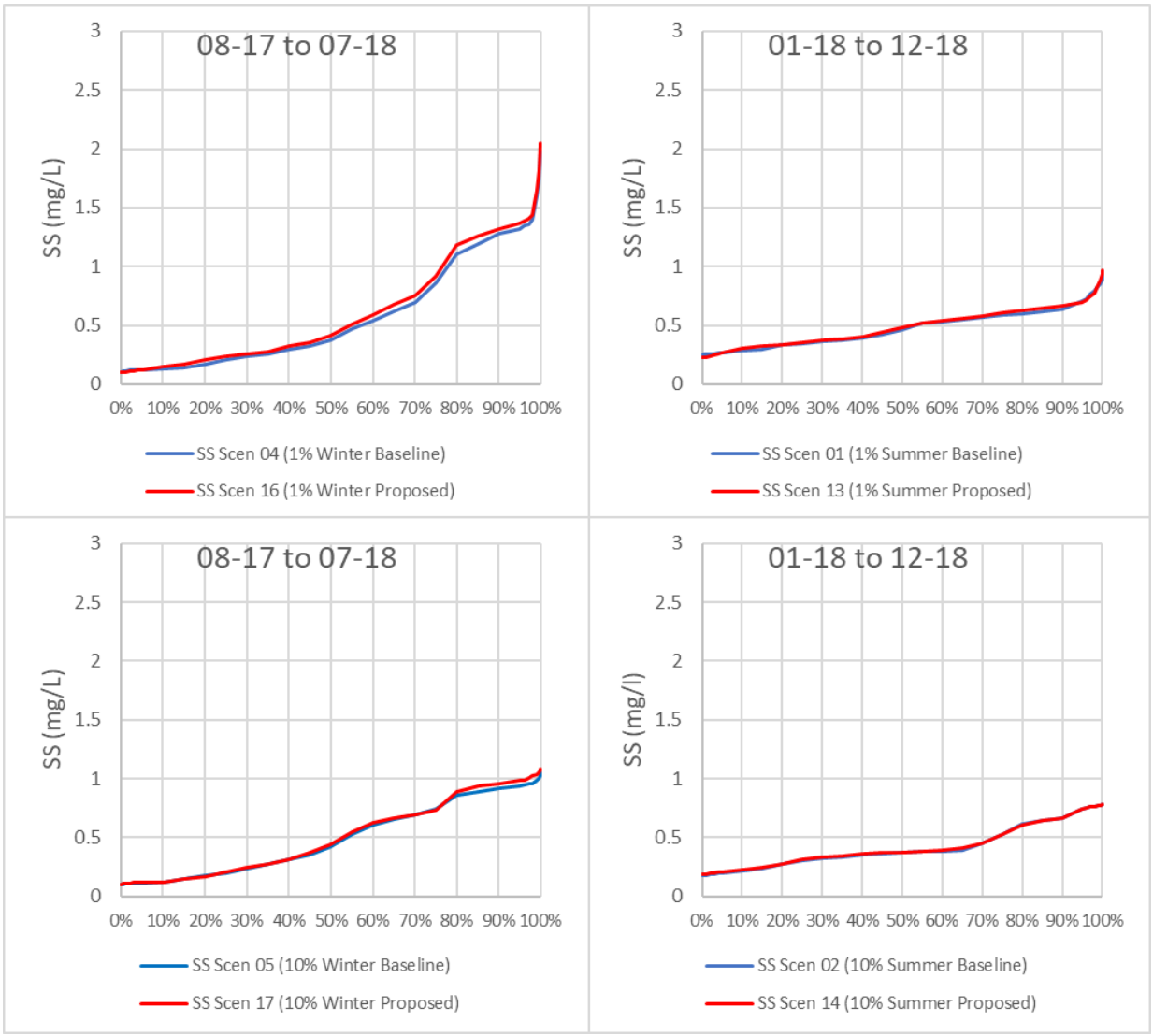


Figure 59 ***Percentile plots of simulated South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

5.3.3 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (High Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix G provides the 1% and 10% 7-day AEP flood event model inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SDD assuming high drainage failure SS levels (i.e. higher drainage SS of 63 mg/L rather than 31.5 mg/L for the proposed scenarios). Appendix H presents graphical summaries of the simulated SS_{Clay} and SS_{Silt} at the dam wall and up-reservoir locations, and in the withdrawals[15] from the intake tower for these two scenarios with ineffective drainage turbidity management.

A summary of the simulated total silt and clay SS in the SDD withdrawals is provided as time series in Figure 60 and percentile distributions over two one year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 61 for the proposed scenarios with ineffective drainage turbidity management. The simulated SS (silt + clay) concentrations in the withdrawals predict minimal variations between the baseline and proposed scenarios of <0.2 mg/L. In short, SS variations of the withdrawals from mining activity are predicted to cause minimal changes to SS, even with ineffective drainage turbidity management.

The relative changes to the baseline SDD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 14. This summary table provides the predicted relative changes to SDD withdrawal SS from the proposed mining scenarios with high drainage failure SS levels to inform the GHD (2012a) drinking water risk assessment.

Table 14 ***Summary of simulated increases in South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

Statistic	1% AEP Summer Proposed Scenario	10% AEP Summer Proposed Scenario	1% AEP Winter Proposed Scenario	1% AEP Winter Proposed Scenario
Maximum	0.23	0.07	0.19	0.15
99th percentile (~4 cumulative days over 1 year)	0.09	0.04	0.17	0.10
95th percentile (~20 cumulative days over 1 year)	0.07	0.04	0.15	0.08
80th percentile (~70 cumulative days over 1 year)	0.04	0.02	0.06	0.03

[15] Appendix H also shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

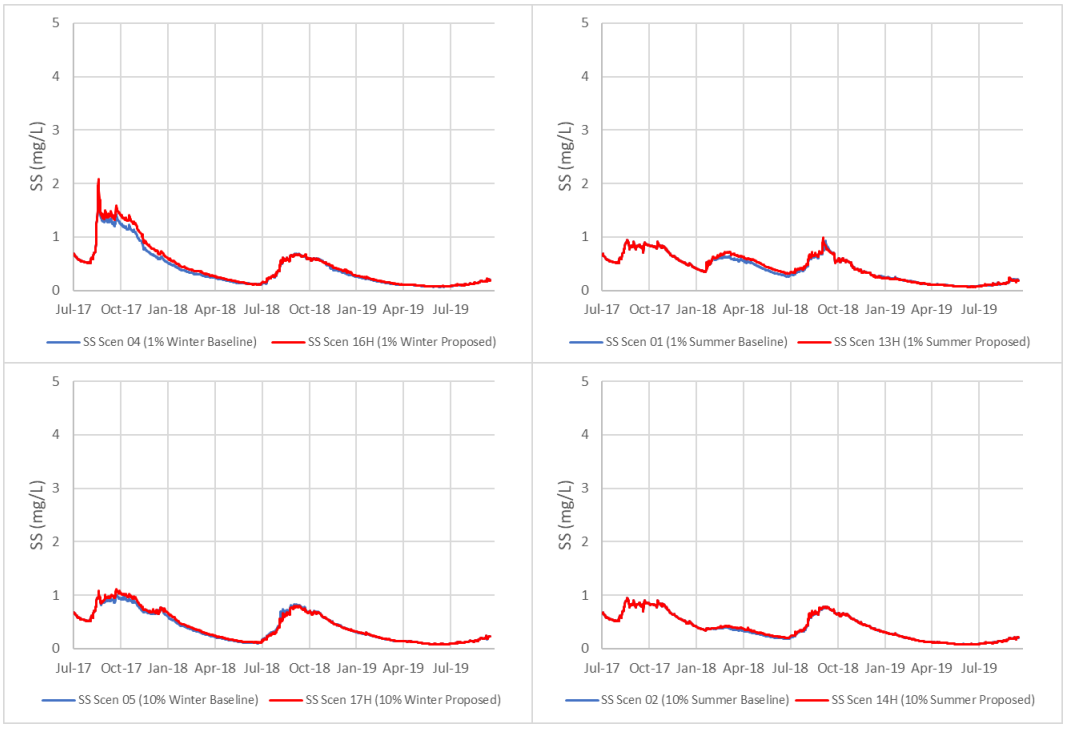


Figure 60 ***Time series of simulated South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

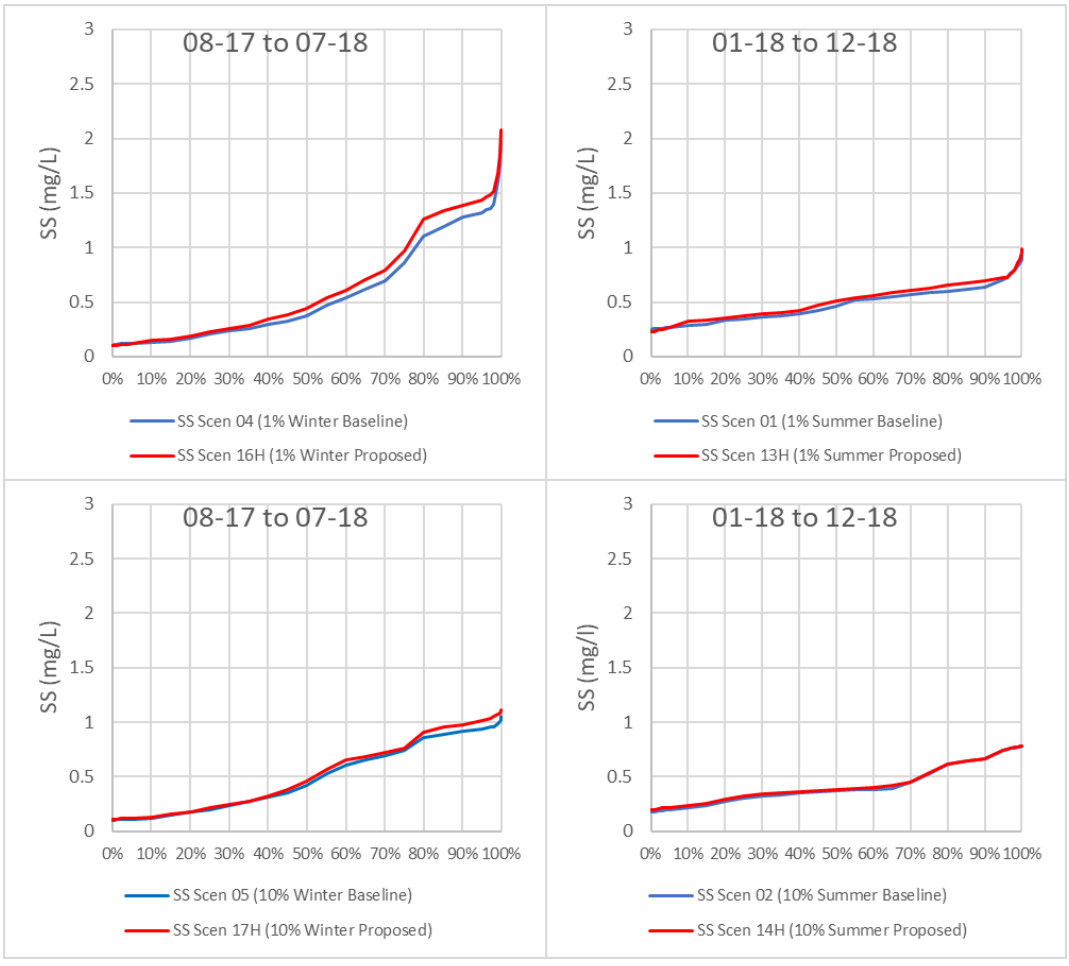


Figure 61 ***Percentile plots of simulated South Dandalup Dam (SDD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

5.4 Serpentine Pipehead Dam (SPD)

5.4.1 Existing 2017-2019 Scenarios (Cryptosporidium and Hydrocarbon Spill Assessment)

Suspended Solids

Patterns of suspended inorganic solids (SS) in SPD are described in Section 4.3.2 for this scenario.

Cryptosporidium

Simulated cryptosporidium concentrations along the SPD thalweg at 4 day intervals over the first 3 weeks of reference hazard 4D (i.e. mobilisation of infected human stool from catchment 20 closest to the dam) is illustrative of the potential risk from this pathogen (Figure 62). Similar to SDD, spatial patterns of simulated cryptosporidium levels of this incident for SPD were similar between the 2017 and 2018 inflow events with vertical mixing distributing this pathogen through the water column. Further, as with SDD, large scale transport processes did not distribute pathogens to the same degree throughout the up-reservoir SPD volume.

Isopleths of cryptosporidium concentration near the dam of hazards 1, 2, 3, 4A and 4D for the existing scenario over the 2017-2019 simulation period is summarised in Figure 63. As no STP is located in any of the existing (same as proposed) SPD mining catchments, hazards 1, 2 and 3 are not relevant. Further, only two catchments have existing mining activity, and proposed mining activity is also to be limited to these two catchments. The two simulated two infected human stool incidents in the existing mining catchments (hazards 4A and 4B) have peak concentrations at the dam that span a large range wall from ~<1×10^{-5} oocysts/L (hazard 4A in catchment 23) to ~<1×10^{-3} oocysts/L (hazard 4B in catchment 24). Hazard 4D with cryptosporidium loads from catchment 20 closest to the dam has at least an order of magnitude greater simulated concentration (~<1-2×10^{-2} oocysts/L) than the other 2 hazards. Characteristics of simulated cryptosporidium concentrations during hazards 4A, 4B and 4D in SPD include:

– The typical timescale of elevated cryptosporidium levels is ~2-3 months, though it is considerable shorter and of much lower magnitude for hazard 4D in catchment 20.
– Over these ~2-3 months the oocysts occur throughout the water column.
– There is a delay in the arrival of elevated cryptosporidium concentrations for hazard 4A from uppermost catchment 23.

Cryptosporidium levels from hazards 4A, 4B and 4C in the SPD withdrawals to the IWSS for the existing (and proposed) mining scenario over the 2017-2019 simulation period are presented in Figure 64. The catchment from which an infected stool is mobilised has a large effect on the simulated cryptosporidium concentrations in the withdrawals. For hazard 4A in the uppermost catchment at the head of the reservoir, very low levels are predicted at the outlet in contrast with hazard 4D for the catchment closest to the dam wall.

The primary SPD water inputs and outputs are via external transfers and withdrawals, which are both in the vicinity of the dam and promote a high degree of short-circuiting between them. This has major implications on the spatial patterns of water age (i.e. duration a water parcel remains in the reservoir) throughout the SPD water body with much greater water retention in the upper portions of the reservoir relative to near proximity to the dam. This phenomenon induced by the operational configuration and management of the SPD induces a hydrodynamic barrier that decreases the transport of cryptosporidium (and any other contaminants) from catchment 23 to the dam as illustrated in Figure 65.

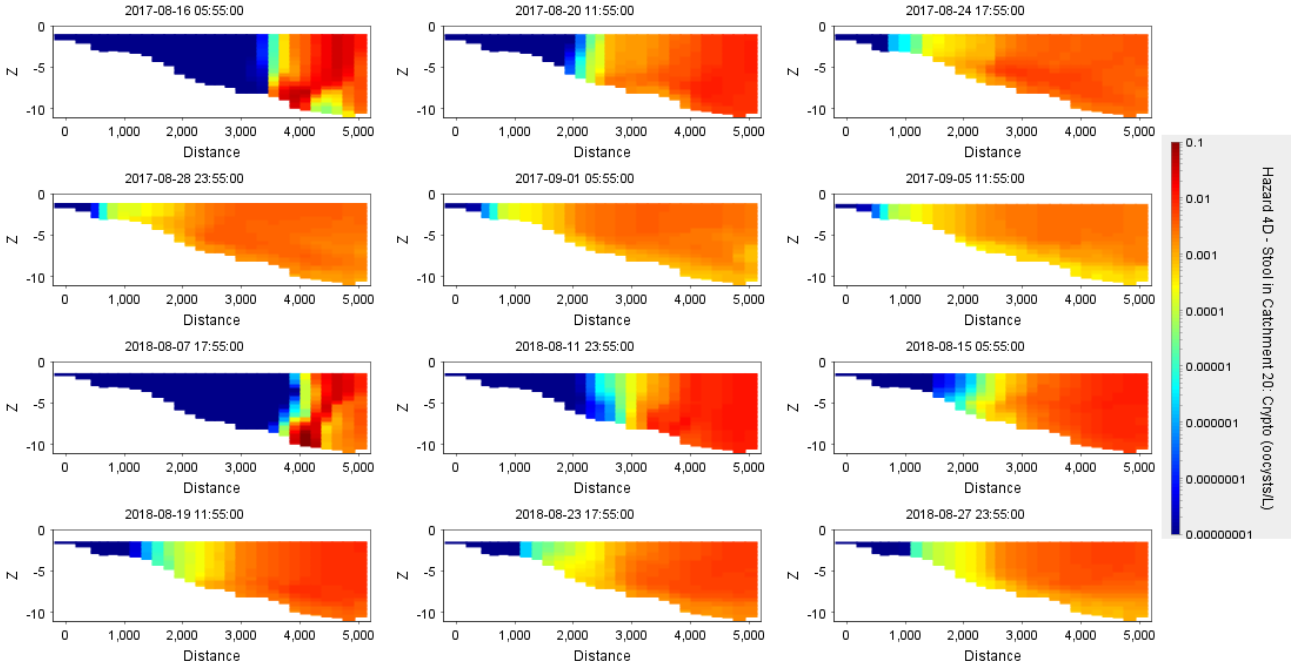


Figure 62 ***Cryptosporidium concentrations along the Serpentine Pipehead Dam (SPD) thalweg over 4 day intervals at the onset of hazard 4D during the 2017 (top 2 panels) and 2018 (bottom 2 panels) winter inflow events.***

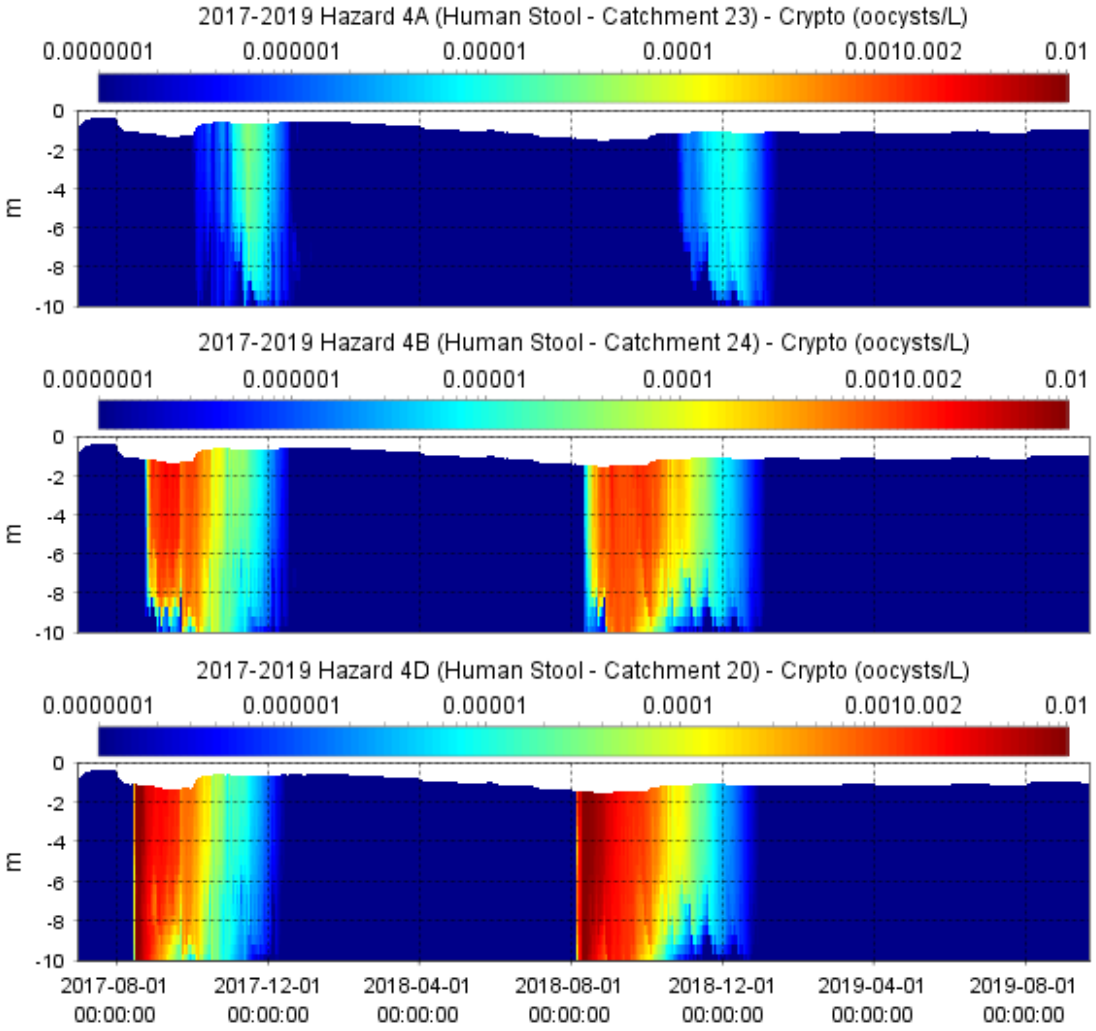


Figure 63 ***Isopleths of cryptosporidium concentrations near the Serpentine Pipehead Dam (SPD) dam wall for 3 relevant hazards for the existing mining scenario over the 2017-2019 simulation period.***

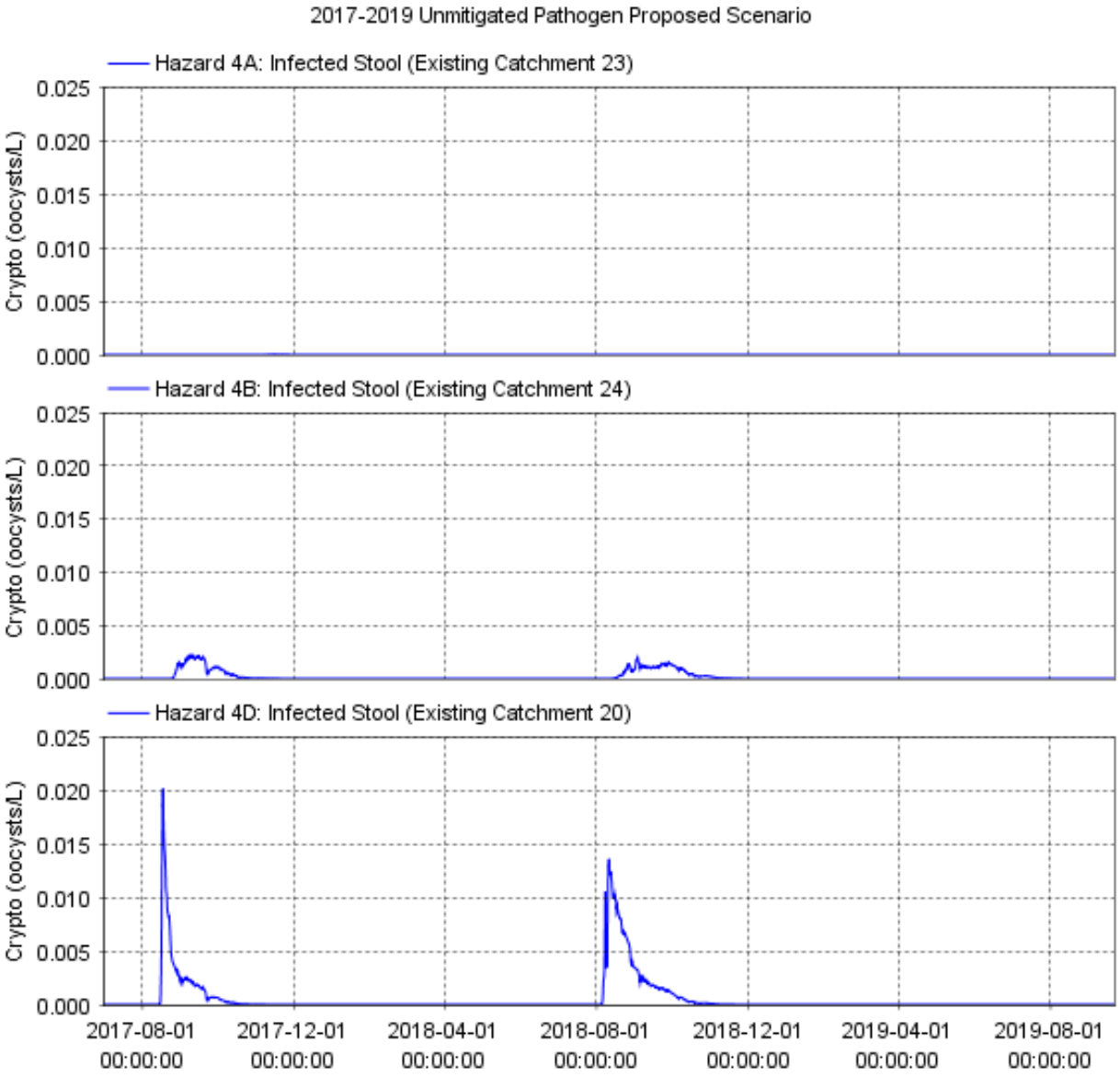


Figure 64 ***Simulated Serpentine Pipehead Dam (SPD) cyrptosporidium withdrawal concentrations of the three relevant incidents for the existing mining scenario over the 2017-2019 simulation period.***

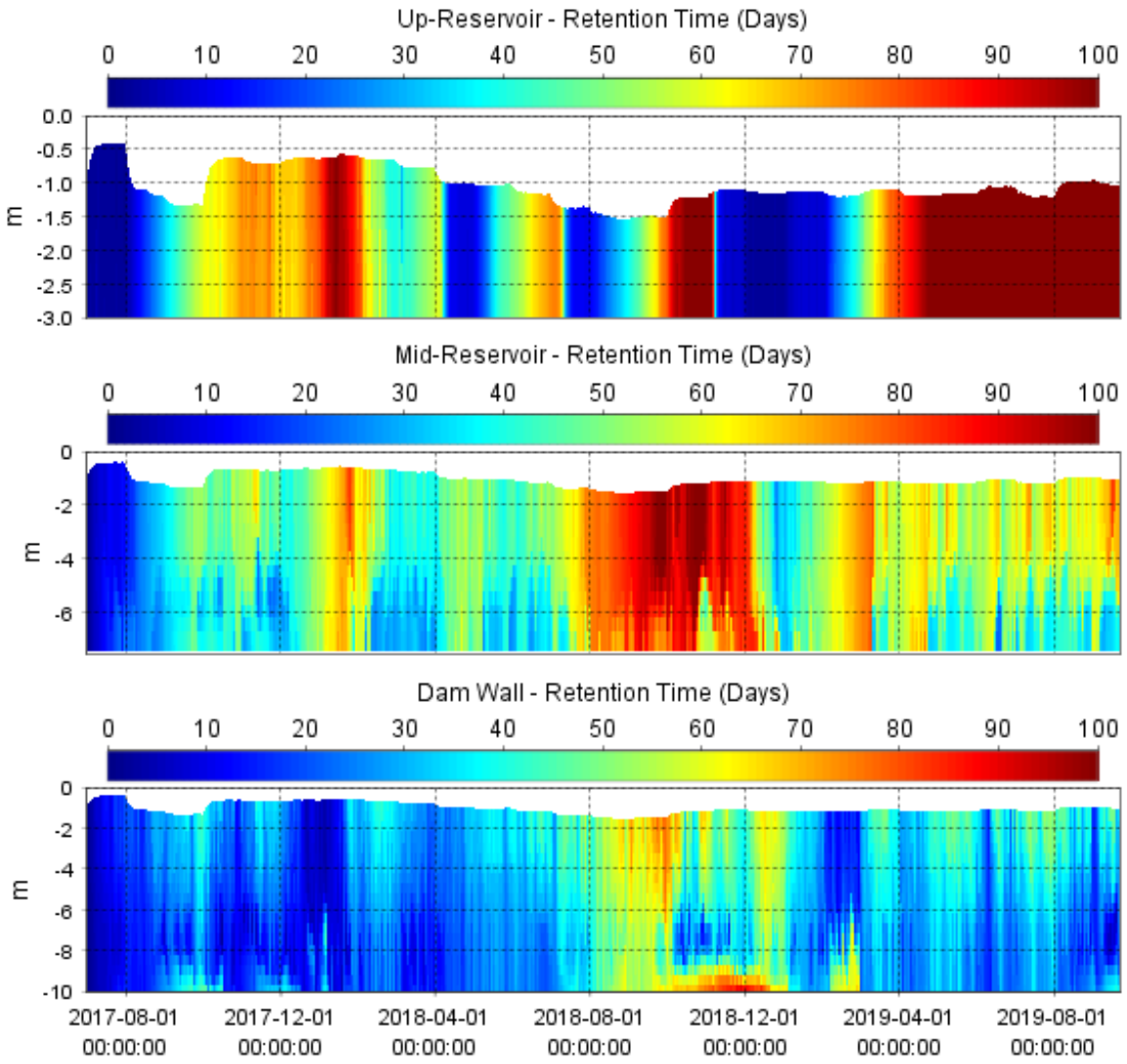


Figure 65 Simulated water age of upper, mid- and near dam Serpentine Pipehead Dam (SPD) assessment sites.

Diesel Spill

Diesel concentrations at the dam wall and withdrawals from spills in the selected SPD existing mining catchments (i.e. haul roads with stream crossings) had similar spatial and temporal patterns (Figure 66 and Figure 67) as the cryptosporidium predictions for hazards 4A (catchment 23) and 4B (catchment 24). The diesel concentrations from a spill in catchment 23 (upper reservoir) had much lower concentrations than those from catchment 24 (mid-reservoir), with the simulated arrival of diesel at the dam wall ~2 months later. As with variations in cryptosporidium, the hydrodynamic barrier effect induced by short-circuiting of the primary inflow (external transfers) and outflow (withdrawals) in the region of the dam effectively decreased the transport and dispersion of diesel from a spill in the upper reservoir catchment. Peak diesel concentrations from a spill in mid-reservoir catchment 24 of 5 µg/L was considerably greater than the peaks of ~1 µg/L for SMD and SDD. However, the spill in SPD catchment 23 had a similar peak of ~1.5 µg/L in the withdrawals as the much larger SMD and SDD reservoirs. Because of SPD's relatively small volume and high outflow, diesel levels were predicted to decrease to ~0 µg/L within ~10-12 months of the spill. As noted in section 5.1.2, simulated diesel concentrations do not account for any fate losses due to volatilisation, degradation or settling to adhered particles (i.e. diesel modelled as a conservative tracer in the reservoir).

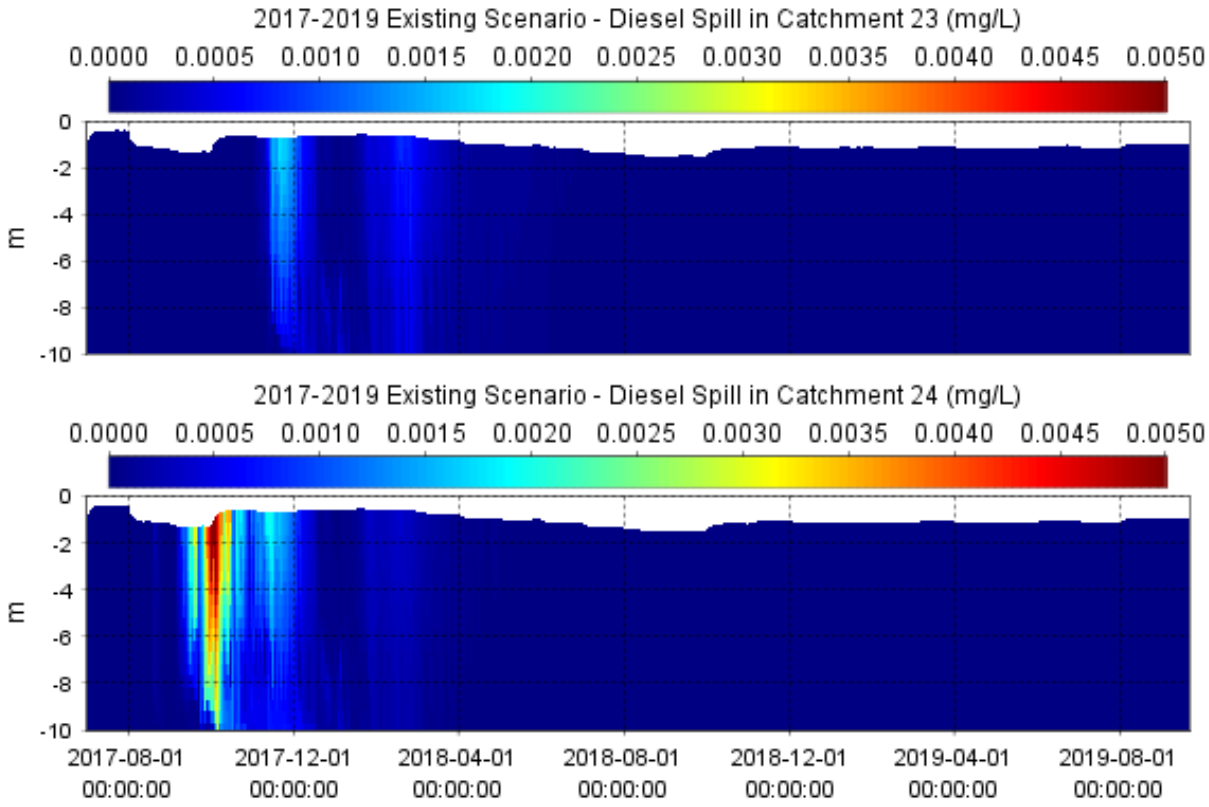


Figure 66 ***Isopleths of diesel concentration near the Serpentine Pipehead (SPD) dam wall of spills for the existing mining scenario over the 2017-2019 simulation period.***

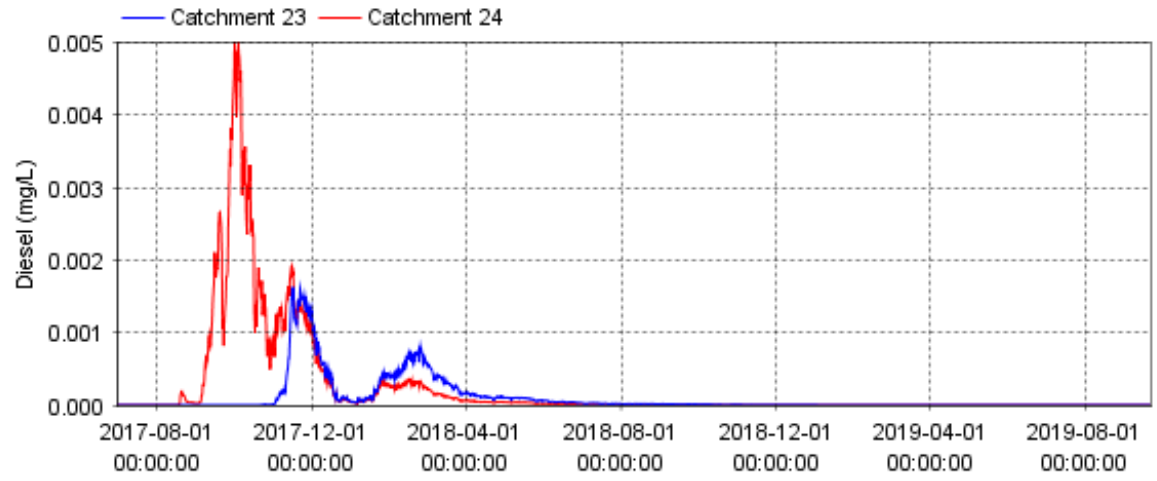


Figure 67 ***Diesel concentrations of Serpentine Pipehead Dam (SPD) withdrawals of spills occuring for the existing mining scenario over the 2017-2019 simulation period.***

5.4.2 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (Moderate Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix I provides the 1% and 10% AEP flood event model inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SPD assuming moderate drainage failure SS levels, which can be summarised as:

– The total baseline (i.e. un-mined, fully rehabilitated mining and no drainage failures in mined catchments) discharge over the 14 day inflow events were 1,254 ML and 538 ML for the 1% and 10% AEP scenarios, respectively. Both of these volumes are considerably larger than the 2017 and 2018 maximum 14-day totals of 488 ML and 342 ML, respectively.
– An additional 128 ML of discharge was inputted from drainage failures of the 1% AEP inflow event (75% drainage failures) for the proposed mining scenario. For the 10% AEP inflow event (30% drainage failures) an additional 47 ML of discharge was estimated for the proposed mining scenario.
– All of the baseline (no mining) scenarios had SS_{clay} and SS_{silt} catchment concentrations representative of the natural catchment of 5 and 15 mg/L, respectively, as no drainage failures with associated higher SS levels were assumed.
– Depending on the proportion of the catchment area for the existing mining scenario, the SS_{clay} catchment concentrations ranged from ~6-12 mg/L.

Inspection of the scenario simulations at the upper, mid- and near-dam locations in Appendix J[16] illustrate the following:

– As the SDD scenarios, the SPD scenarios did not predict any material differences in the 1% and 10% AEP summer and winter inflow events between the baseline and existing scenarios (note no proposed mining scenario for SPD). The hydrodynamic barrier effect induced by the SPD primary inflow and outflow in proximity to the dam wall increases the duration for settling to occur prior to transport of the clay particles to the dam wall. Further, the high external transfers with assumed low SS levels effectively dilutes elevated catchment particles as they are transported to the dam wall.
– As with the 2017-2019 scenarios, elevated SS_{silt} for all scenarios was of short duration due to relatively rapid settling. The duration of elevated SS was primarily due to clay particles.

A summary of the simulated total silt and clay SS in the SPD withdrawals is provided as time series in Figure 68 and percentile distributions over two one year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 69. The simulated SS (silt + clay) concentrations in the withdrawals predict minimal variations between the baseline and proposed scenarios for the 1% and 10% AEP inflow events. In short, SS variations from existing SPD mining activity is predicted to not cause large relative changes between the baseline and existing scenarios, even for the 1% AEP inflow events. A combination of the hydrodynamic barrier effect discussed previously on retarding the transport of SS loads from the mid-reservoir (catchment 24) and upper reservoir (catchment 23) catchment confluences, and dilution with the low SS external transfers near the dam wall contribute to the predicted minimal effect on inorganic particle levels relative to the baseline.

The relative changes to the baseline SPD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 15. This summary table provides the predicted relative changes to SPD withdrawal SS from the proposed mining scenarios with moderate drainage failure SS levels to inform the GHD (2012a) drinking water risk assessment.

[16] Appendix J shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

Table 15 ***Summary of simulated increases in Serpentine Pipehead Dam (SPD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

Statistic	1% AEP Summer Existing Scenario	10% AEP Summer Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Winter Existing Scenario
Maximum	0.23	0.07	0.19	0.15
99th percentile (~4 cumulative days over 1 year)	0.09	0.04	0.17	0.10
95th percentile (~20 cumulative days over 1 year)	0.07	0.04	0.15	0.08
80th percentile (~70 cumulative days over 1 year)	0.04	0.02	0.06	0.03

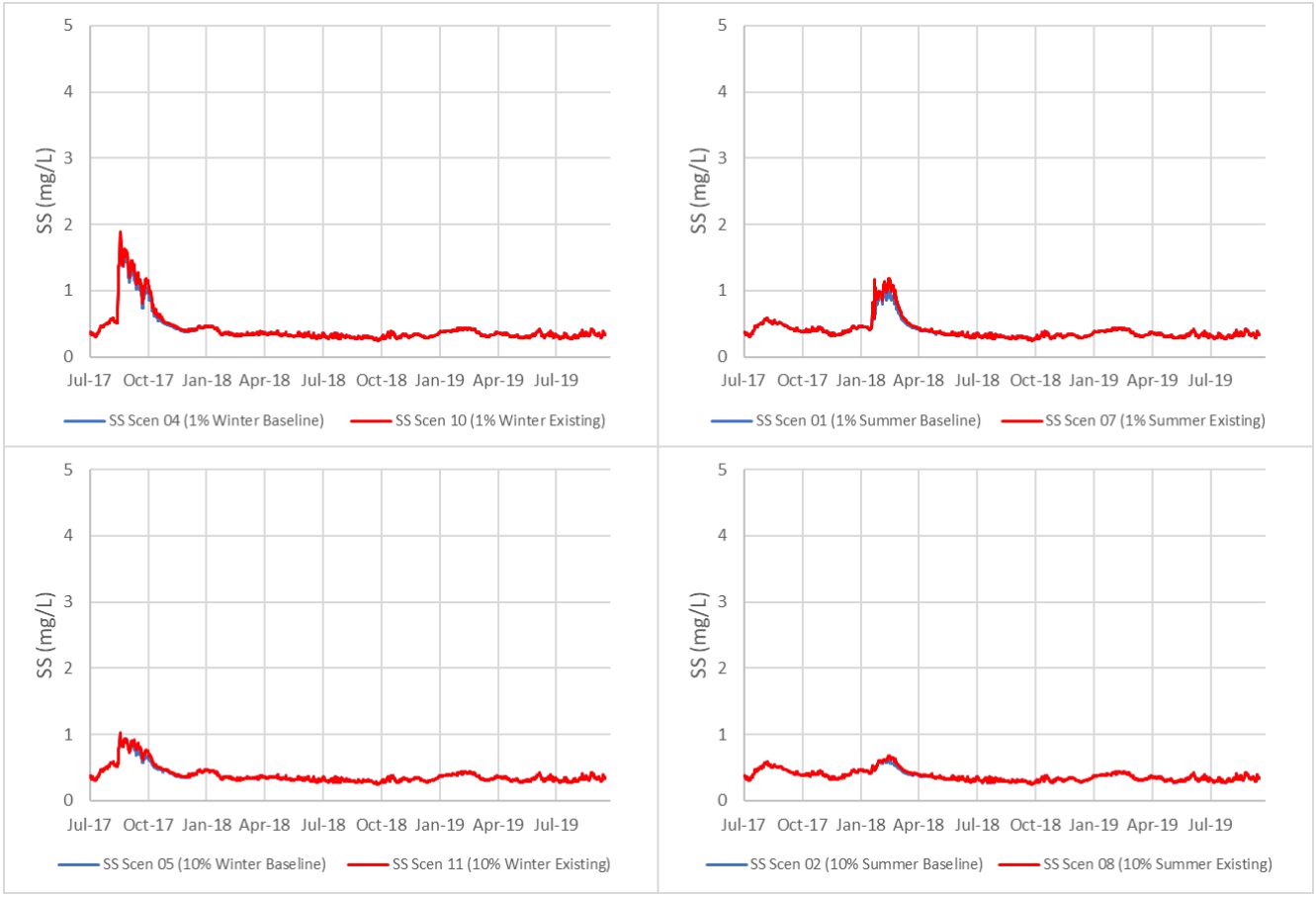


Figure 68 ***Time series of simulated Serpentine Pipehead Dam (SPD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period [AEP] inflow events with moderate drainage failure SS levels.***

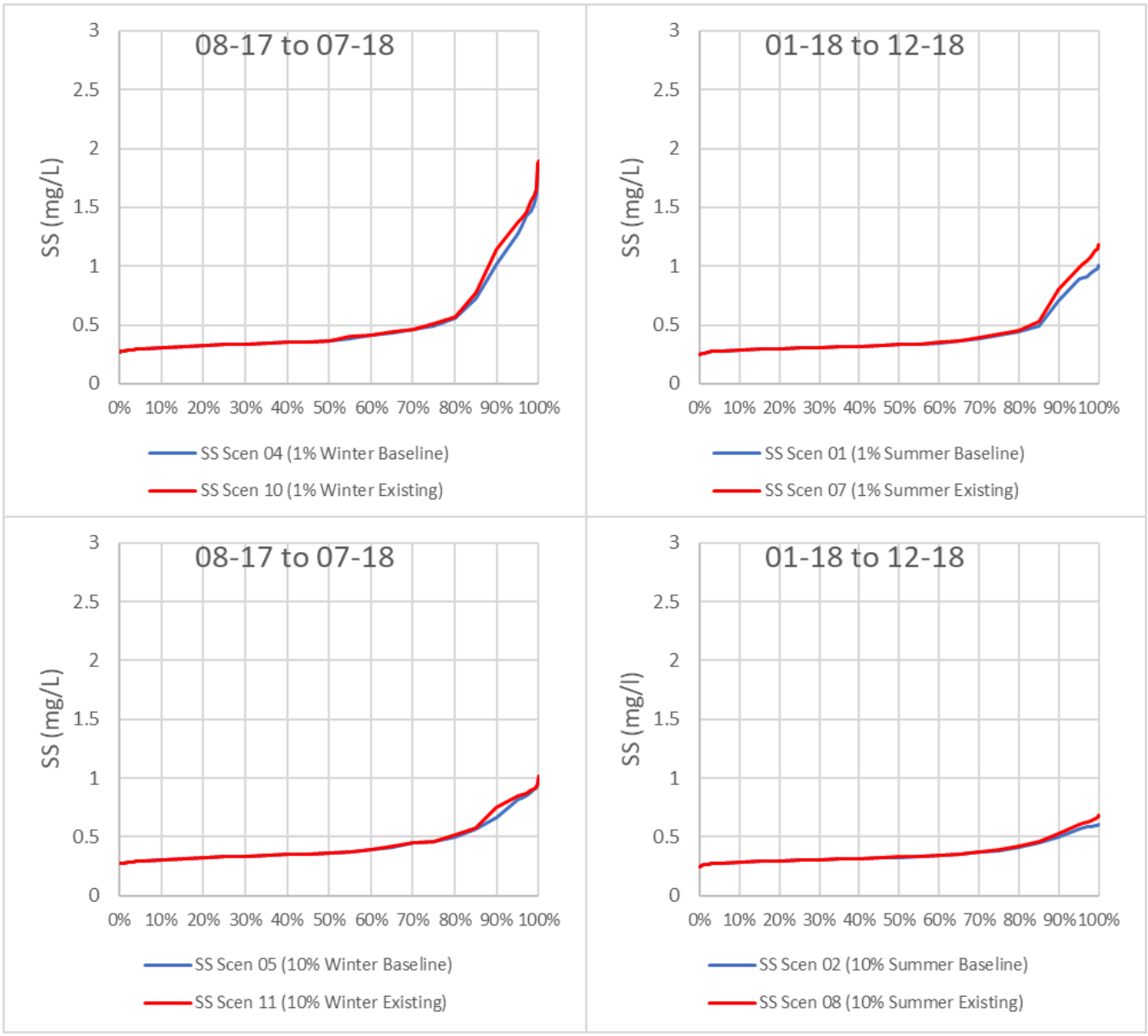


Figure 69 ***Percentile plots of simulated inorganic supended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with moderate drainage failure SS levels.***

5.4.3 1% and 10% Annual Exceedance Period (AEP) Winter and Summer Inflow Events (High Drainage Failure Inorganic Suspended Solids [SS] Levels)

Appendix K provides the 1% and 10% 7-day AEP flood model event inputs (discharge, SS_{clay} and SS_{silt} concentrations) for SPD assuming high drainage failure SS levels (i.e. higher drainage SS of 63 mg/L rather than 31.5 mg/L for the proposed scenarios). Appendix L presents graphical summaries of the simulated SS_{Clay} and SS_{Silt} at the dam wall and up-reservoir locations, and in the withdrawals from the intake tower[17] for these two scenarios with ineffective drainage turbidity management.

A summary of the simulated total silt and clay SS in the SPD withdrawals is provided as time series in Figure 70 and percentile distributions over two one year periods (August 2017 to July 2018 for winter scenarios and January to December 2018 for summer scenarios) in Figure 71 for the existing scenarios with ineffective drainage turbidity management. The simulated SS (silt + clay) concentrations in the withdrawals predict minimal variations between the baseline and existing scenarios. A combination of the hydrodynamic barrier of the mid-reservoir (catchment 24) and upper reservoir (catchment 23) catchment confluences and dilution with the low SS external transfers near the dam wall contribute to this prediction of minimal effect relative to the baseline.

The relative changes to the baseline SPD withdrawal SS (SS_{clay}+ SS_{silt}) concentrations over 1 year after the winter and summer 1% and 10% AEP inflow events are summarised in Table 16. This summary table provides the predicted relative changes to SPD withdrawal SS from the proposed mining scenarios with high drainage failure SS levels to inform the GHD (2012a) drinking water risk assessment.

Table 16 ***Summary of simulated increases in Serpentine Pipehead Dam (SPD) withdrawal inorganic suspended solids (SS) (mg/L) for existing and proposed mining scenarios relative to baseline scenarios over 1 year after winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

Statistic	1% AEP Summer Existing Scenario	10% AEP Summer Existing Scenario	1% AEP Winter Existing Scenario	1% AEP Winter Existing Scenario
Maximum	0.23	0.07	0.19	0.15
99th percentile (~4 cumulative days over 1 year)	0.09	0.04	0.17	0.10
95th percentile (~20 cumulative days over 1 year)	0.07	0.04	0.15	0.08
80th percentile (~70 cumulative days over 1 year)	0.04	0.02	0.06	0.03

[17] Appendix L also shows the simulated water levels for the scenario and monthly Water Corporation measurements for comparison (not verification).

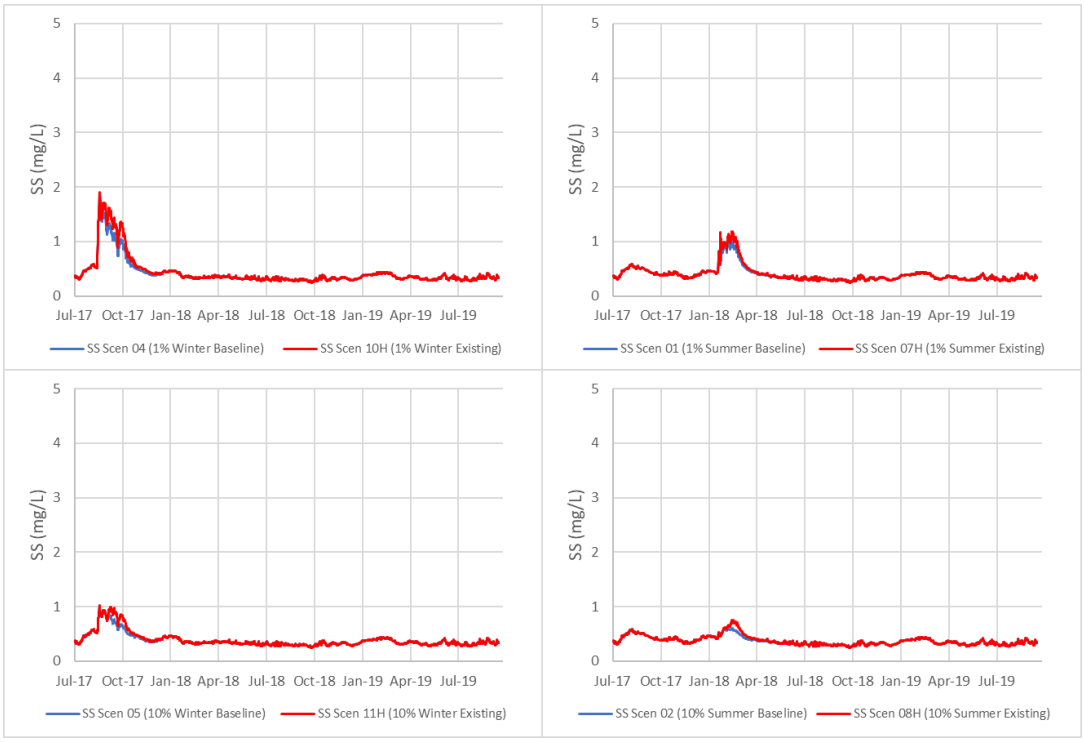


Figure 70 ***Time series of simulated Serpentine Pipehead Dam (SPD) withdrawal inorganic suspended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period [AEP] inflow events with high drainage failure SS levels.***

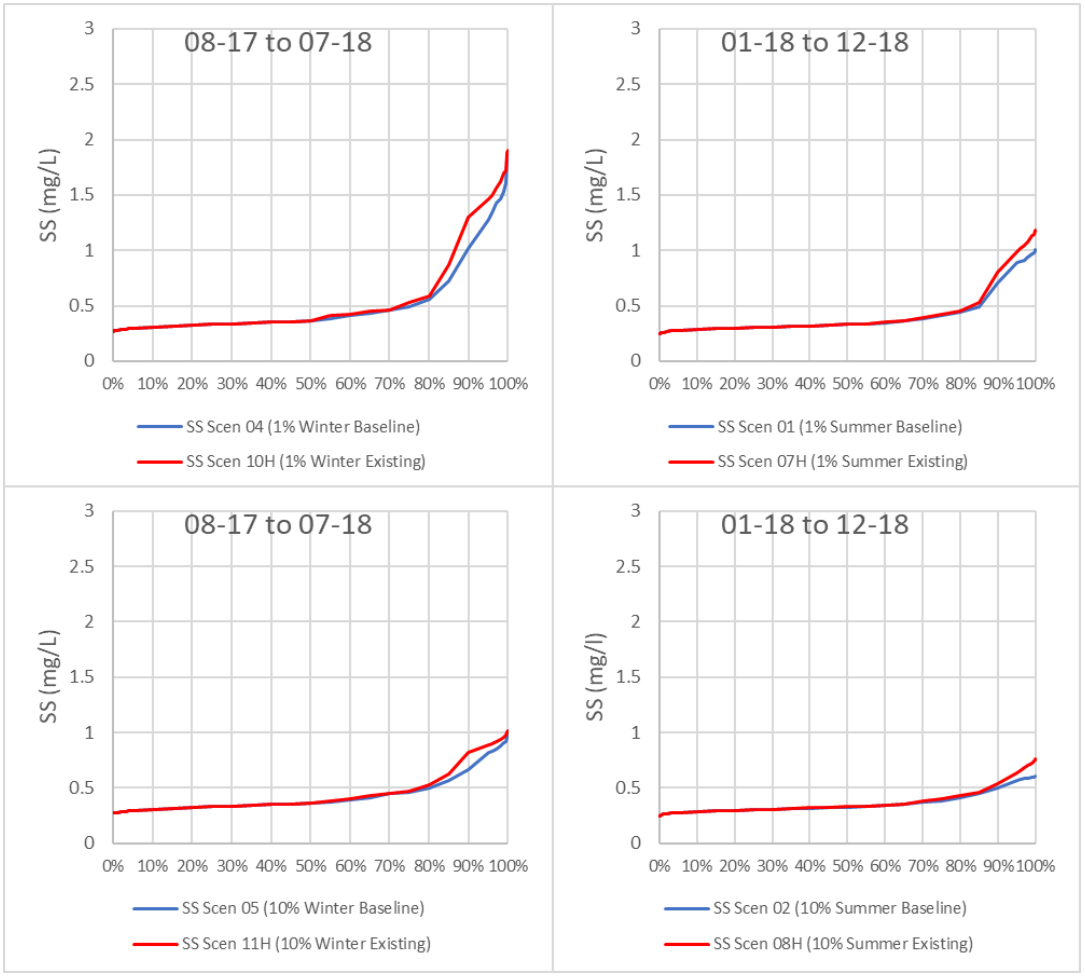


Figure 71 ***Percentile plots of simulated inorganic supended solids (SS [silt + clay]) of winter and summer 1% and 10% Annual Exceedance Period (AEP) inflow events with high drainage failure SS levels.***

6. References

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Appendices

Appendix A

SMD: 1% and 10% AEP Flood Event Inputs (Moderate Drainage Failure SS Levels)

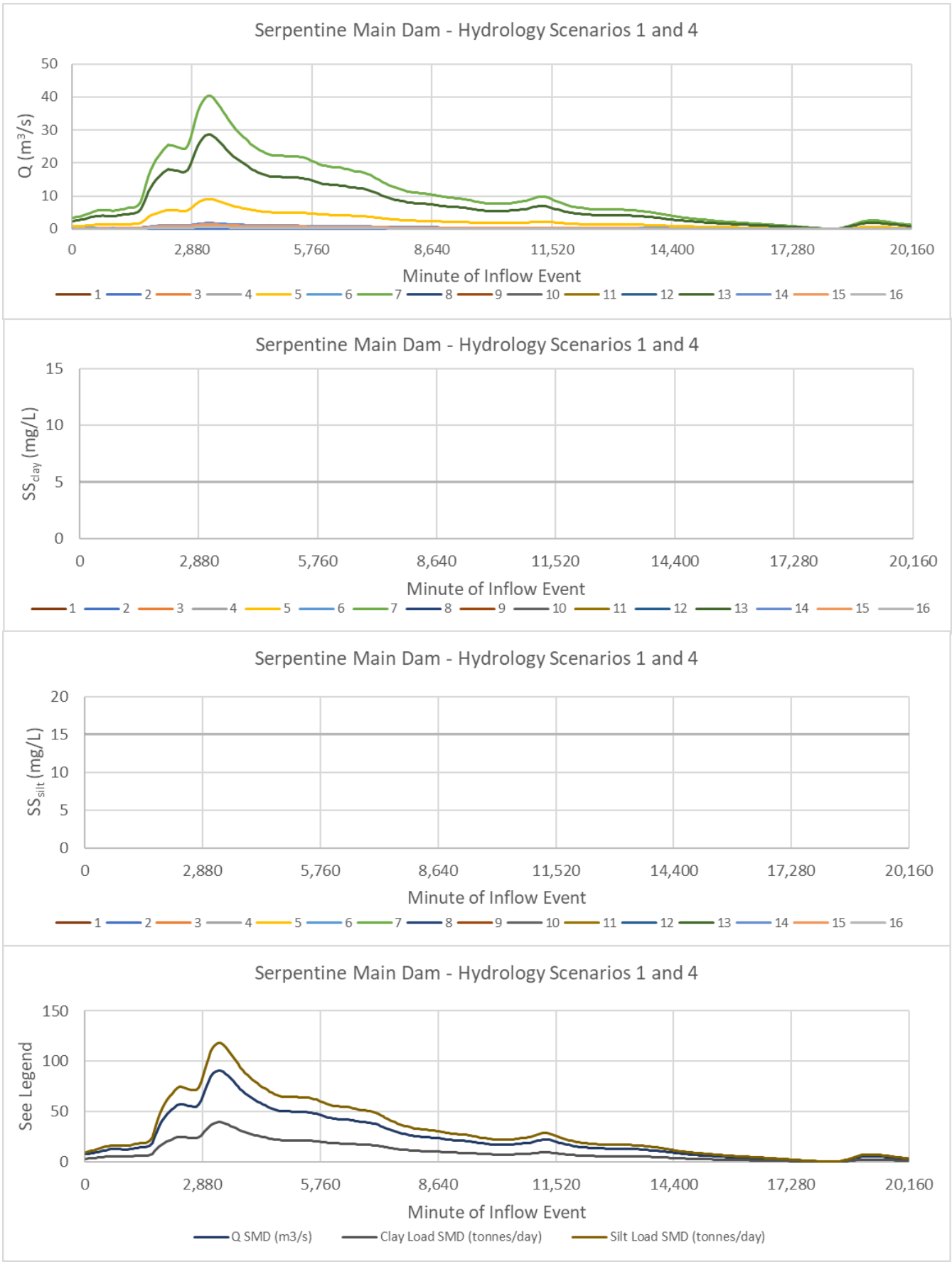


Figure 72 ***SMD hydrology and SS inputs for scenarios 1 and 4.***

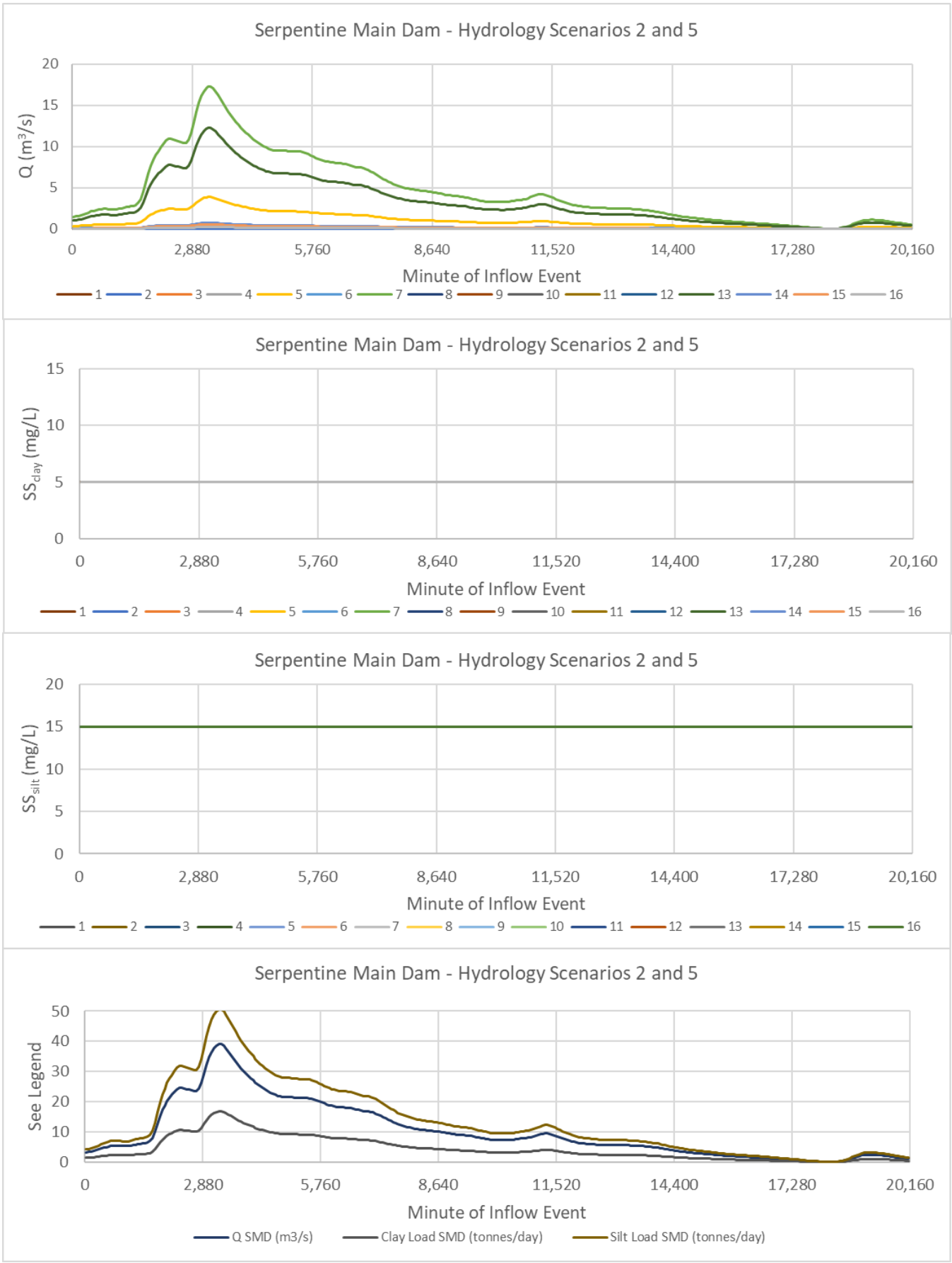


Figure 73 ***As Figure 72 for scenarios 2 and 5.***

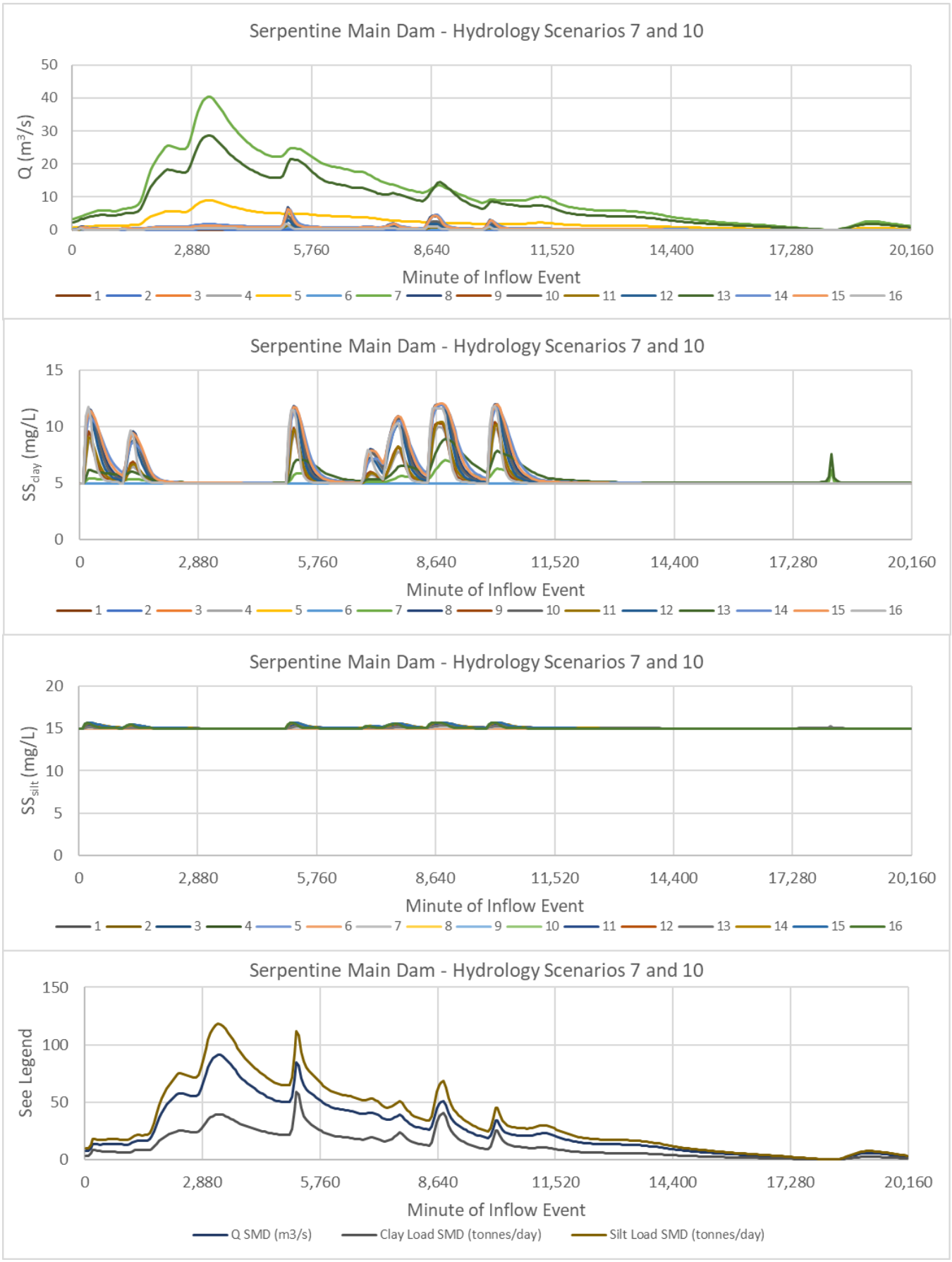


Figure 74 *As Figure 72 scenarios 7 and 10 with moderate drainage failure SS levels.*

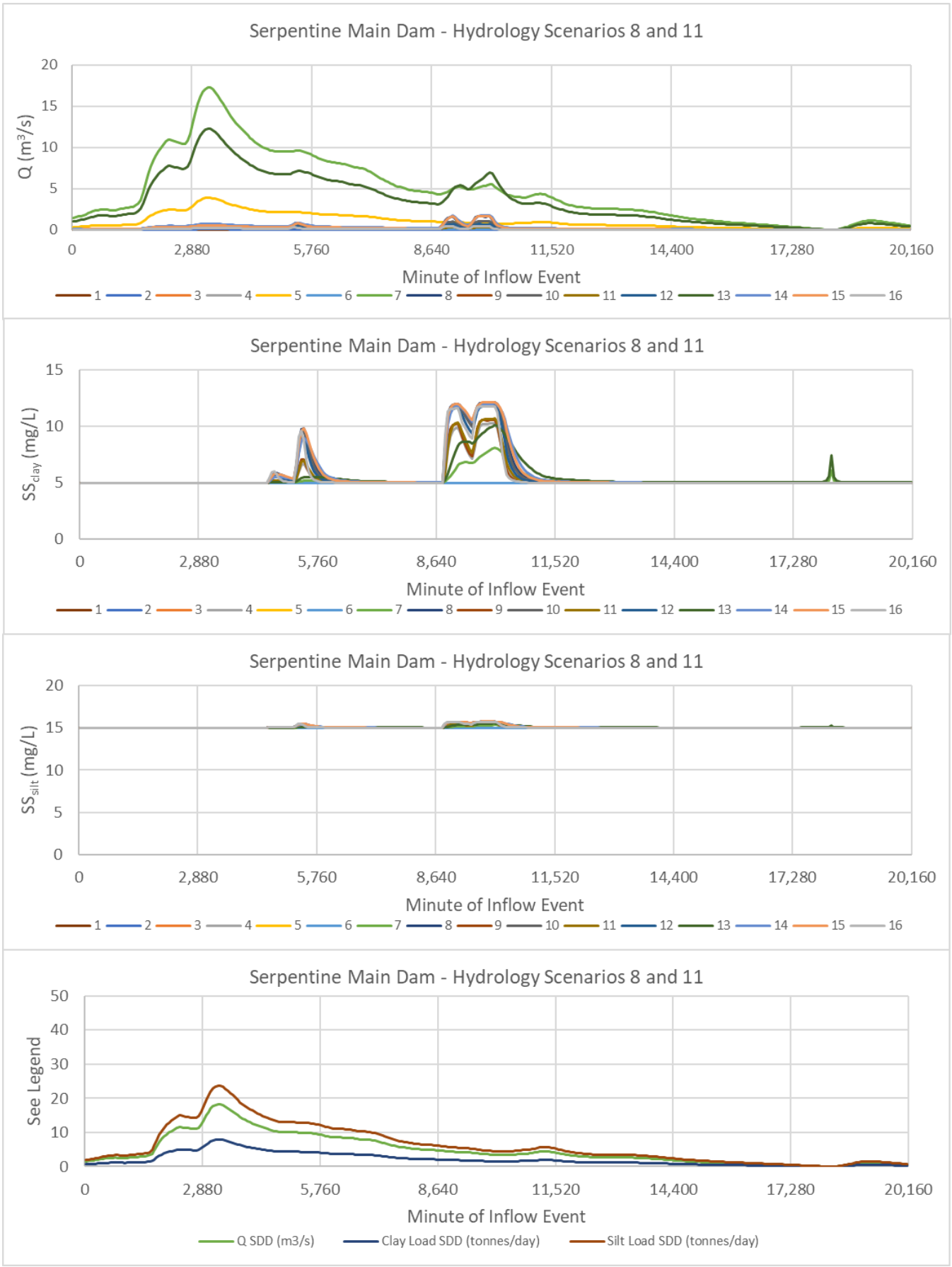


Figure 75 ***As Figure 72 for scenarios 8 and 11 with moderate drainage failure SS levels.***

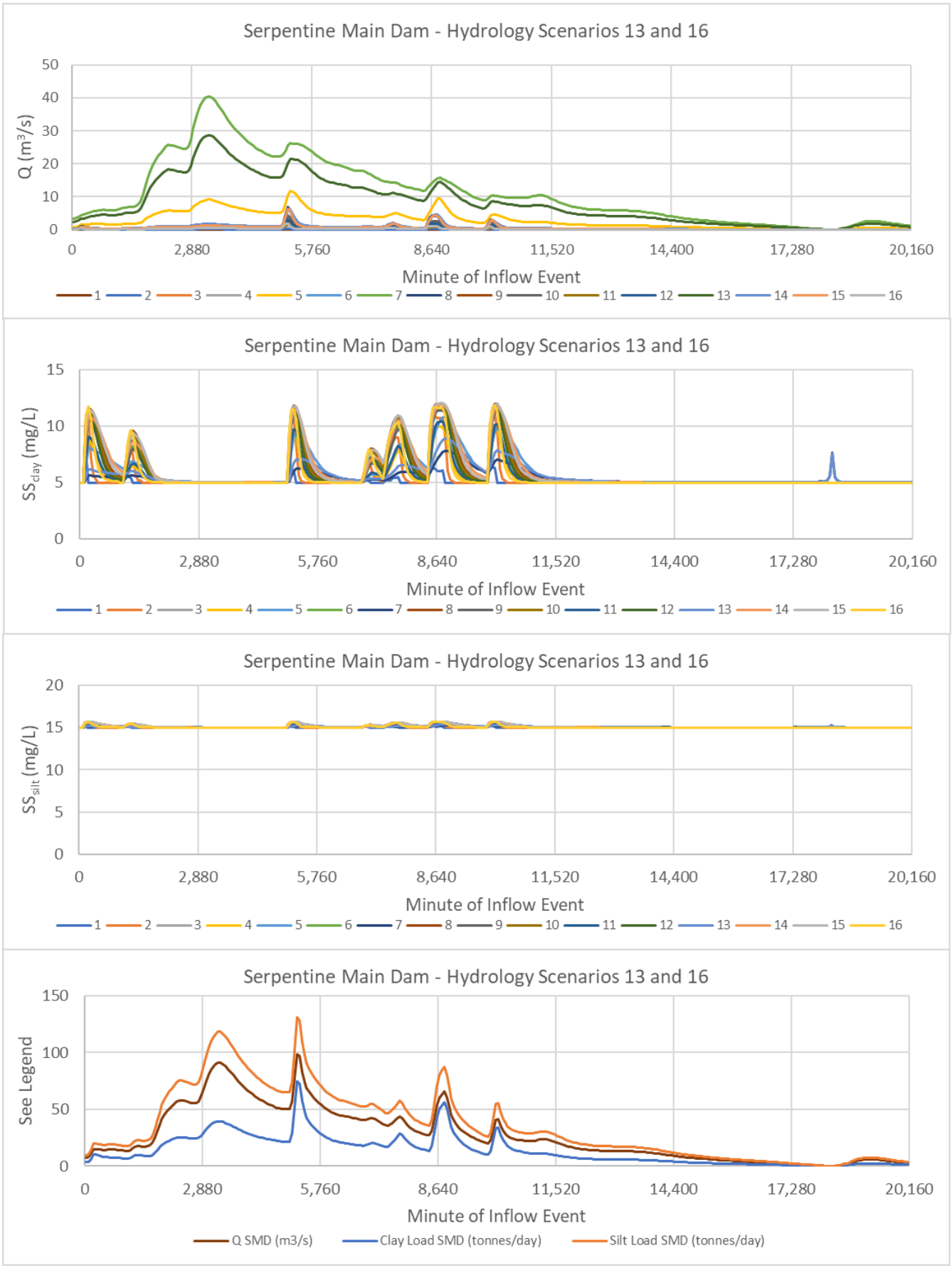


Figure 76 ***As Figure 72 for scenarios 13 and 16 with moderate drainage failure SS levels.***

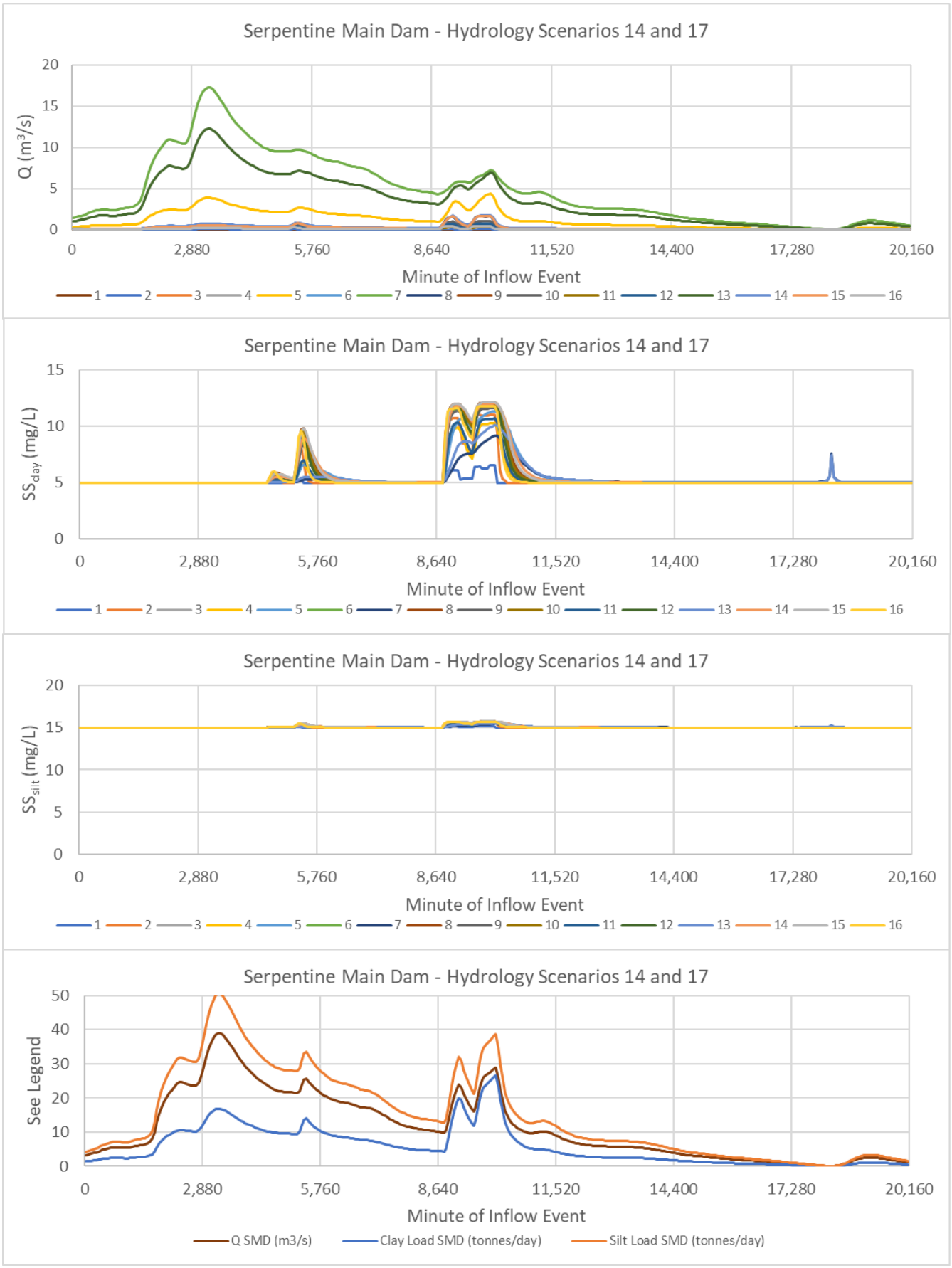


Figure 77 ***As Figure 72 for scenarios 14 and 17 with moderate drainage failure SS levels.***

Appendix B

SMD: 1% and 10% AEP Flood Event Simulations (Moderate Drainage Failure SS Levels)

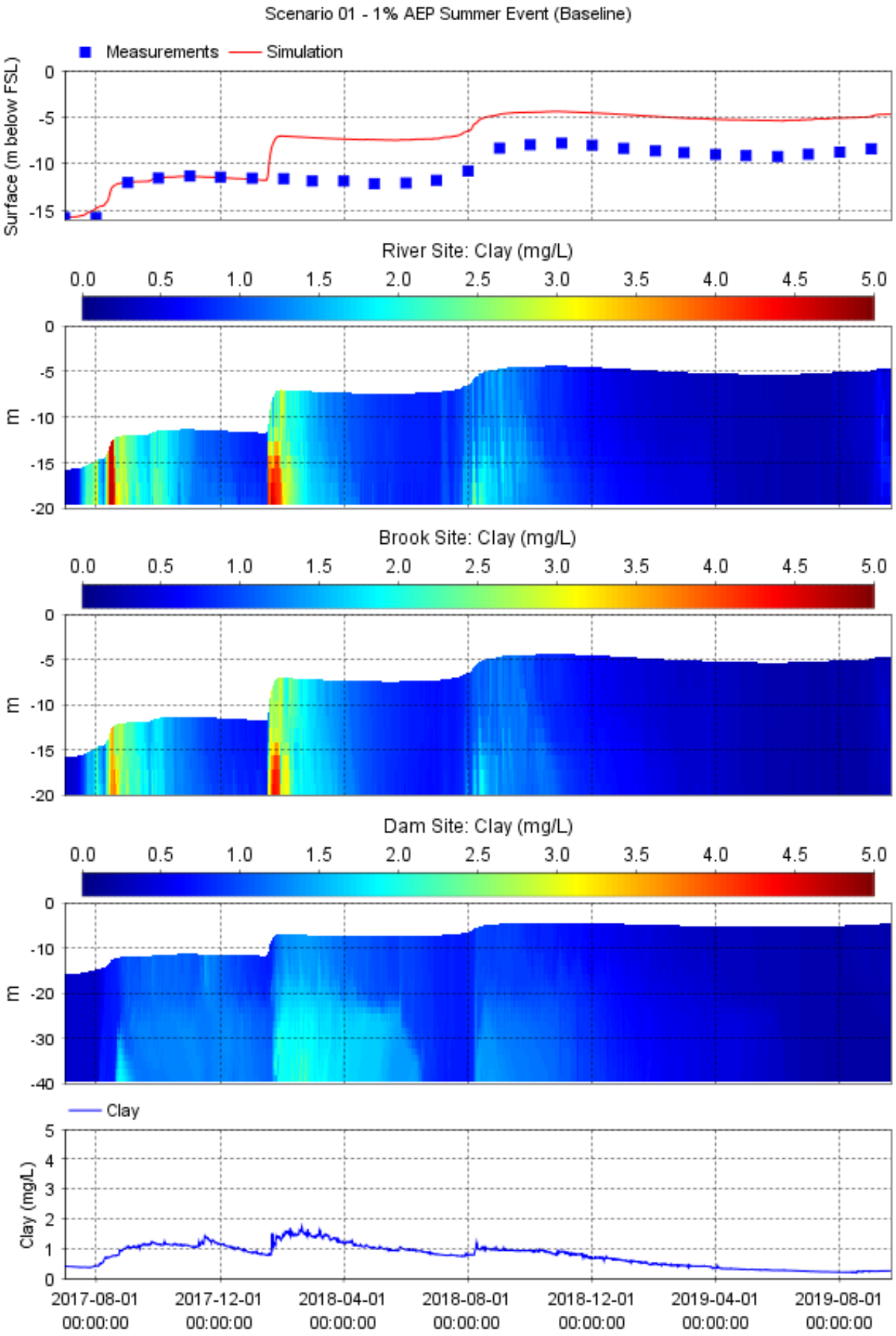


Figure 78 ***SMD simulated levels of clay for scenario 1 (summer baseline case 1% AEP flood event).***

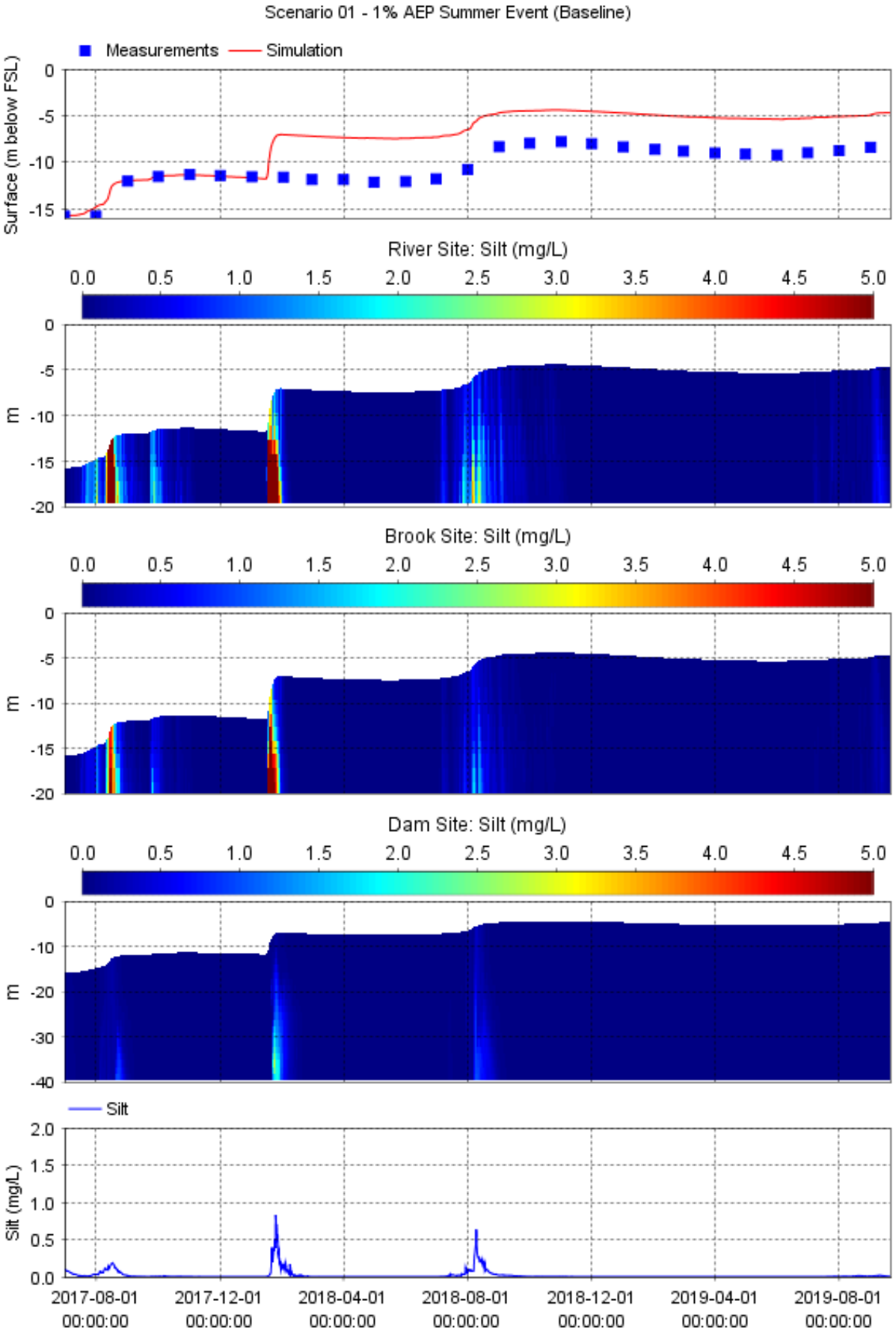


Figure 79 ***SMD simulated levels of silt for scenario 1 (summer baseline case 1% AEP flood event).***

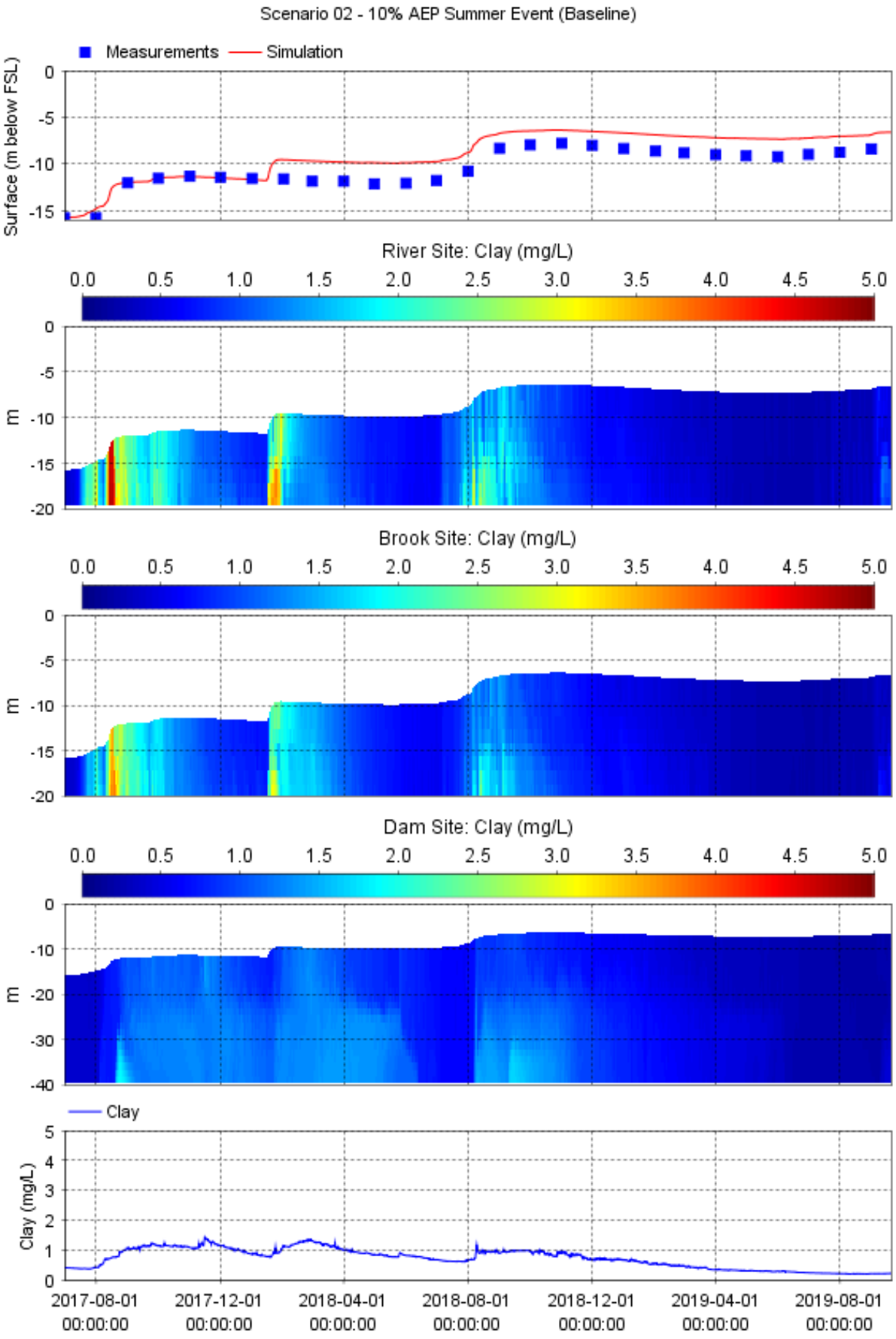


Figure 80 ***SMD simulated levels of clay for scenario 2 (summer baseline case 10% AEP flood event).***

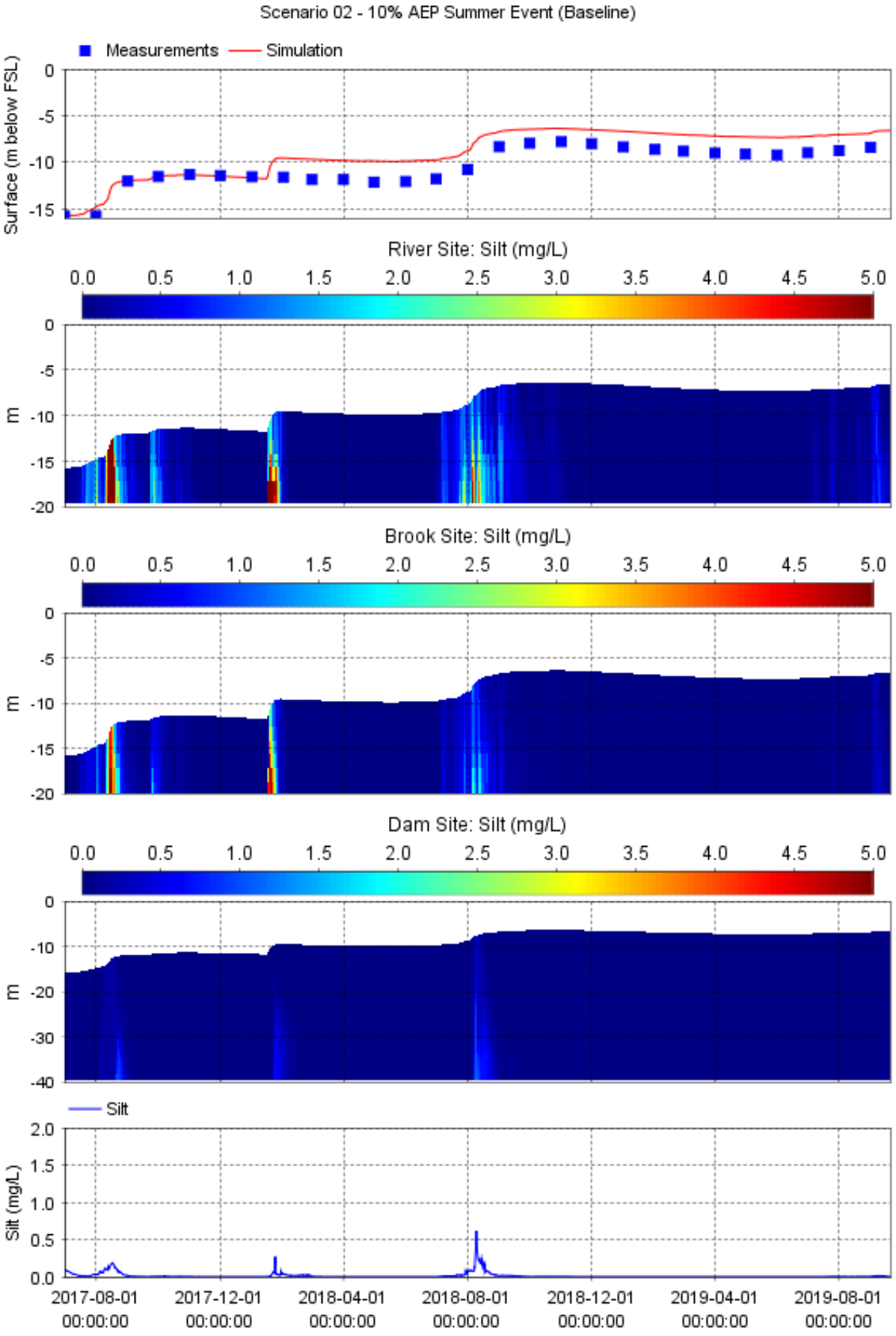


Figure 81 ***SMD simulated levels of silt for scenario 2 (summer baseline case 10% AEP flood event).***

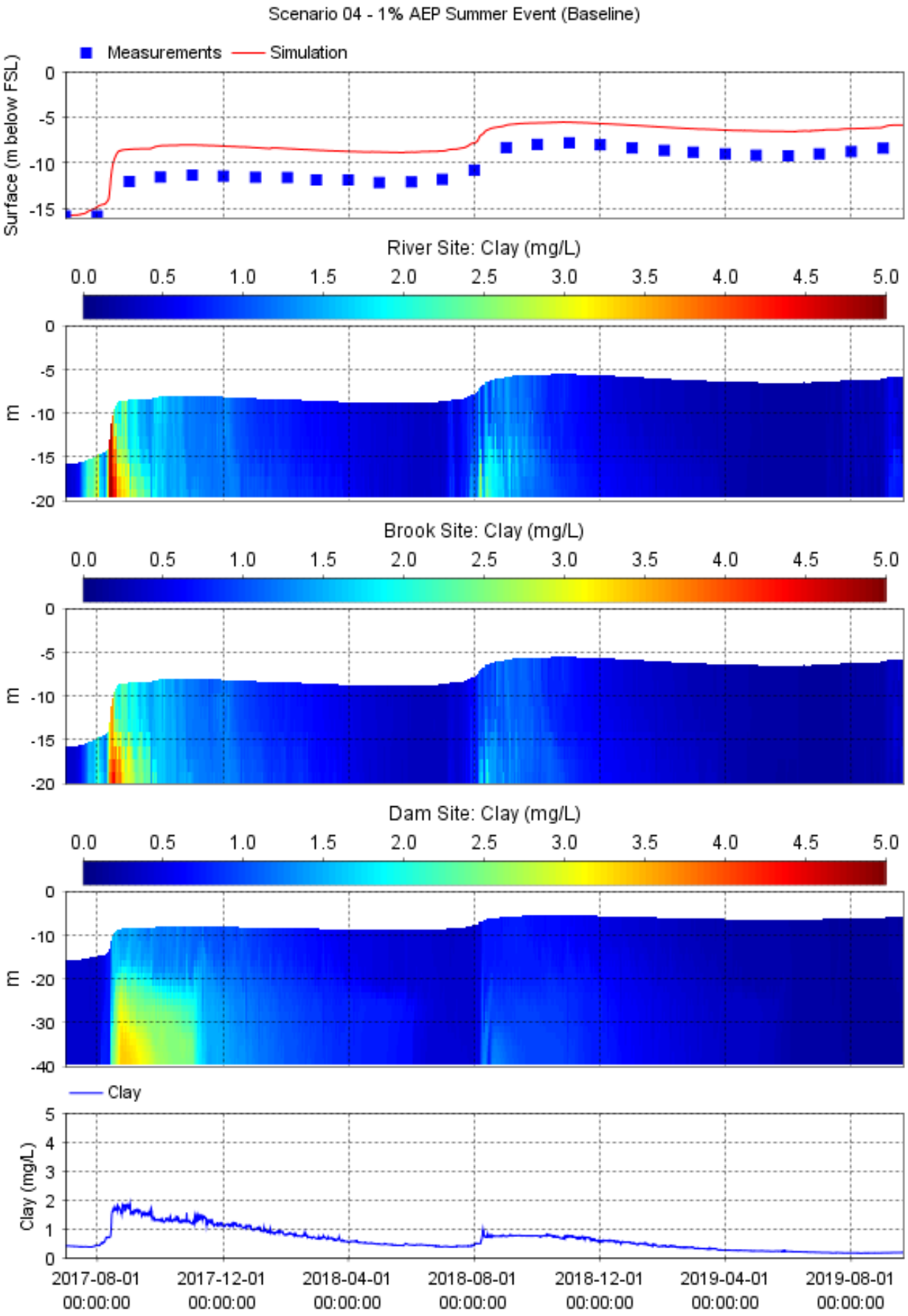


Figure 82 ***SMD simulated levels of clay for scenario 4 (winter baseline case 1% AEP flood event).***

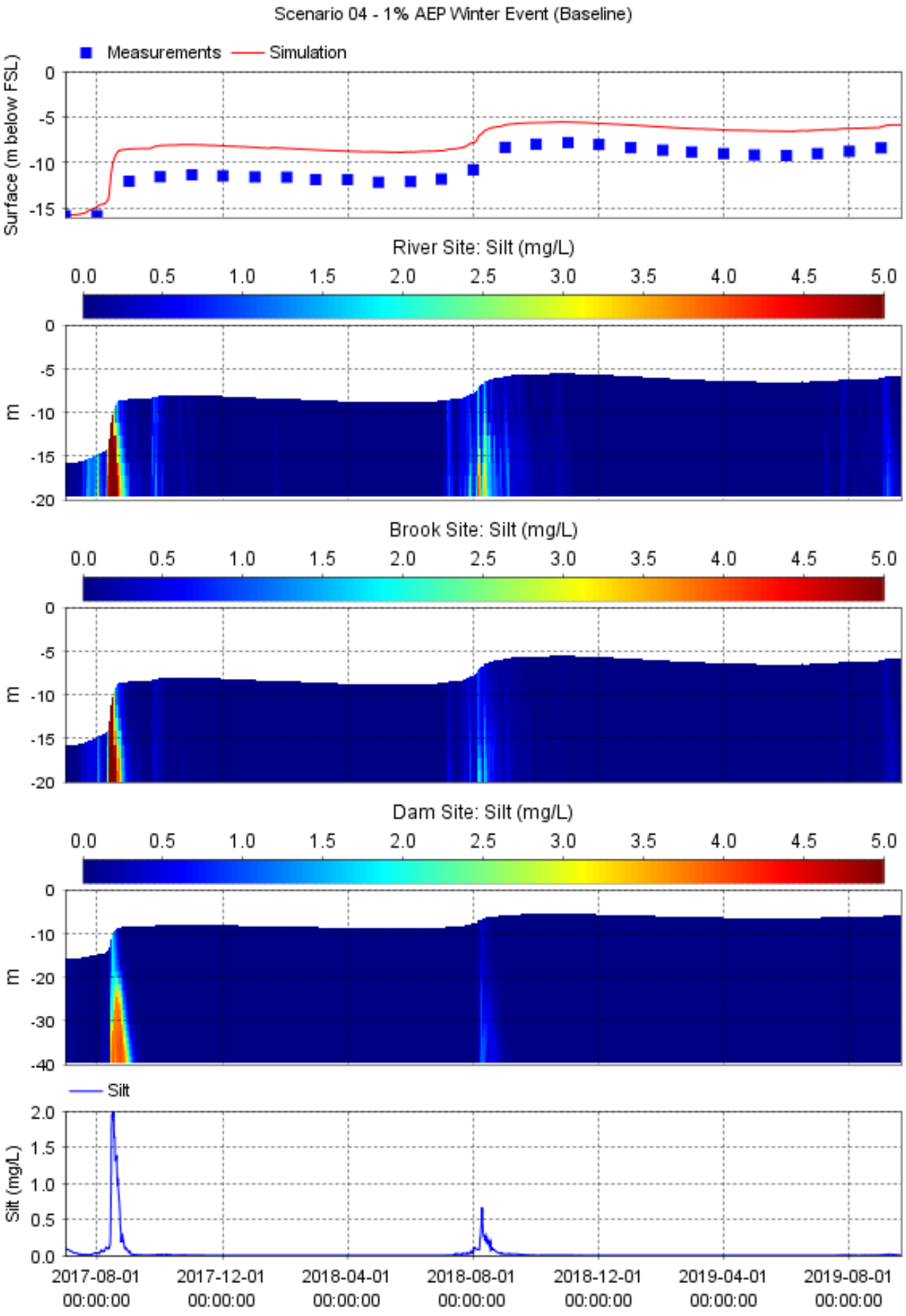


Figure 83 ***SMD simulated levels of silt for scenario 4 (winter baseline case 1% AEP flood event).***

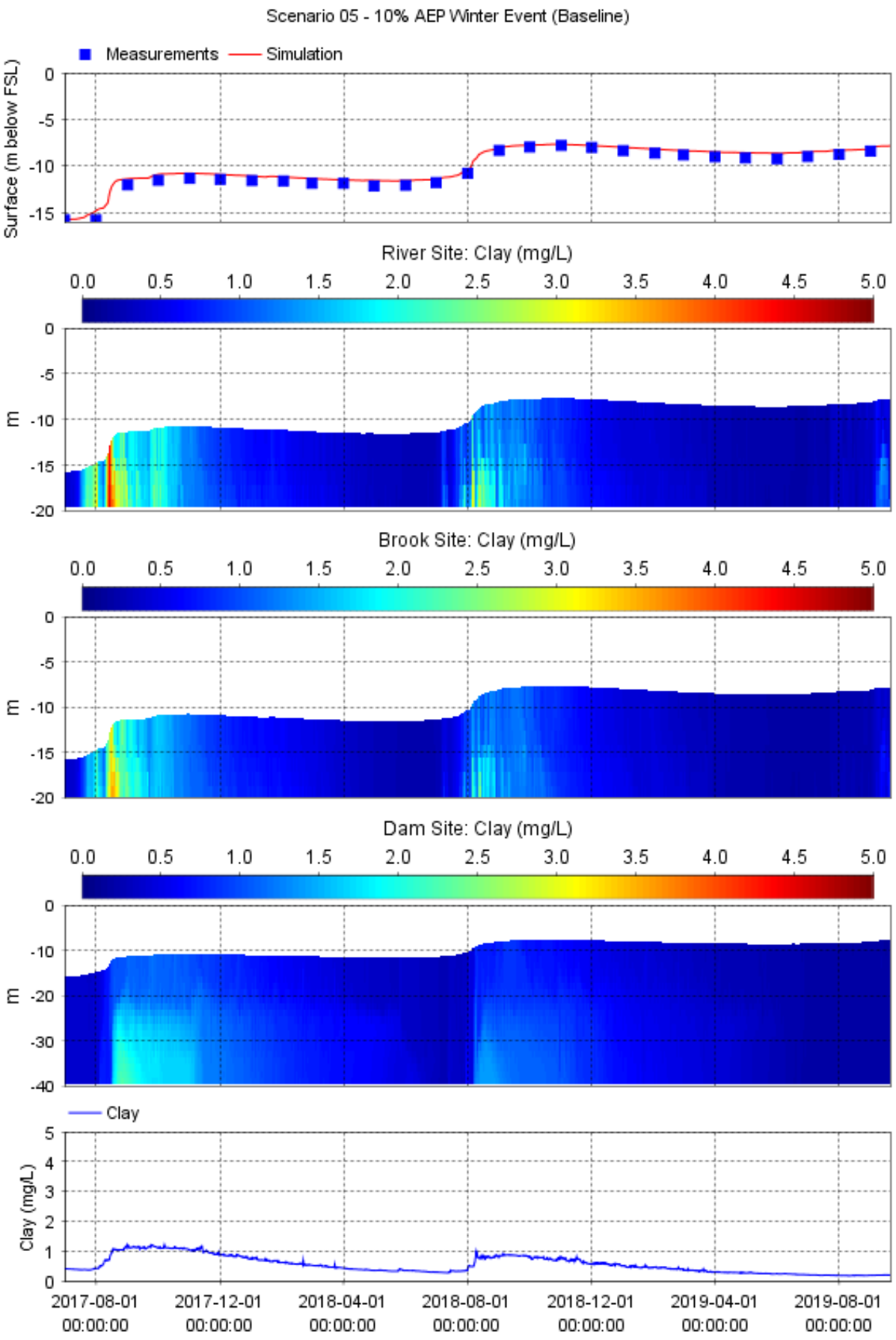


Figure 84 ***SMD simulated levels of clay for scenario 5 (winter baseline case 10% AEP flood event).***

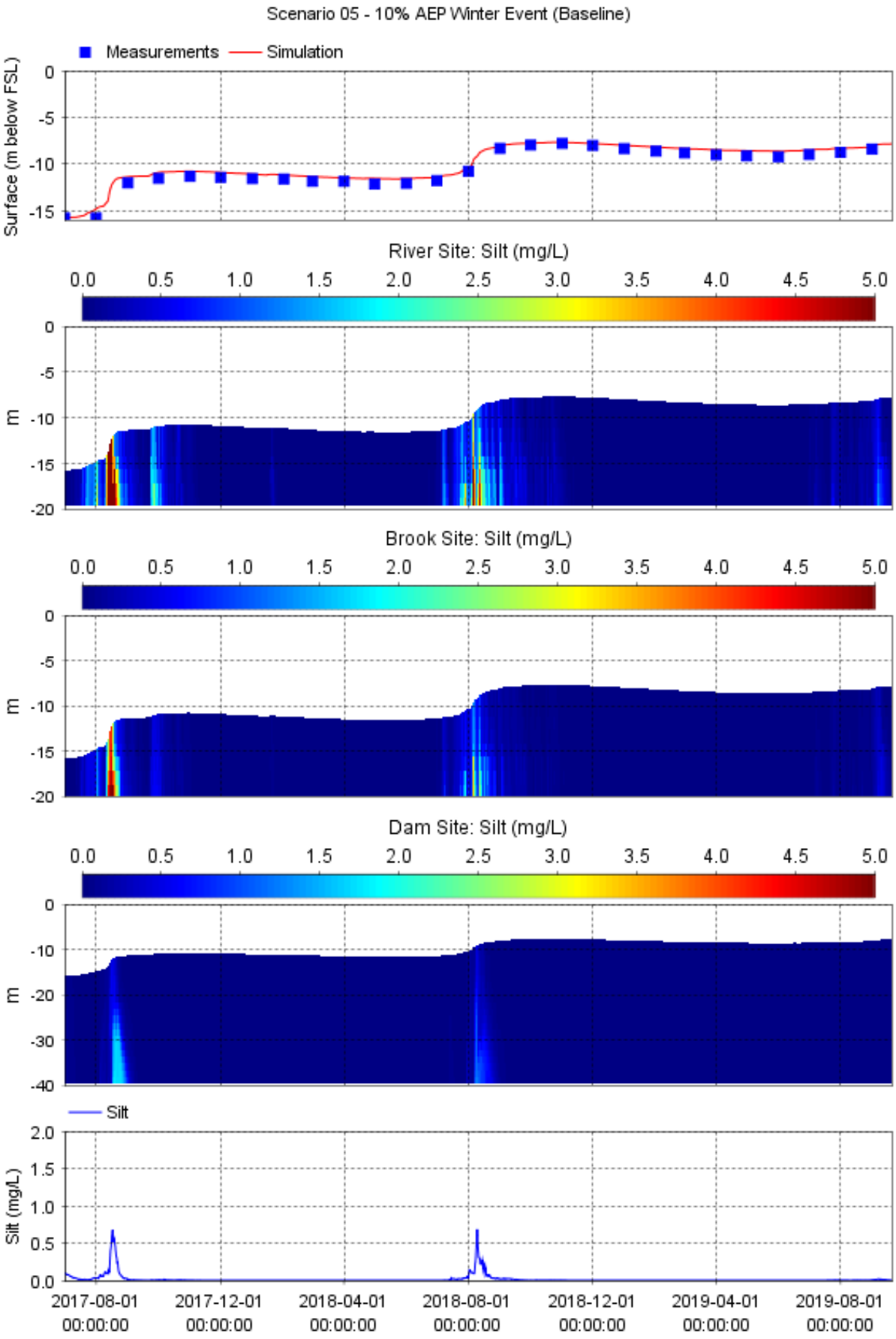


Figure 85 *SMD simulated levels of silt for scenario 5 (winter baseline case 10% AEP flood event).*

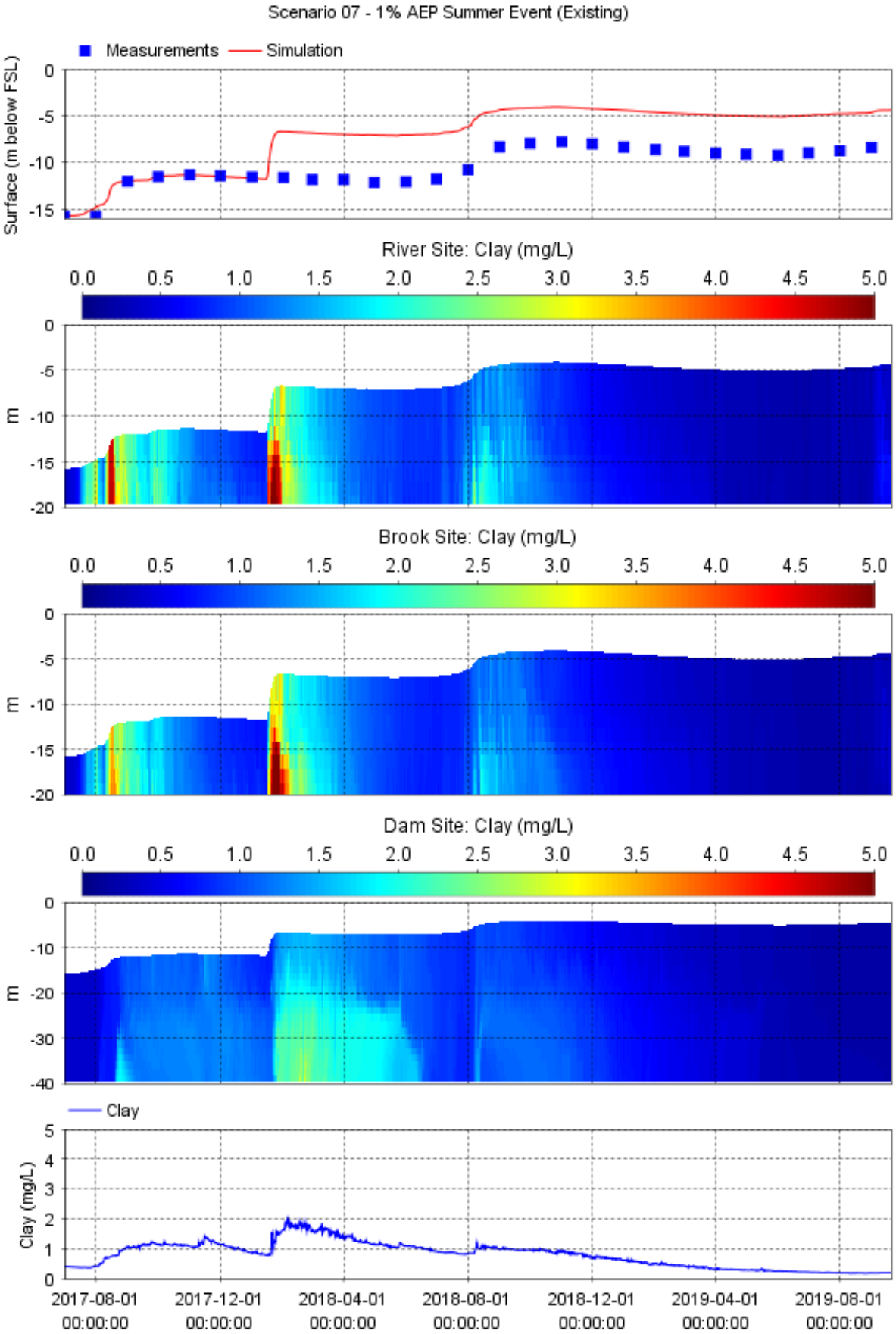


Figure 86 ***SMD simulated levels of clay for scenario 7 (summer existing case 1% AEP flood event) with moderate drainage failure SS levels.***

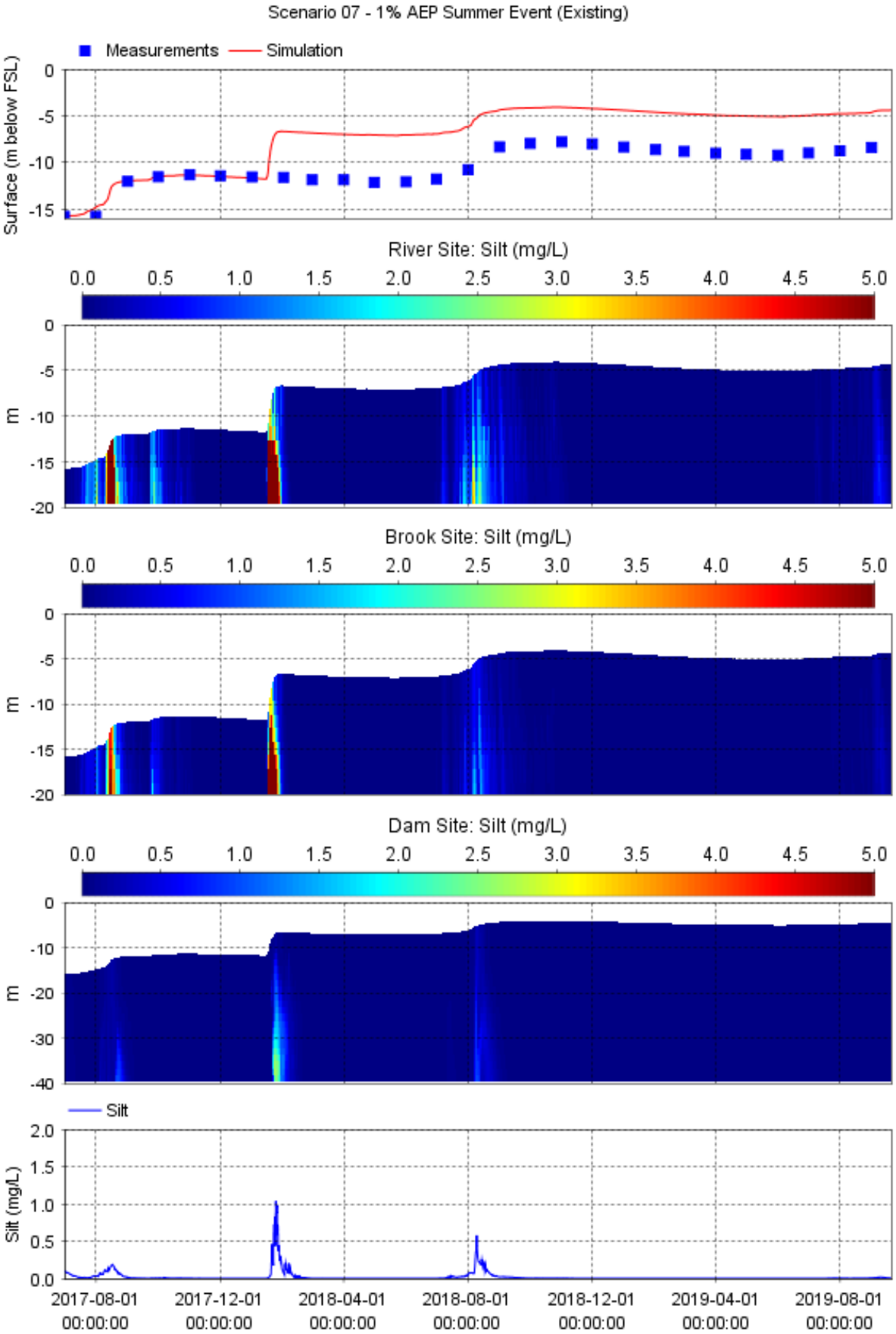


Figure 87 ***SMD simulated levels of silt for scenario 7 (summer existing case 1% AEP flood event) with moderate drainage failure SS levels.***

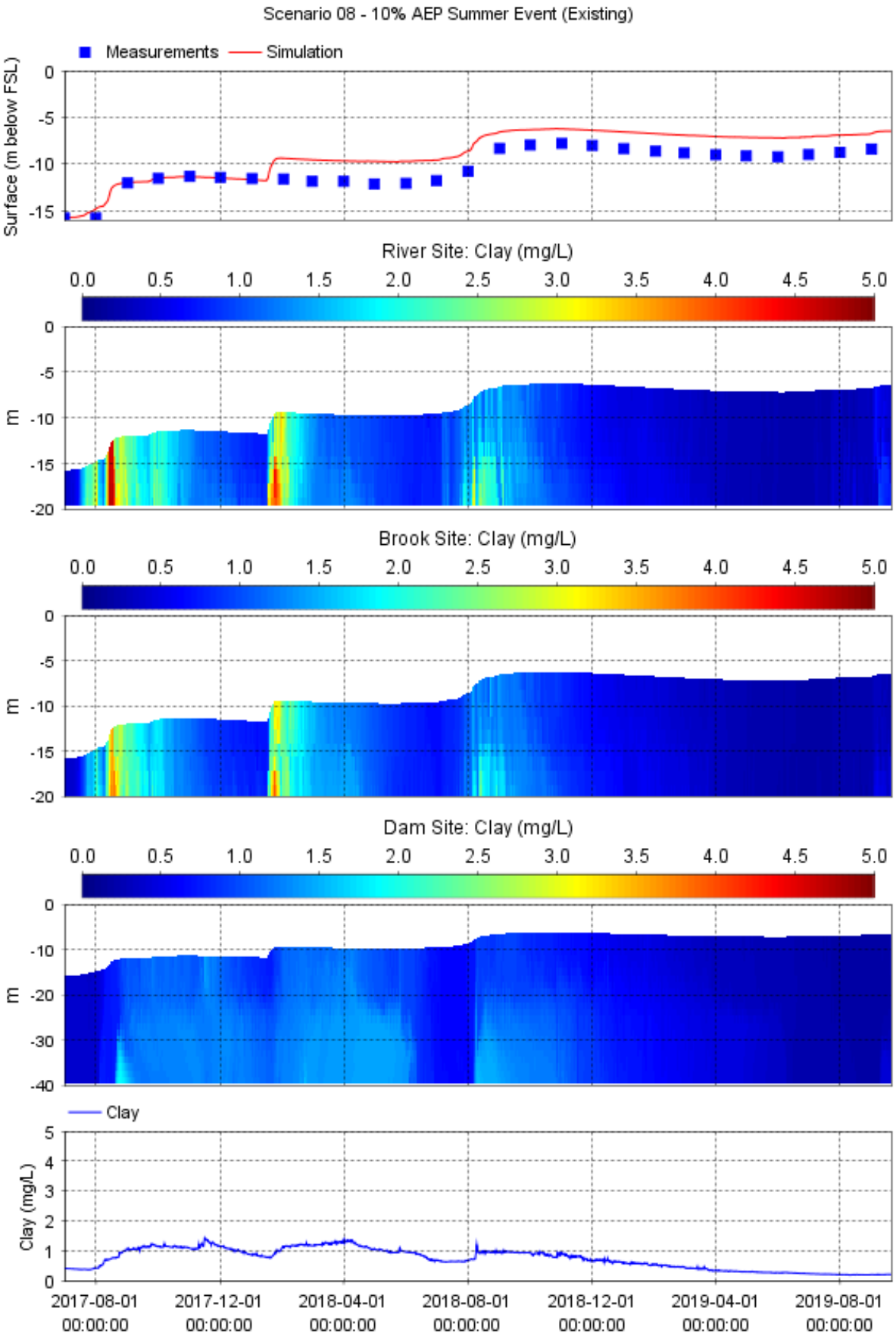


Figure 88 ***SMD simulated levels of clay for scenario 8 (winter existing case 10% AEP flood event) with moderate drainage failure SS levels.***

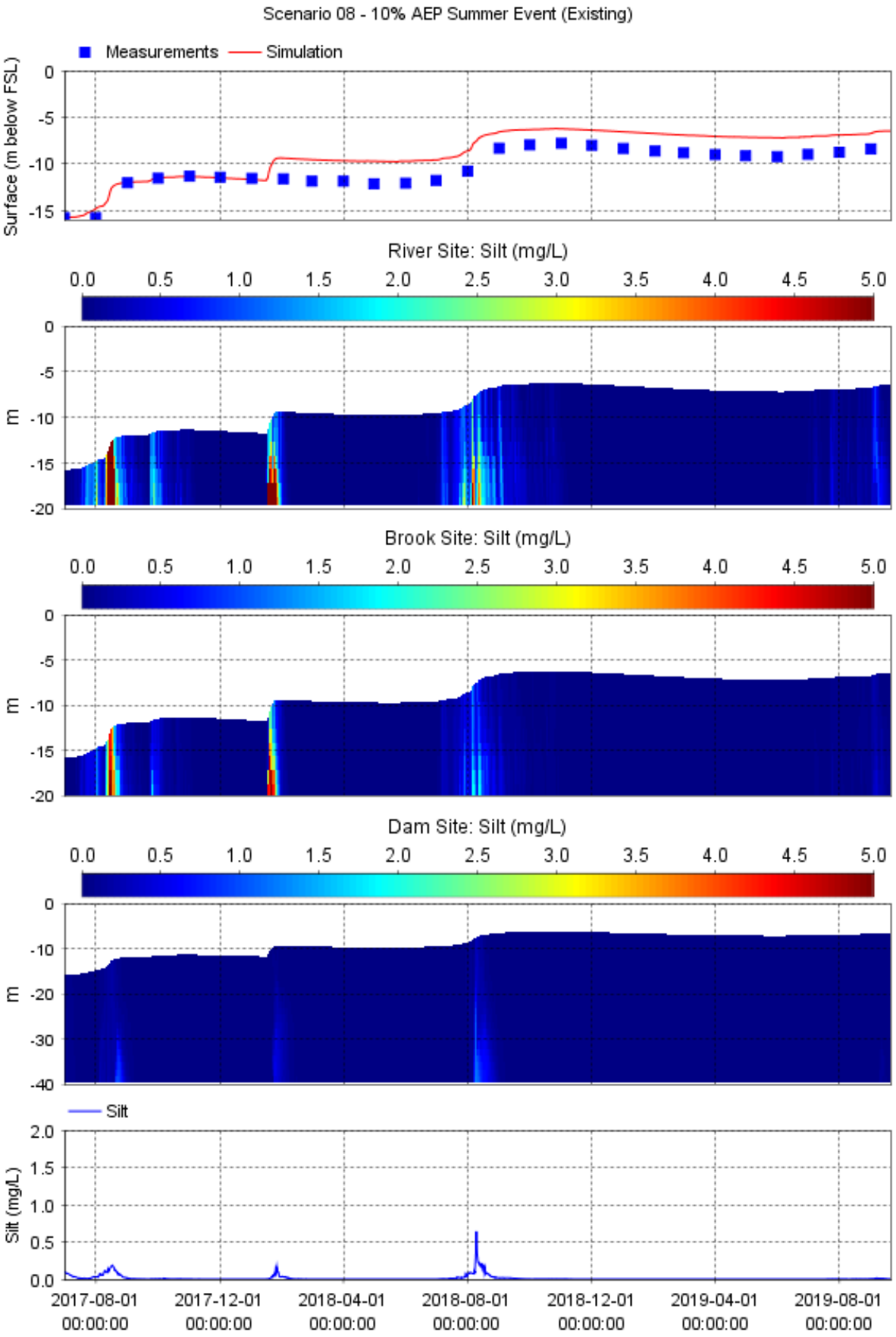


Figure 89 ***SMD simulated levels of silt for scenario 8 (summer existing case 10% AEP flood event) with moderate drainage failure SS levels.***

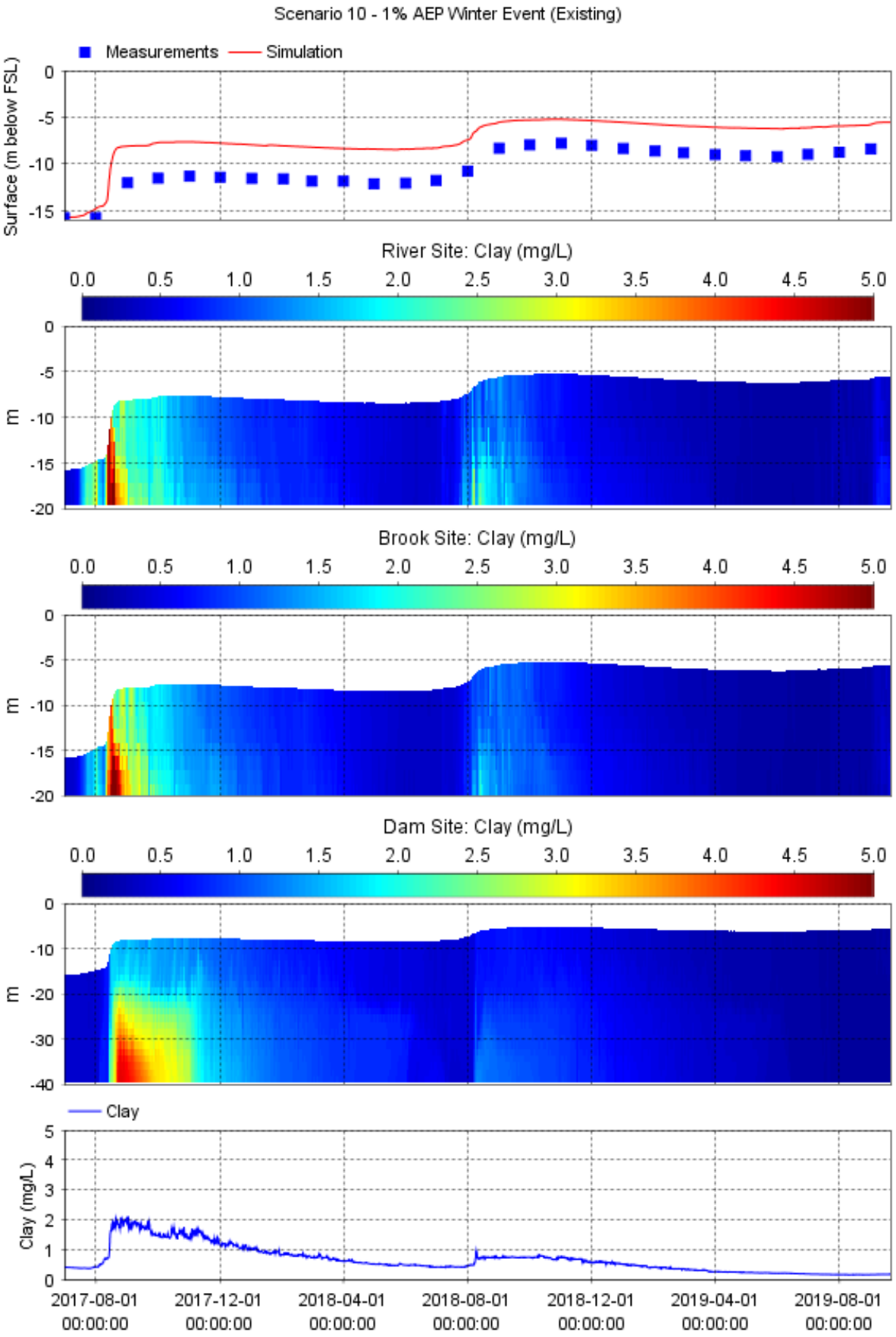


Figure 90 ***SMD simulated levels of clay for scenario 10 (winter existing case 1% AEP flood event) with moderate drainage failure SS levels.***

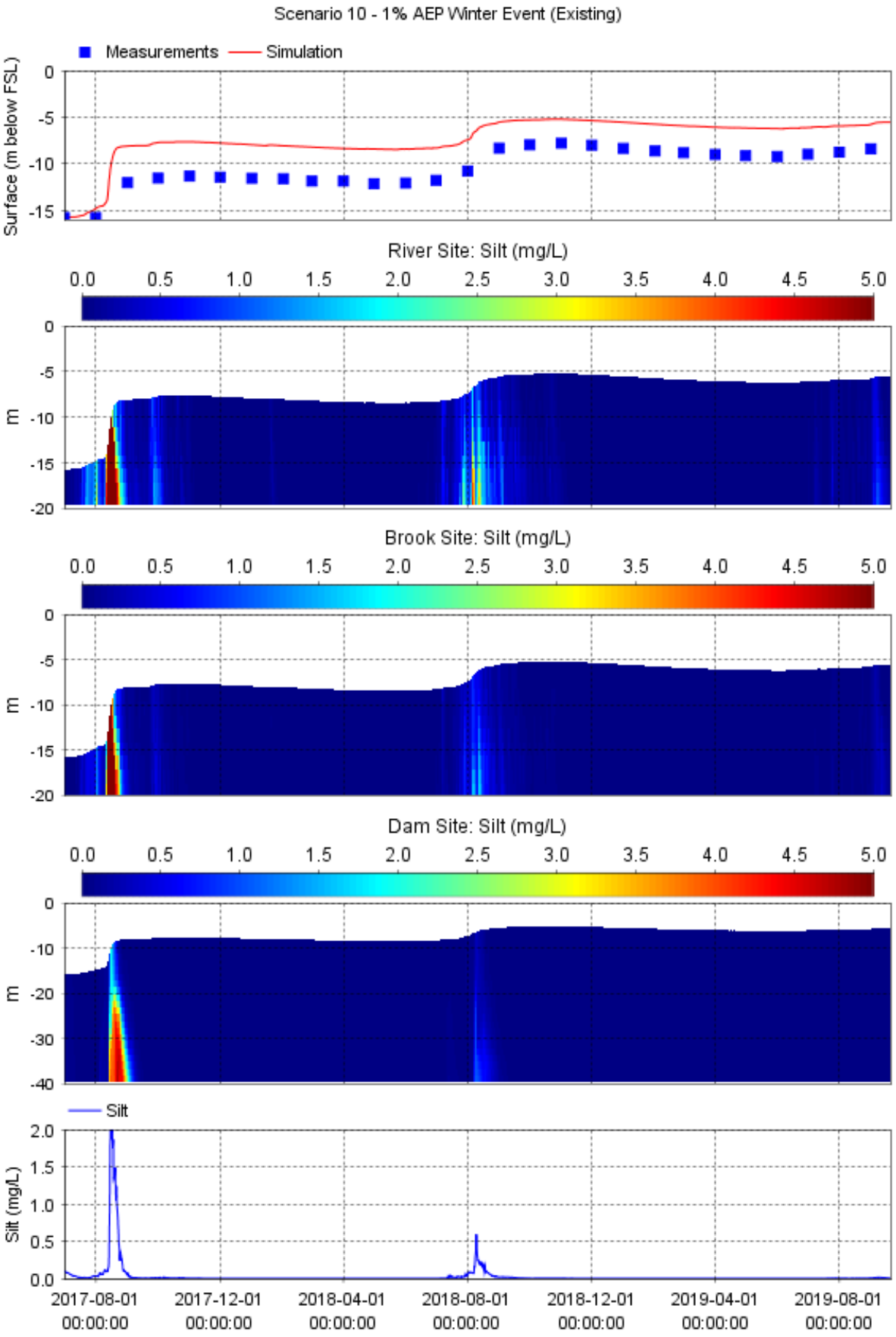


Figure 91 ***SMD simulated levels of silt for scenario 10 (winter existing case 1% AEP flood event) with moderate drainage failure SS levels.***

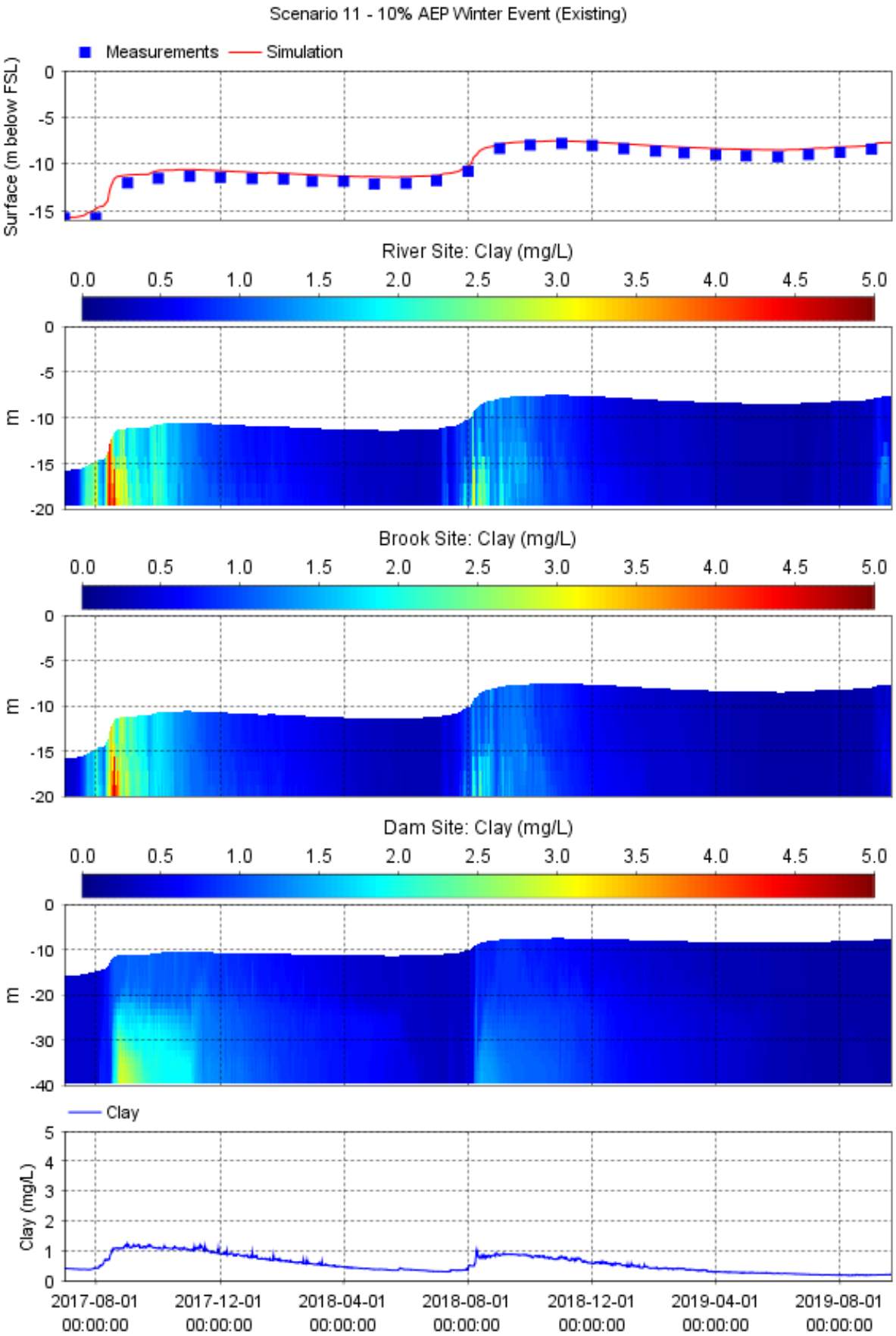


Figure 92 ***SMD simulated levels of clay for scenario 11 (winter existing case 10% AEP flood event) with moderate drainage failure SS levels.***

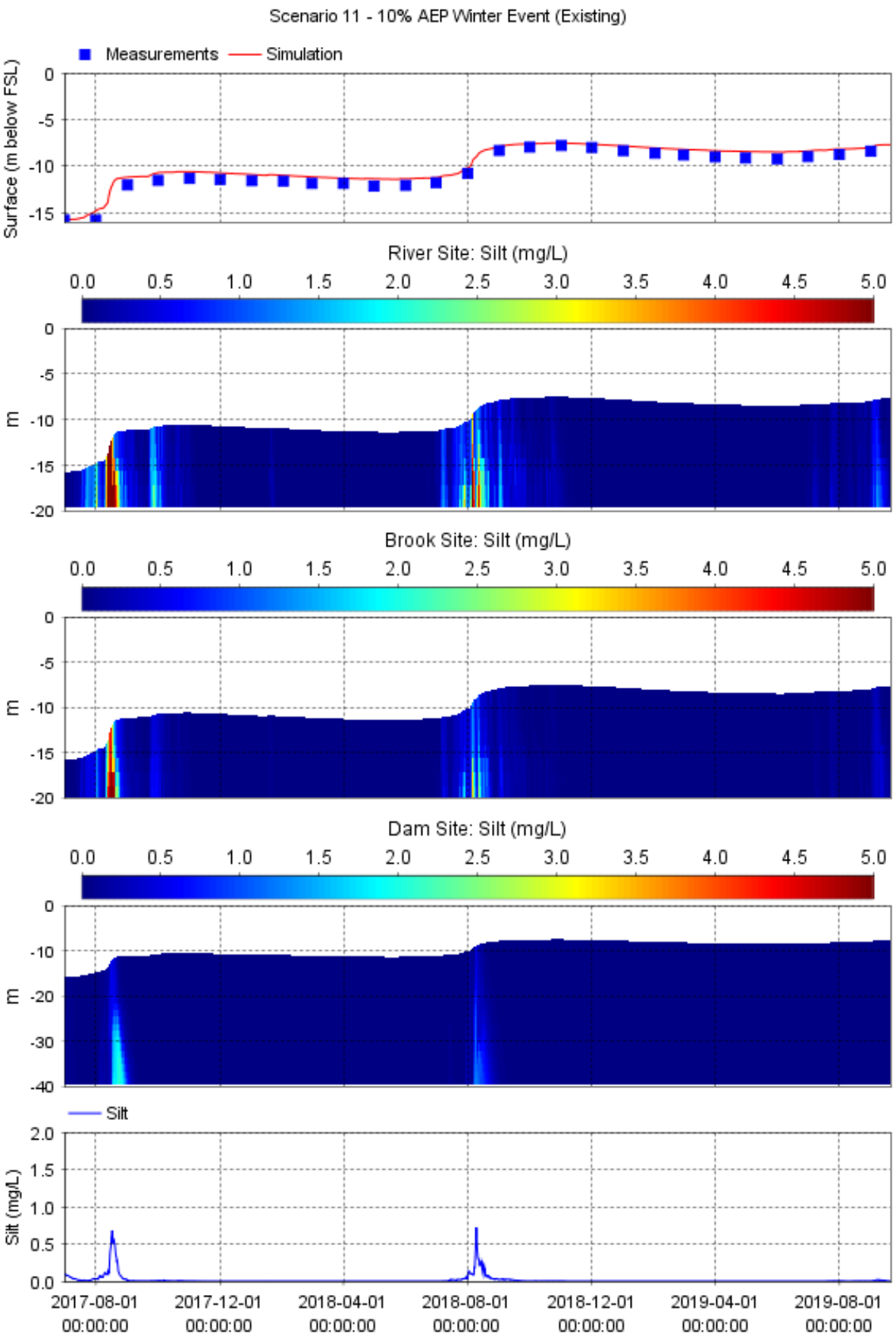


Figure 93 ***SMD simulated levels of silt for scenario 11 (winter existing case 10% AEP flood event) with moderate drainage failure SS levels.***

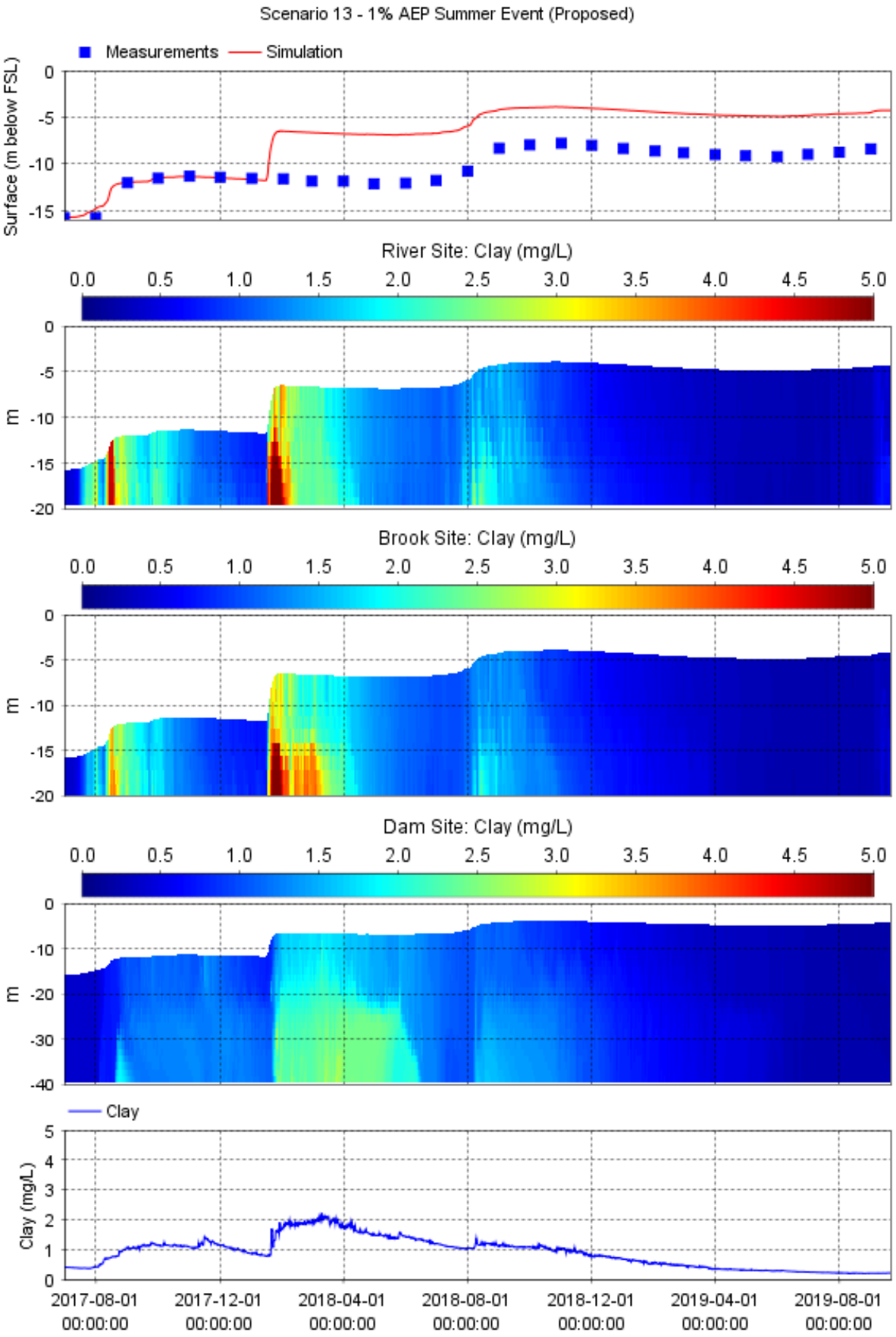


Figure 94 ***SMD simulated levels of clay for scenario 13 (summer proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

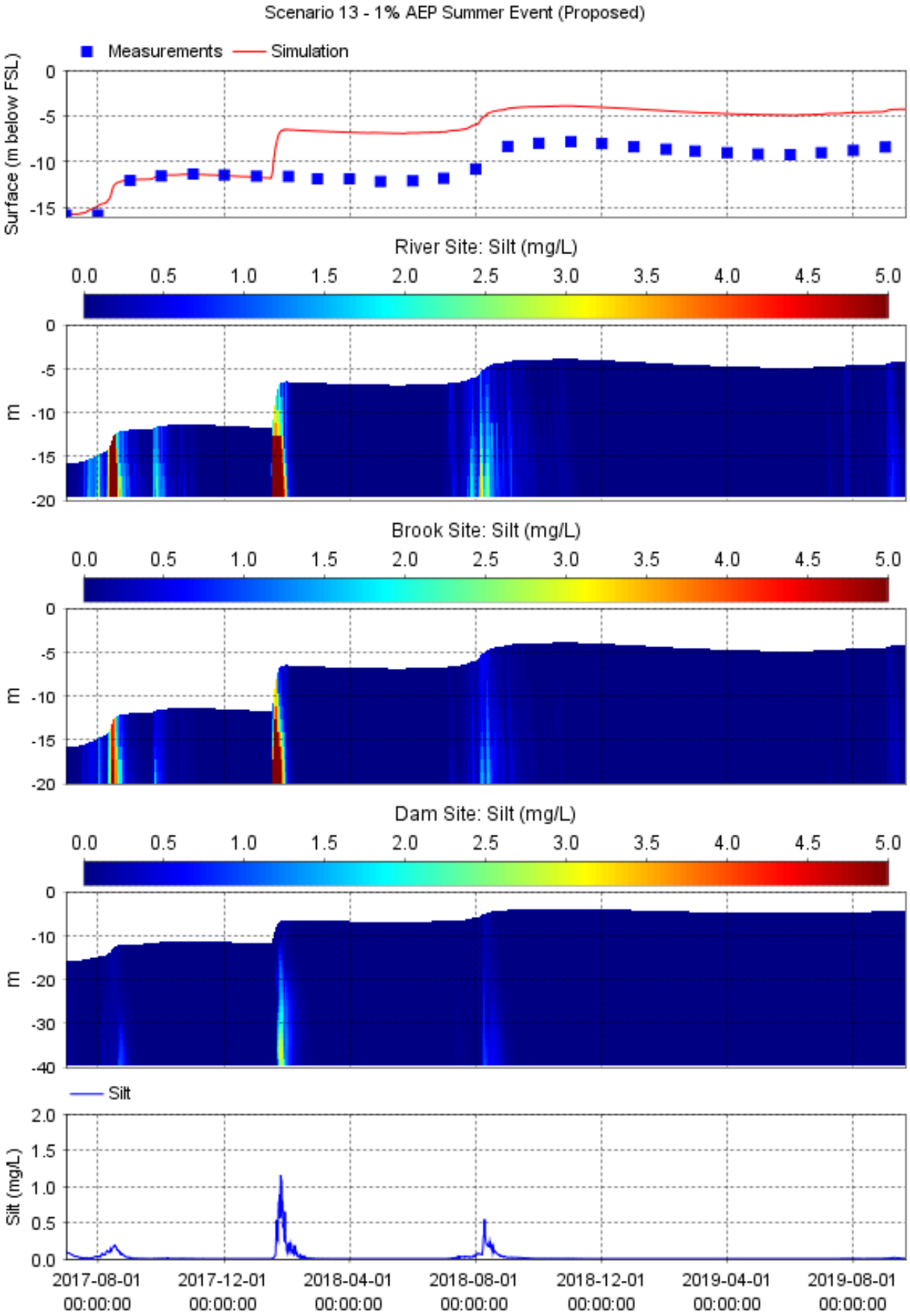


Figure 95 ***SMD simulated levels of silt for scenario 13 (summer proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

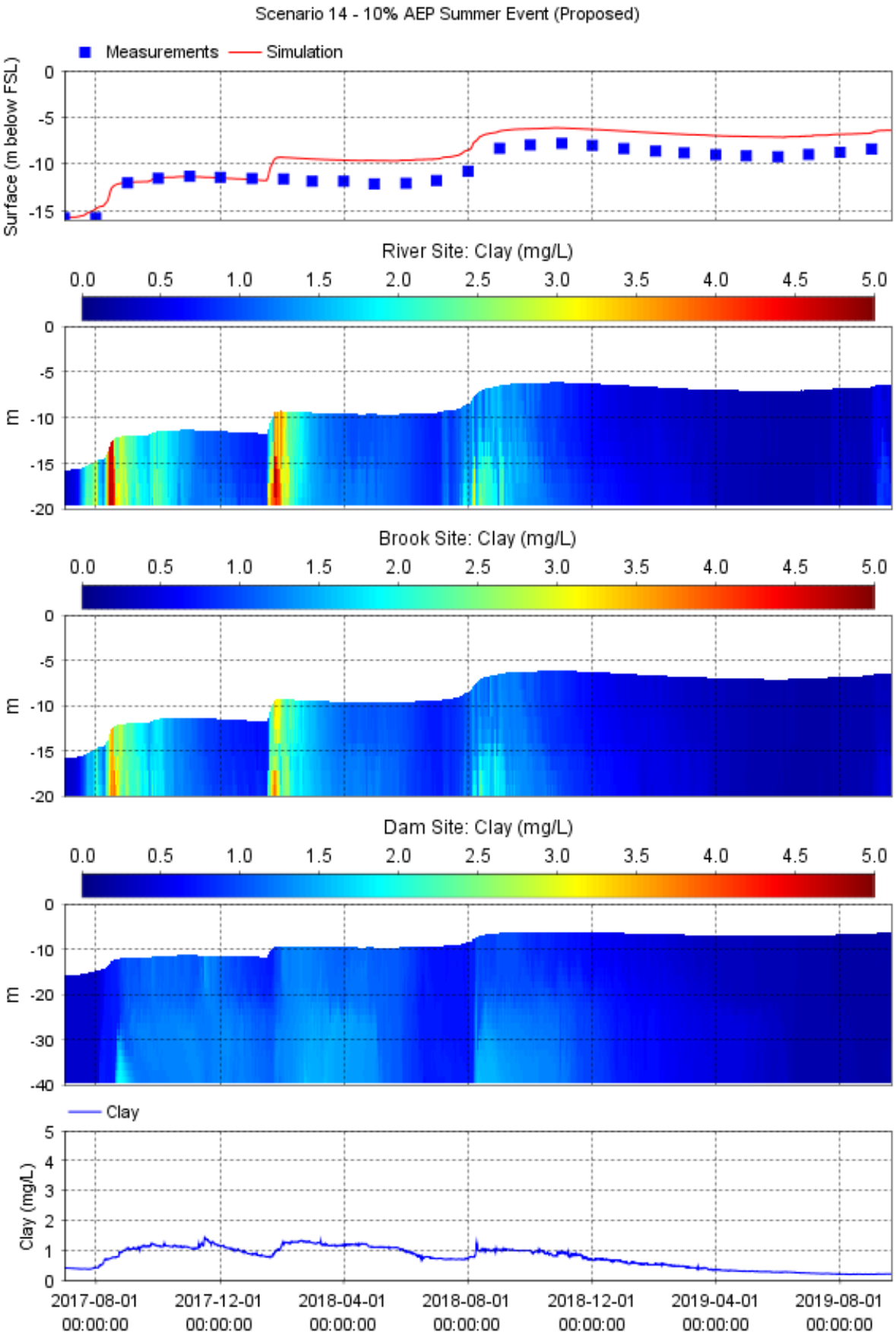


Figure 96 ***SMD simulated levels of clay for scenario 14 (summer proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

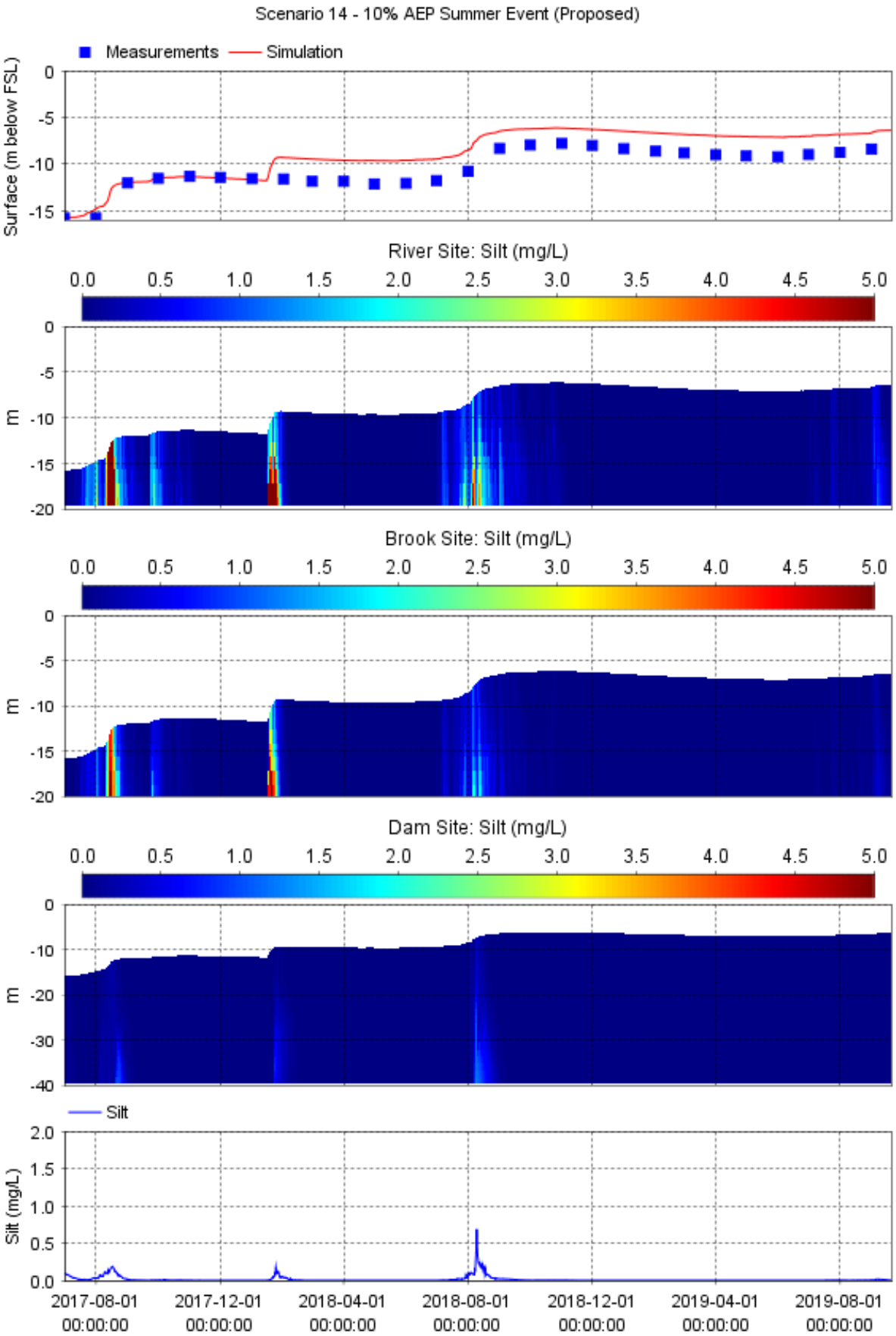


Figure 97 ***SMD simulated levels of silt for scenario 14 (summer proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

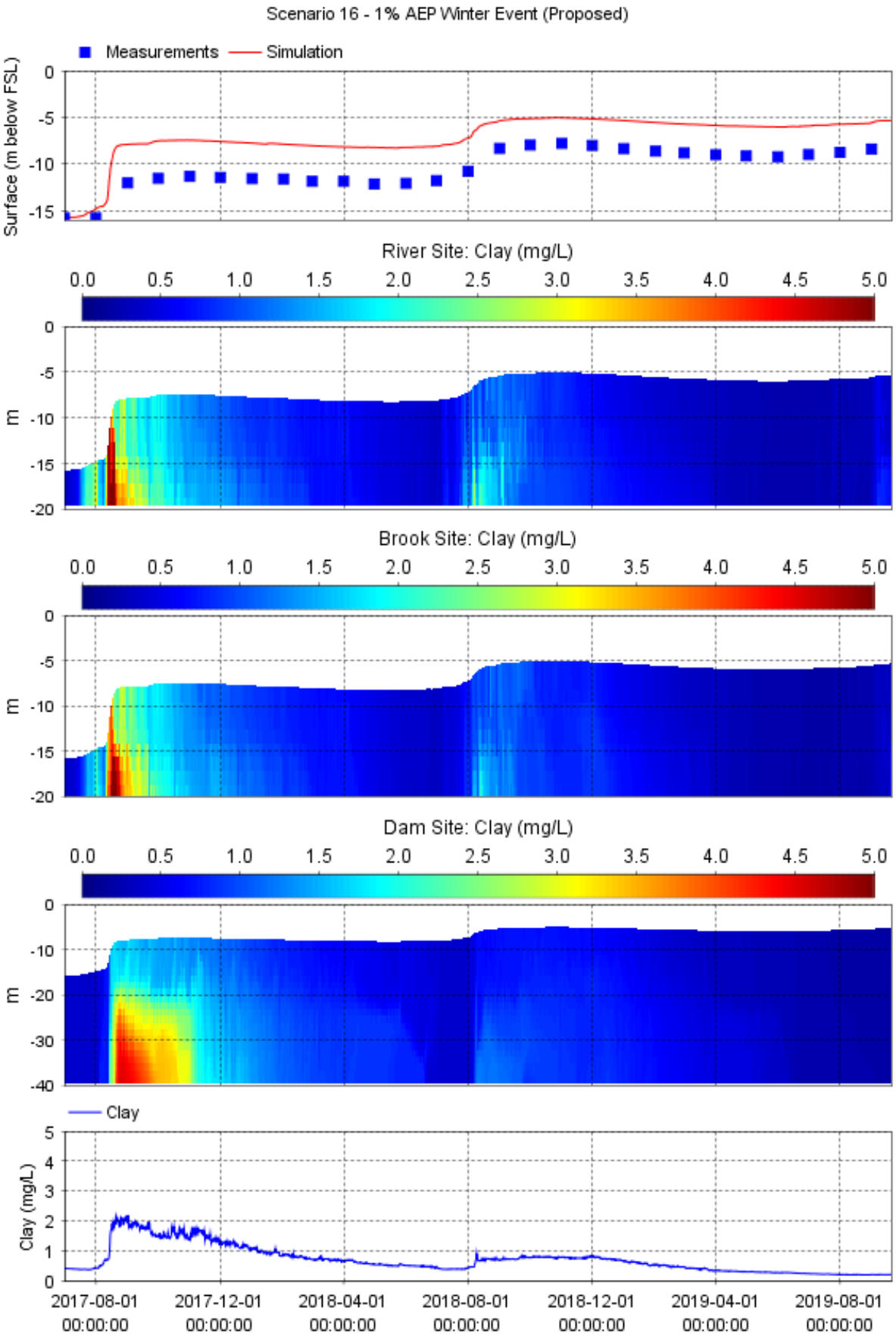


Figure 98 ***SMD simulated levels of clay for scenario 16 (winter proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

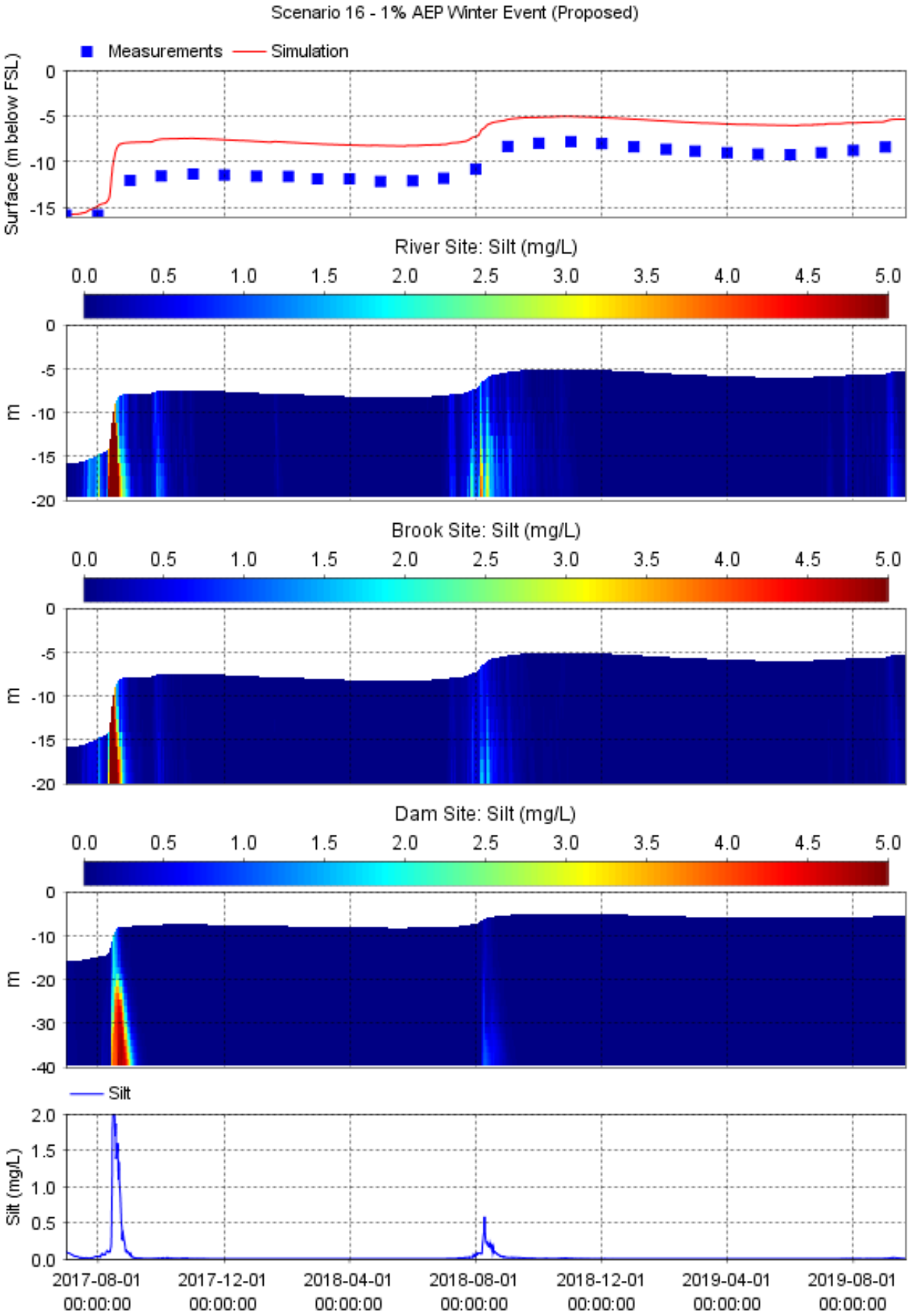


Figure 99 ***SMD simulated levels of silt for scenario 16 (winter proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

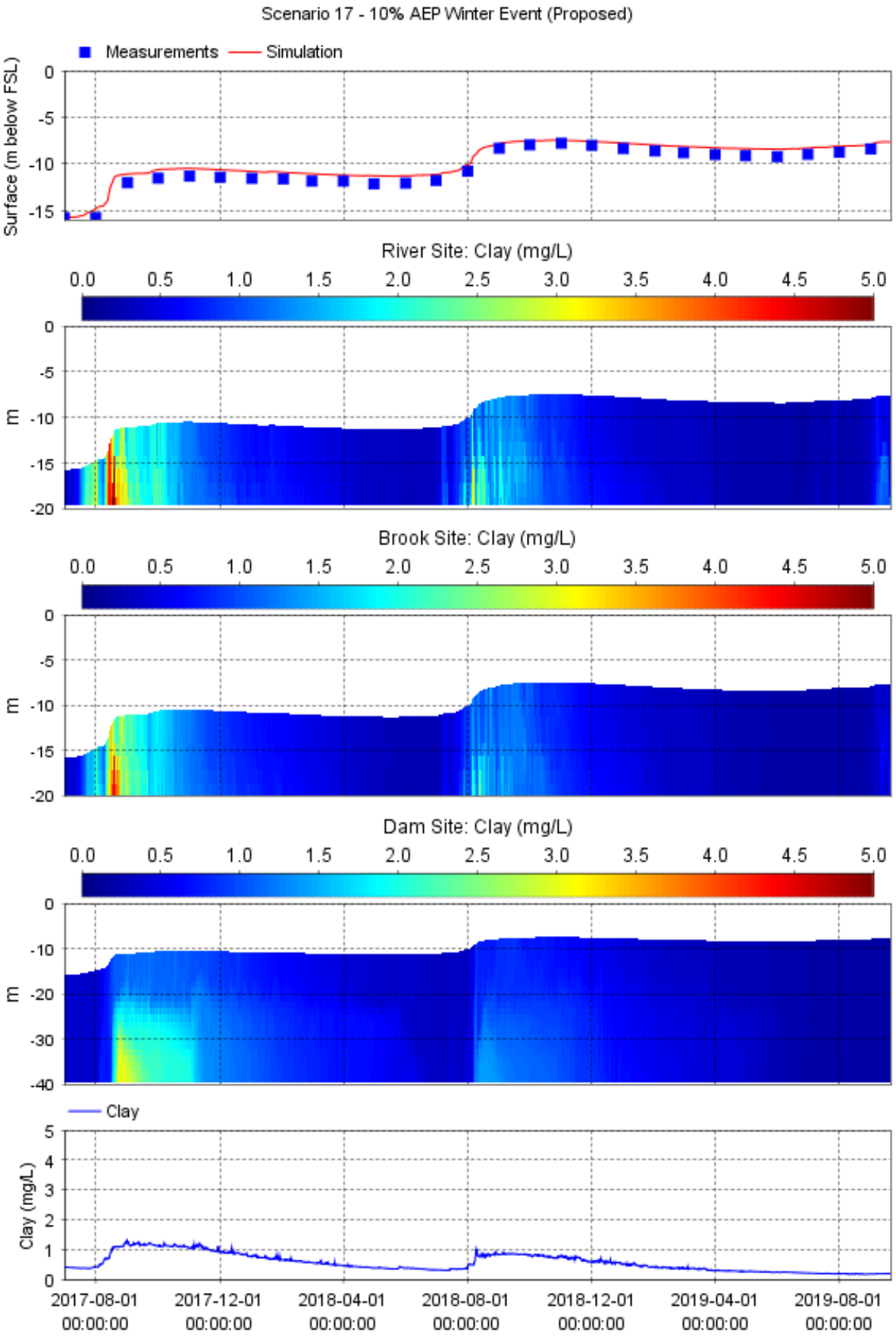


Figure 100 ***SMD simulated levels of clay for scenario 17 (winter proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

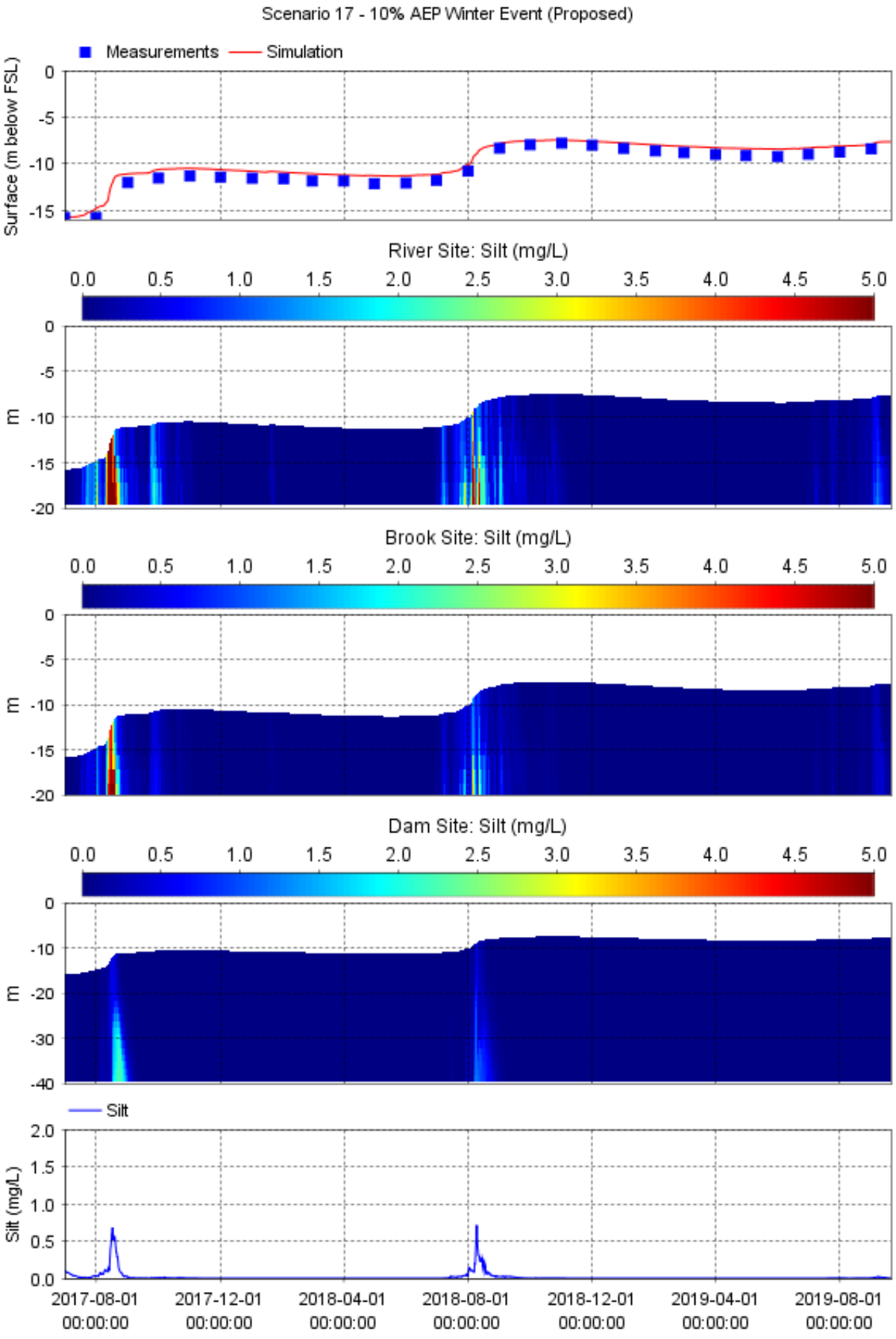


Figure 101 ***SMD simulated levels of silt for scenario 17 (winter proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

Appendix C

SMD: 1% and 10% AEP Flood Event Inputs (High Drainage Failure SS Levels)

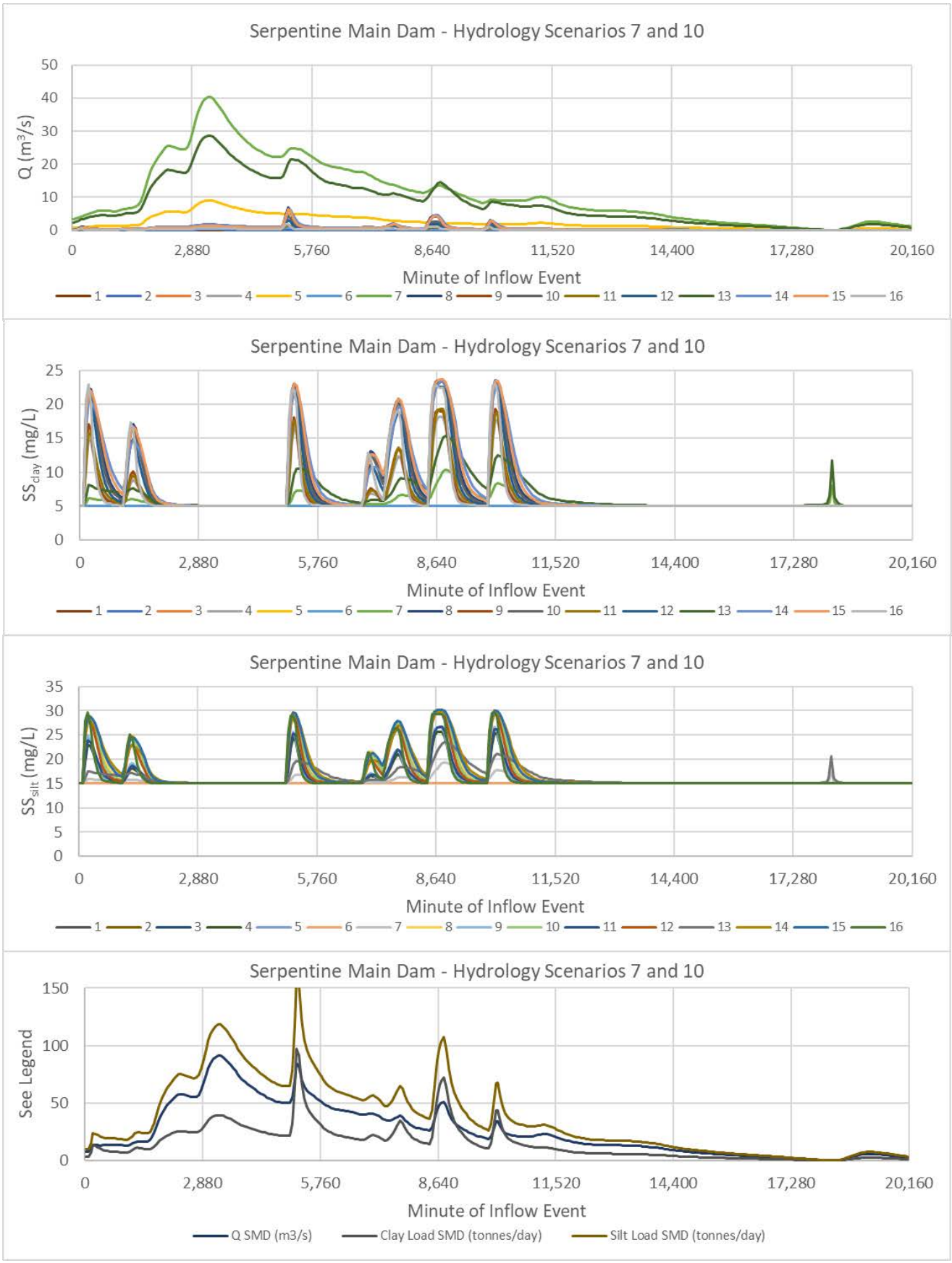


Figure 102 ***SMD hydrology and suspended solids inputs for scenarios 7H and 10H with high drainage failure SS levels.***

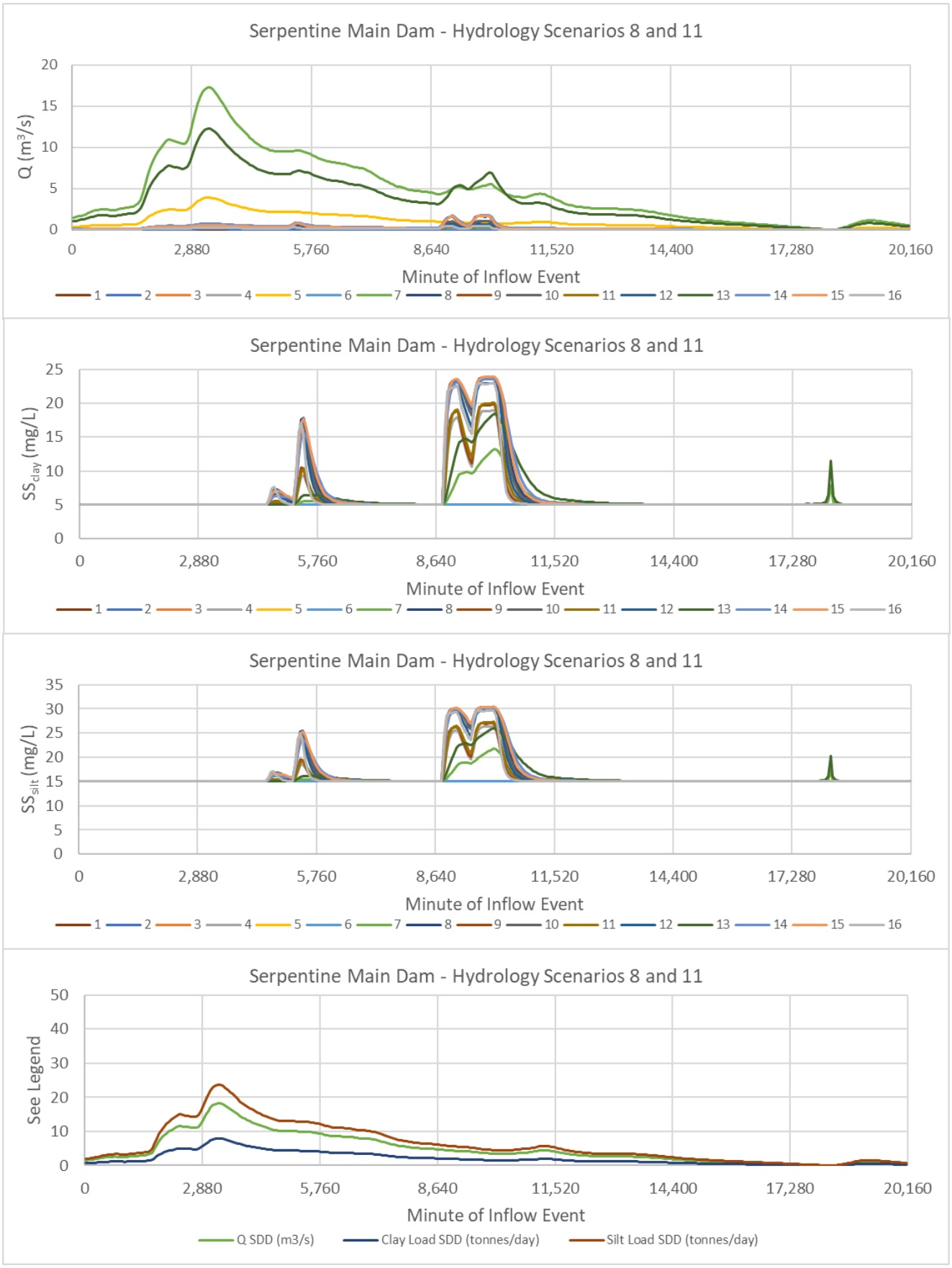


Figure 103 *As Figure 102 for scenarios 8H and 11H with high drainage failure SS levels.*

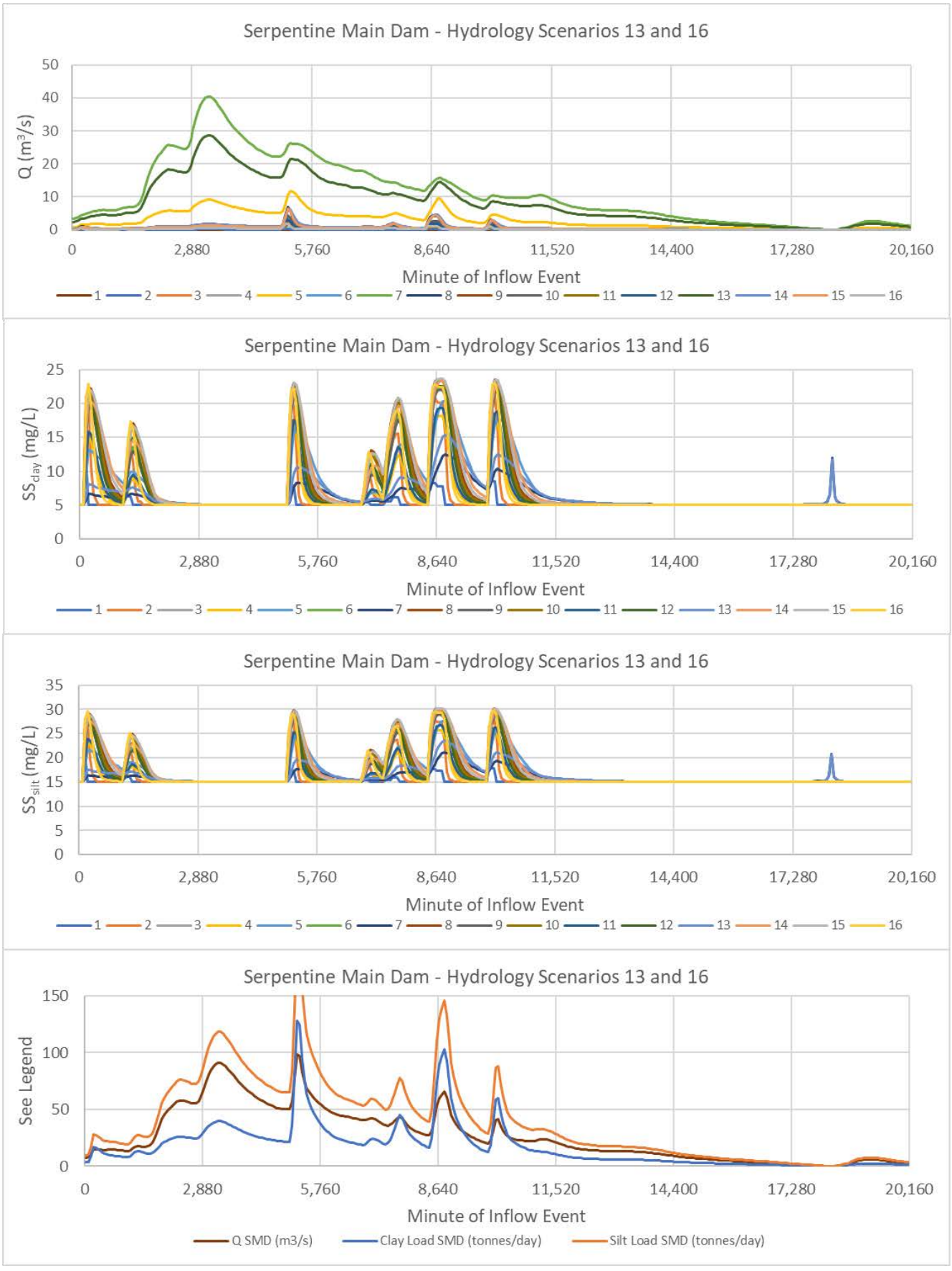


Figure 104 ***As Figure 102 for scenarios 13H and 16H with high drainage failure SS levels.***

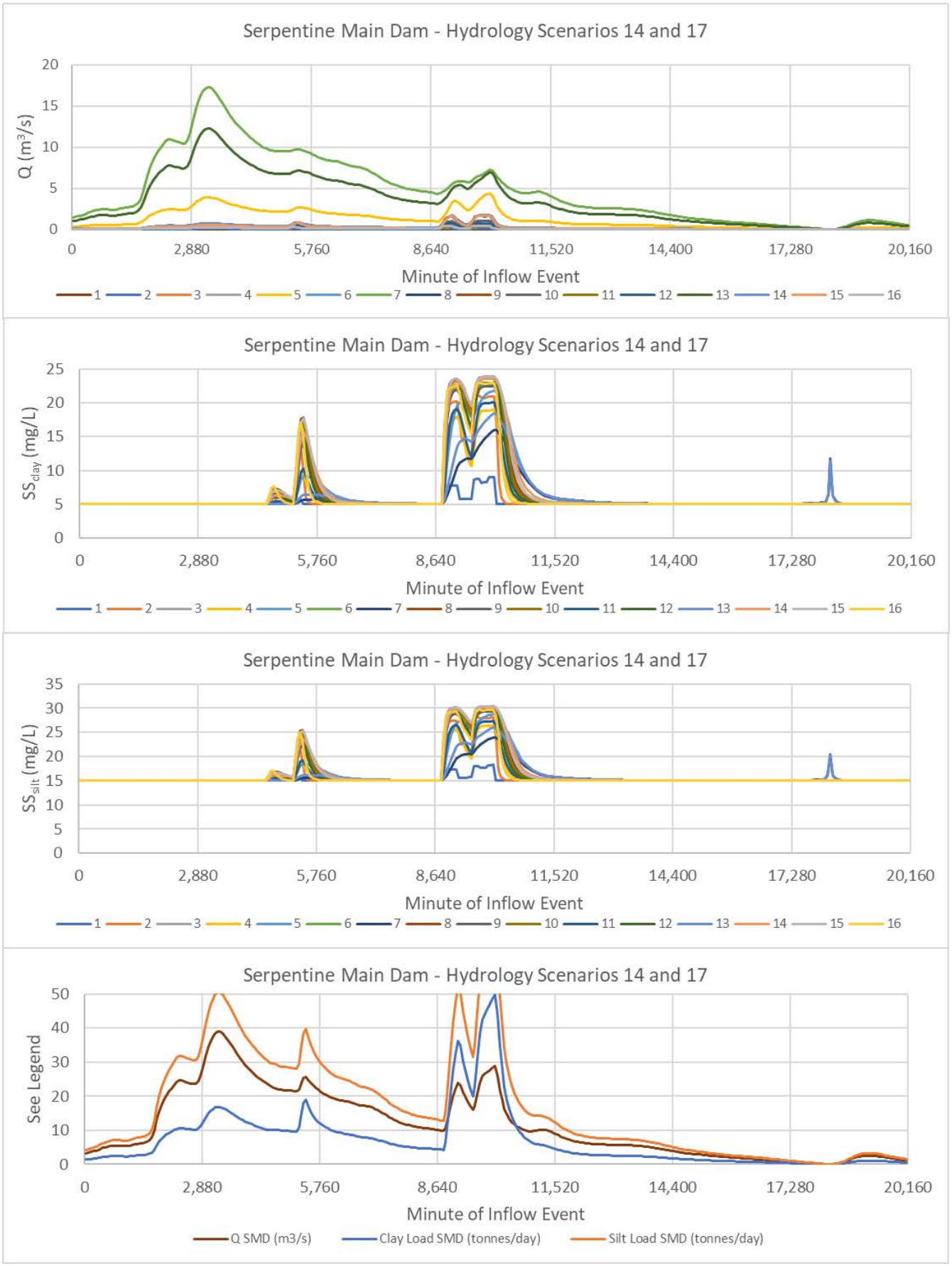


Figure 105 ***As Figure 102 for scenarios 14H and 17H with high drainage failure SS levels.***

Appendix D

SMD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)

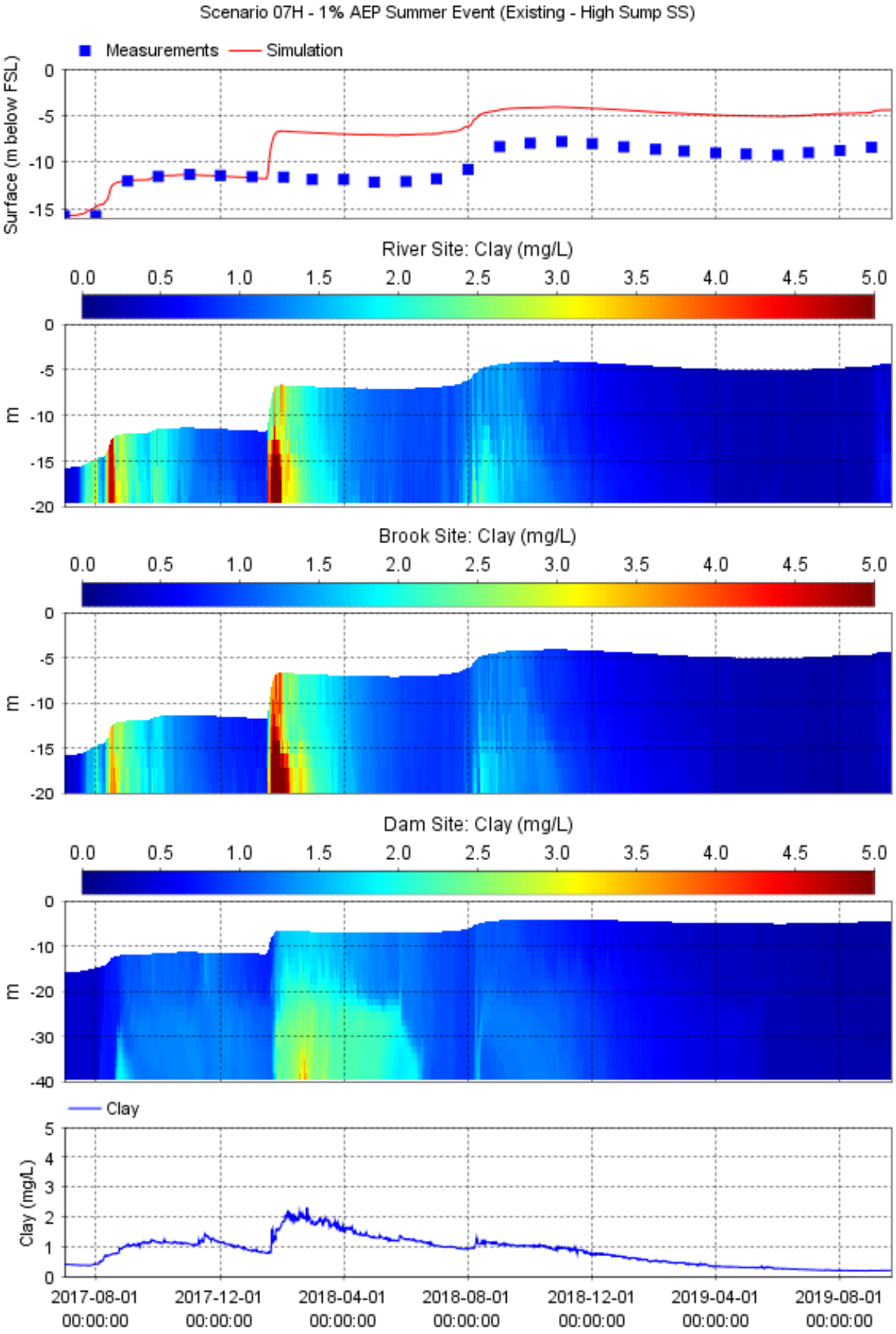


Figure 106 ***SMD simulated levels of clay for scenario 7H (summer existing case 1% AEP flood event) with high drainage failure SS levels.***

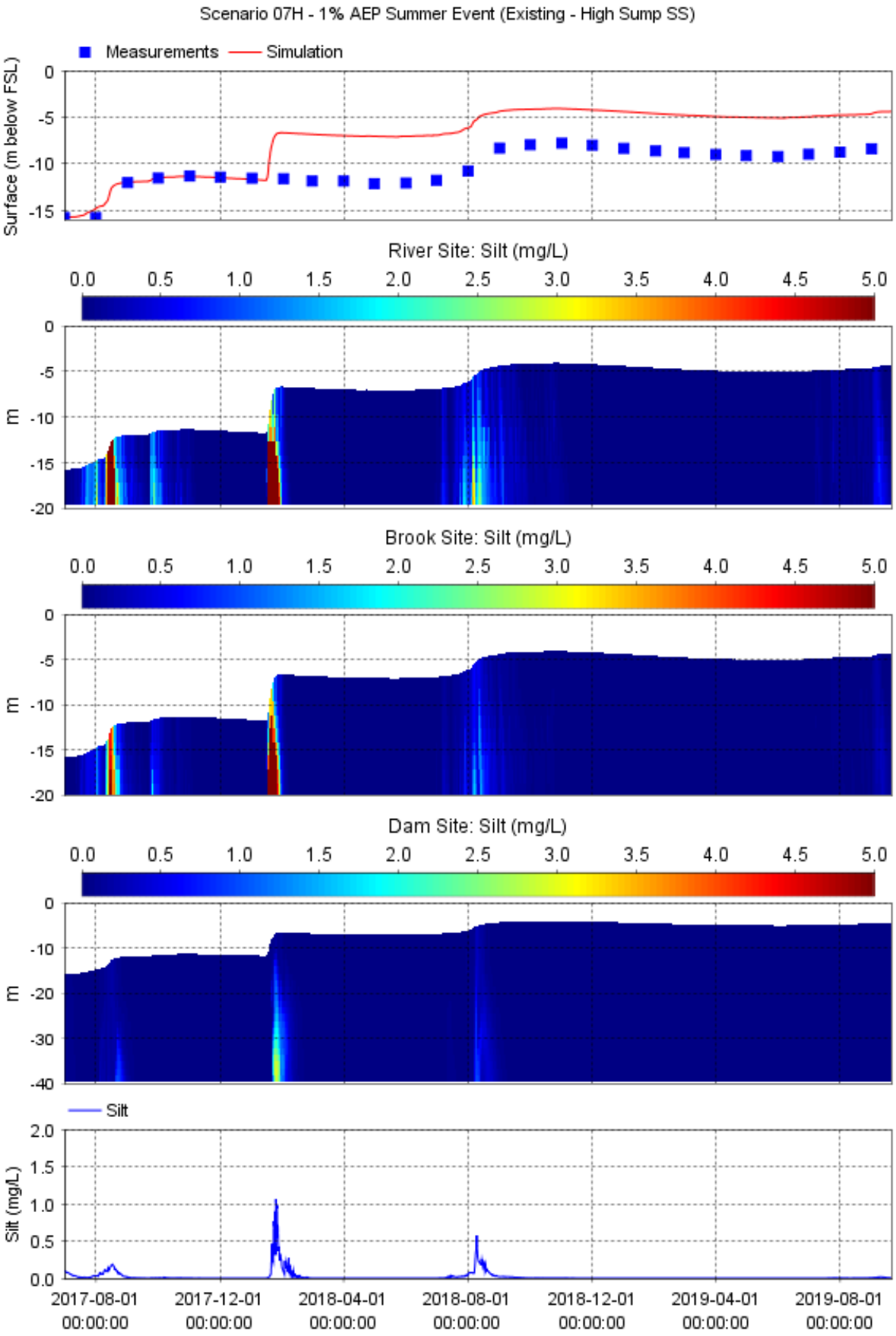


Figure 107 ***SMD simulated levels of silt for scenario 7H (summer existing case 1% AEP flood event) with high drainage failure SS levels.***

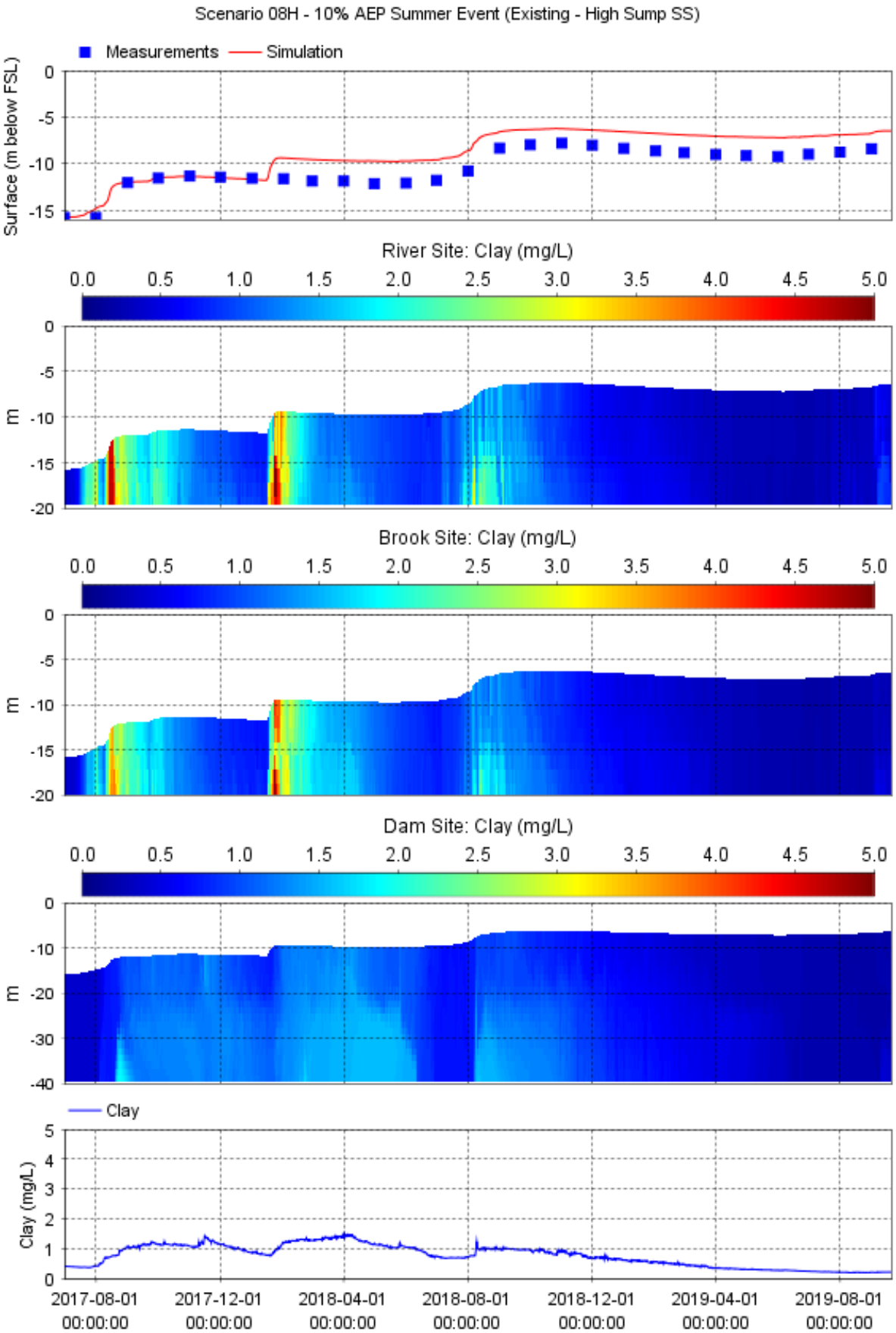


Figure 108 ***SMD simulated levels of clay for scenario 8H (winter existing case 10% AEP flood event) with high drainage failure SS levels.***

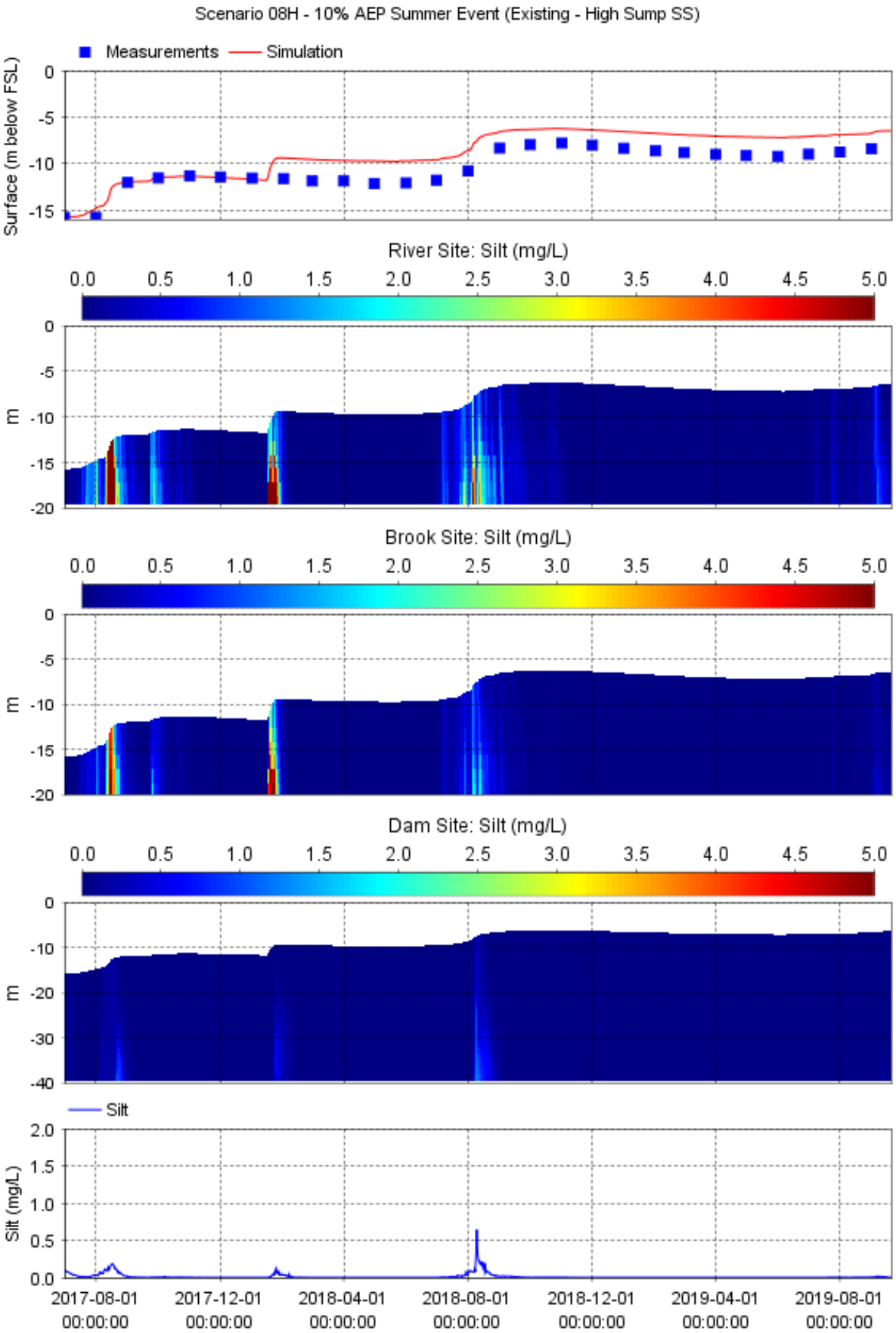


Figure 109 ***SMD simulated levels of silt for scenario 8H (summer existing case 10% AEP flood event) with high drainage failure SS levels.***

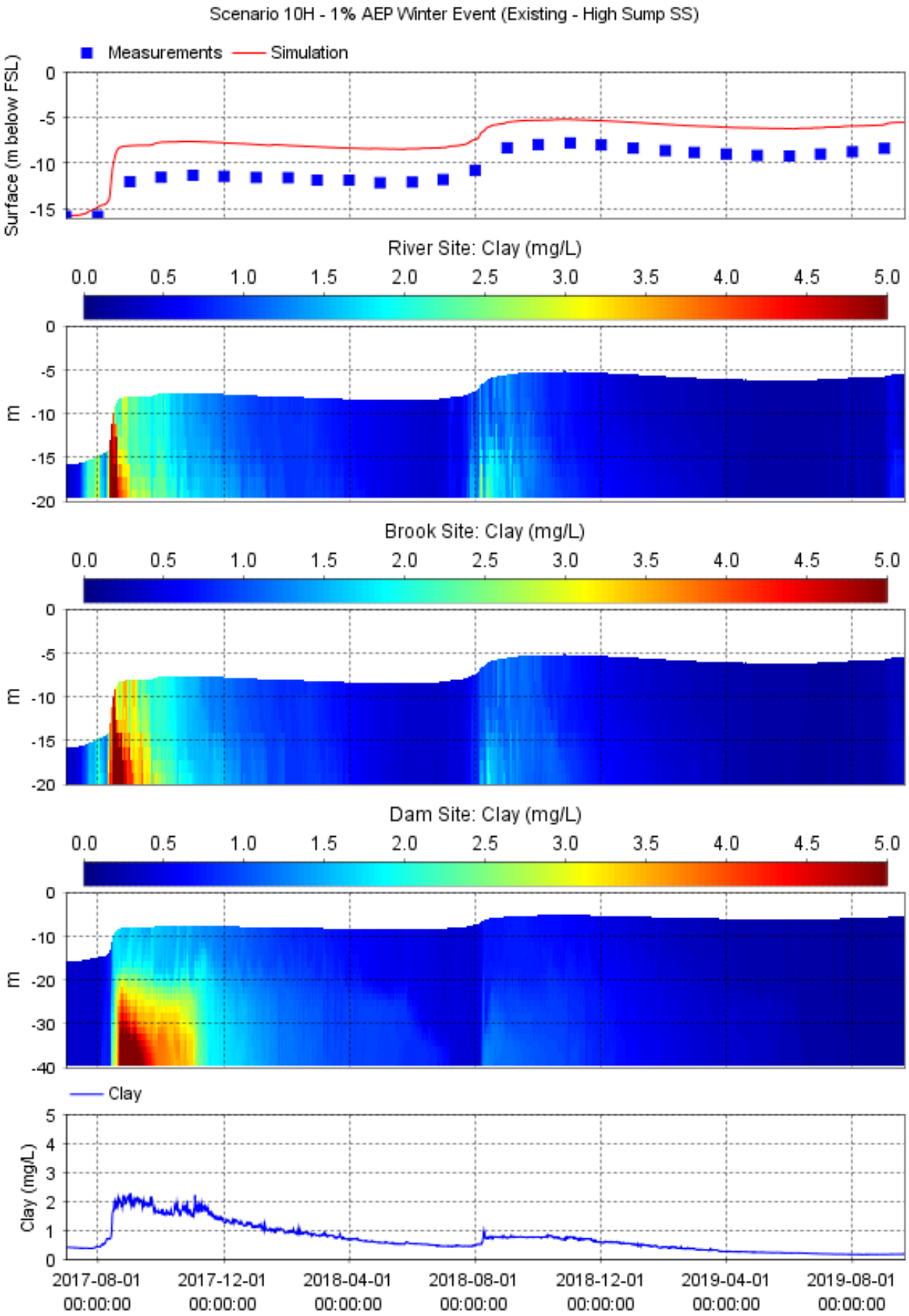


Figure 110 ***SMD simulated levels of clay for scenario 10H (winter existing case 1% AEP flood event) with high drainage failure SS levels.***

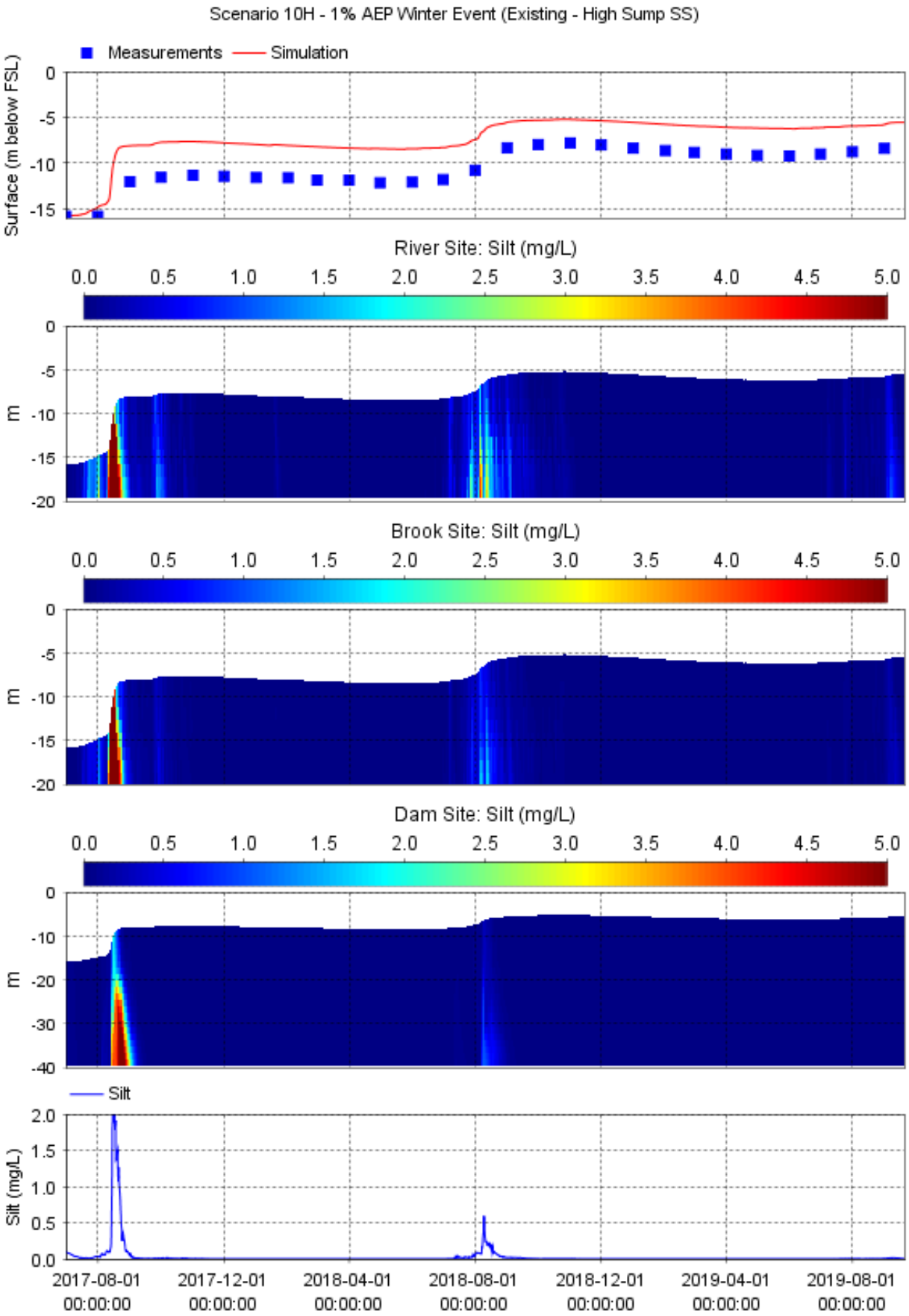


Figure 111 ***SMD simulated levels of silt for scenario 10H (winter existing case 1% AEP flood event) with high drainage failure SS levels.***

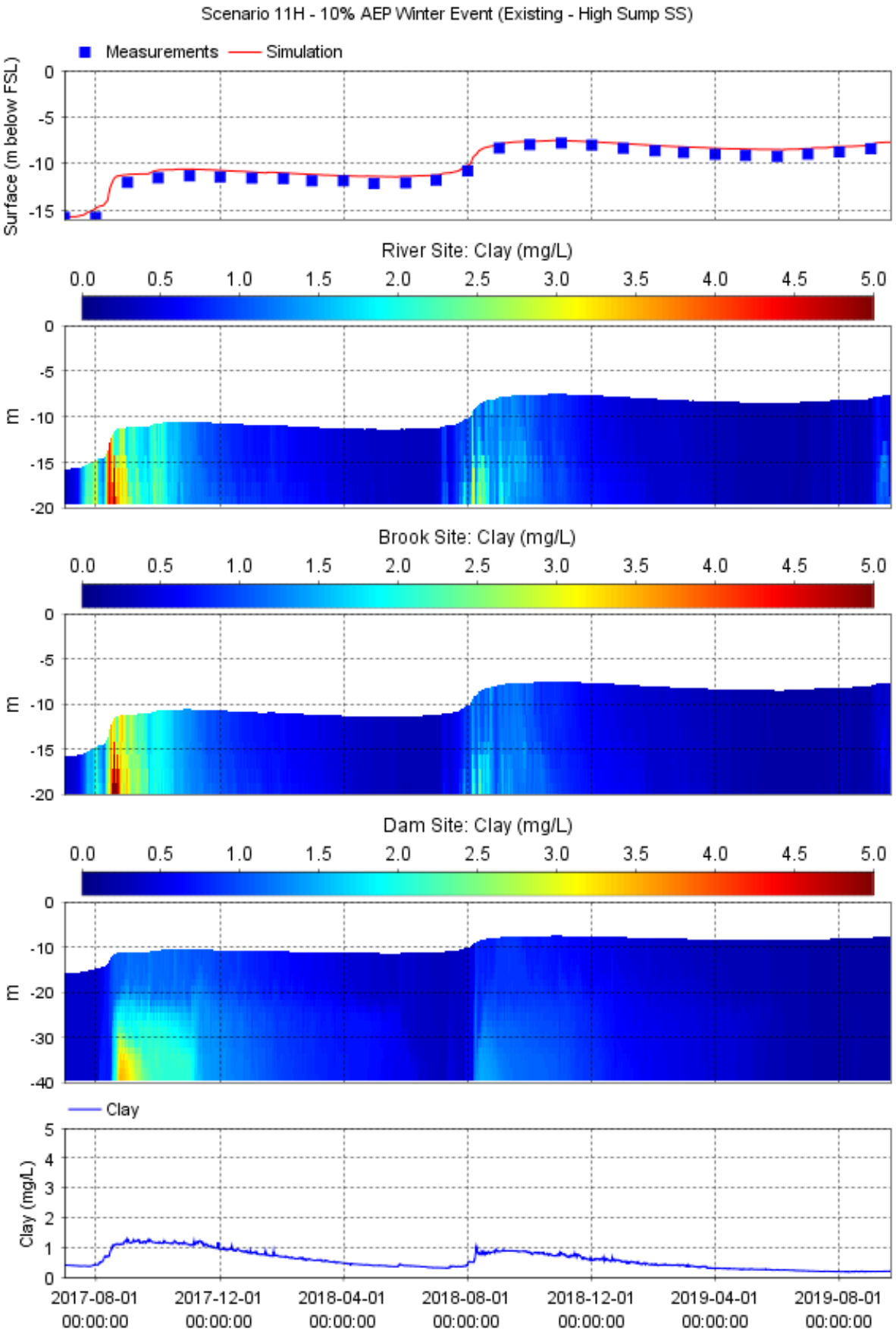


Figure 112 ***SMD simulated levels of clay for scenario 11H (winter existing case 10% AEP flood event) with high drainage failure SS levels.***

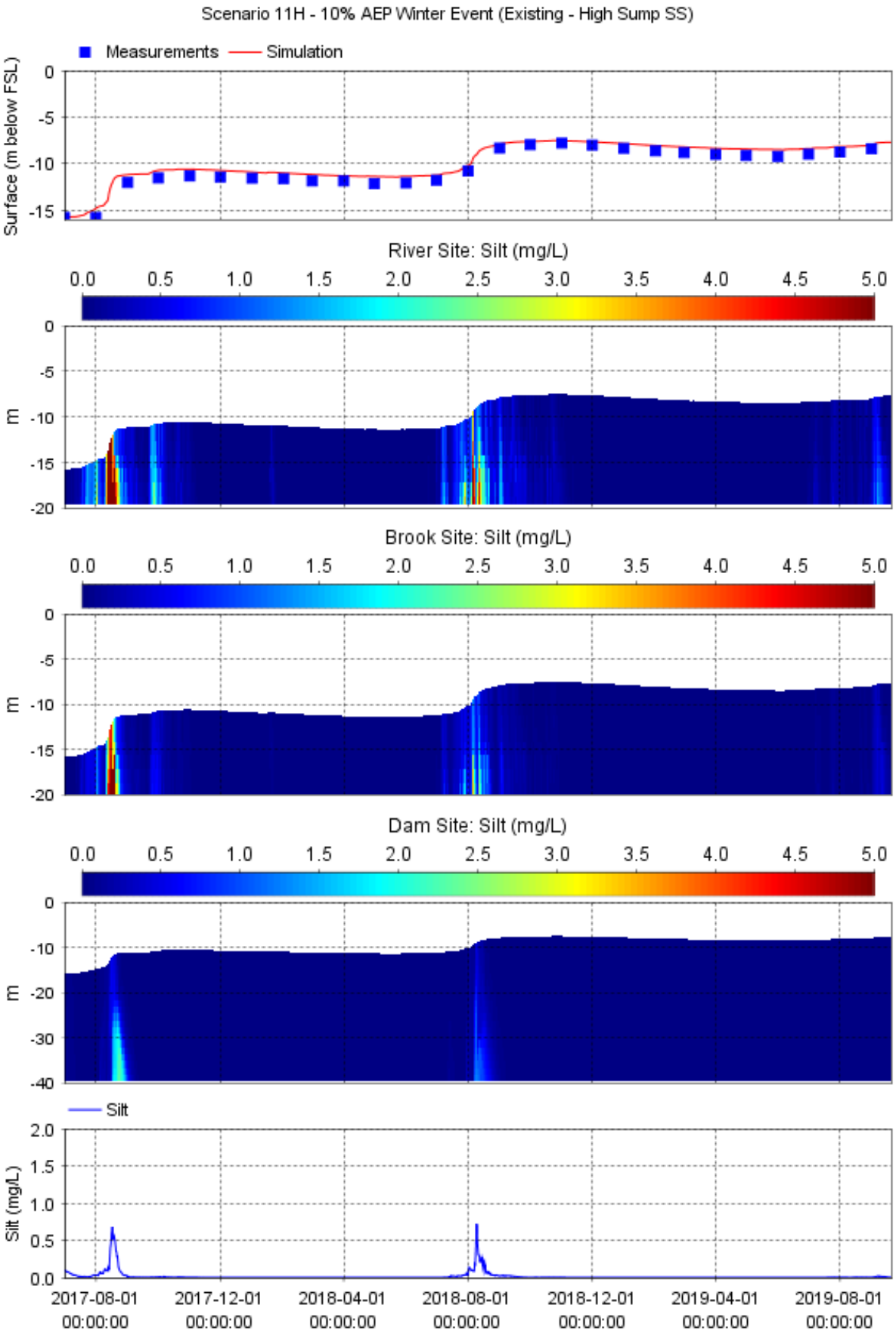


Figure 113 ***SMD simulated levels of silt for scenario 11H (winter existing case 10% AEP flood event) with high drainage failure SS levels.***

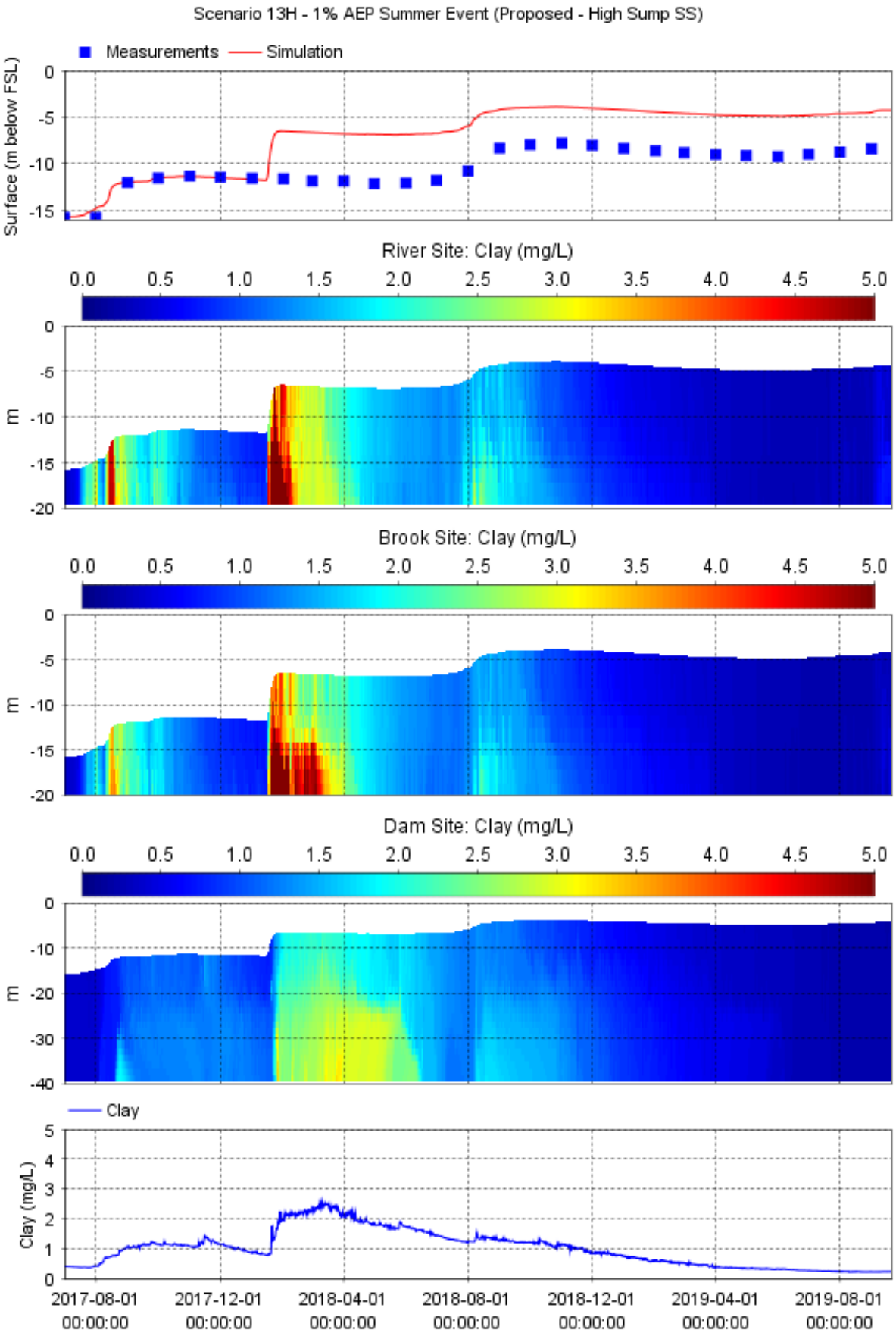


Figure 114 ***SMD simulated levels of clay for scenario 13H (summer proposed case 1% AEP flood event) with high drainage failure SS levels.***

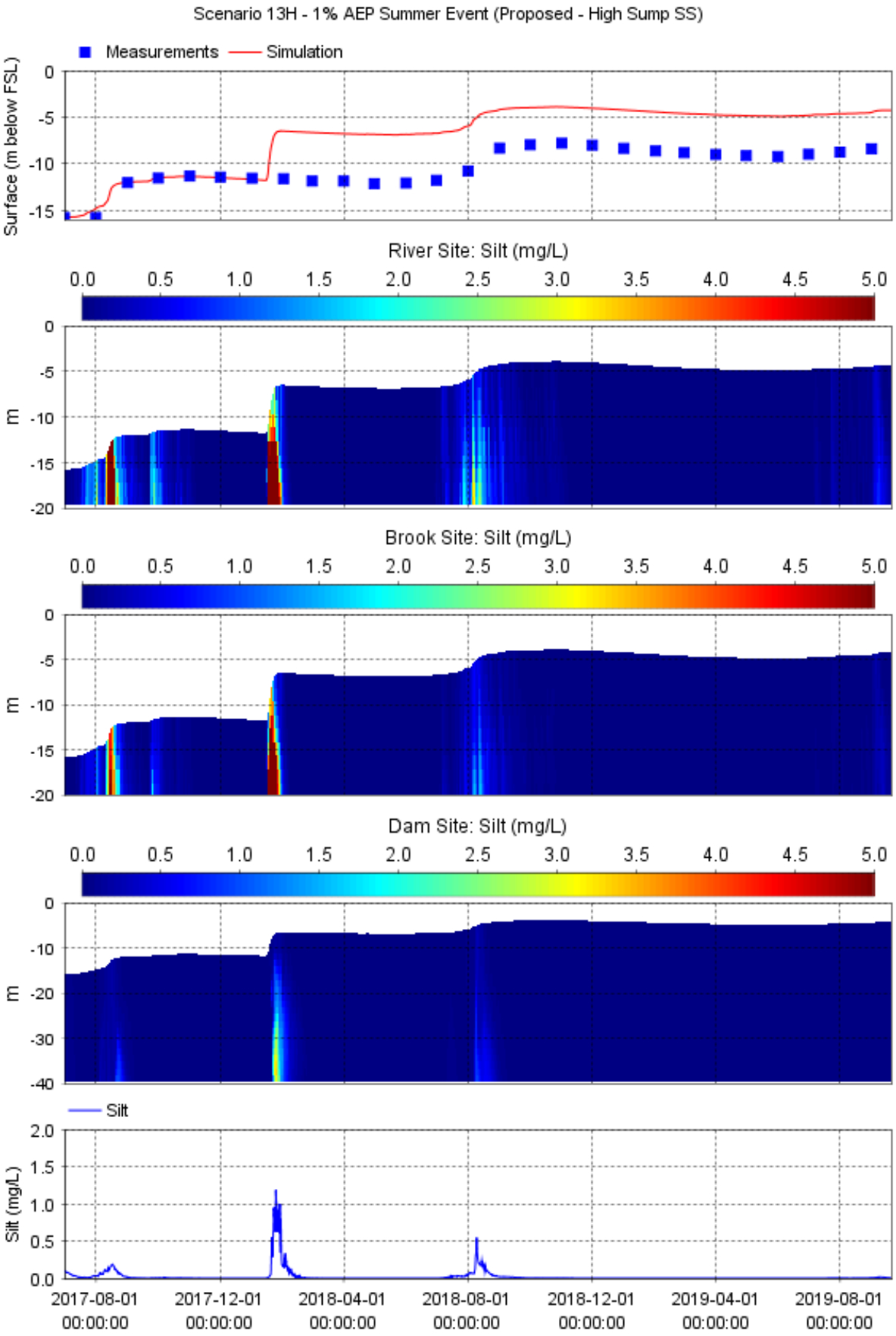


Figure 115 ***SMD simulated levels of silt for scenario 13H (summer proposed case 1% AEP flood event) with high drainage failure SS levels.***

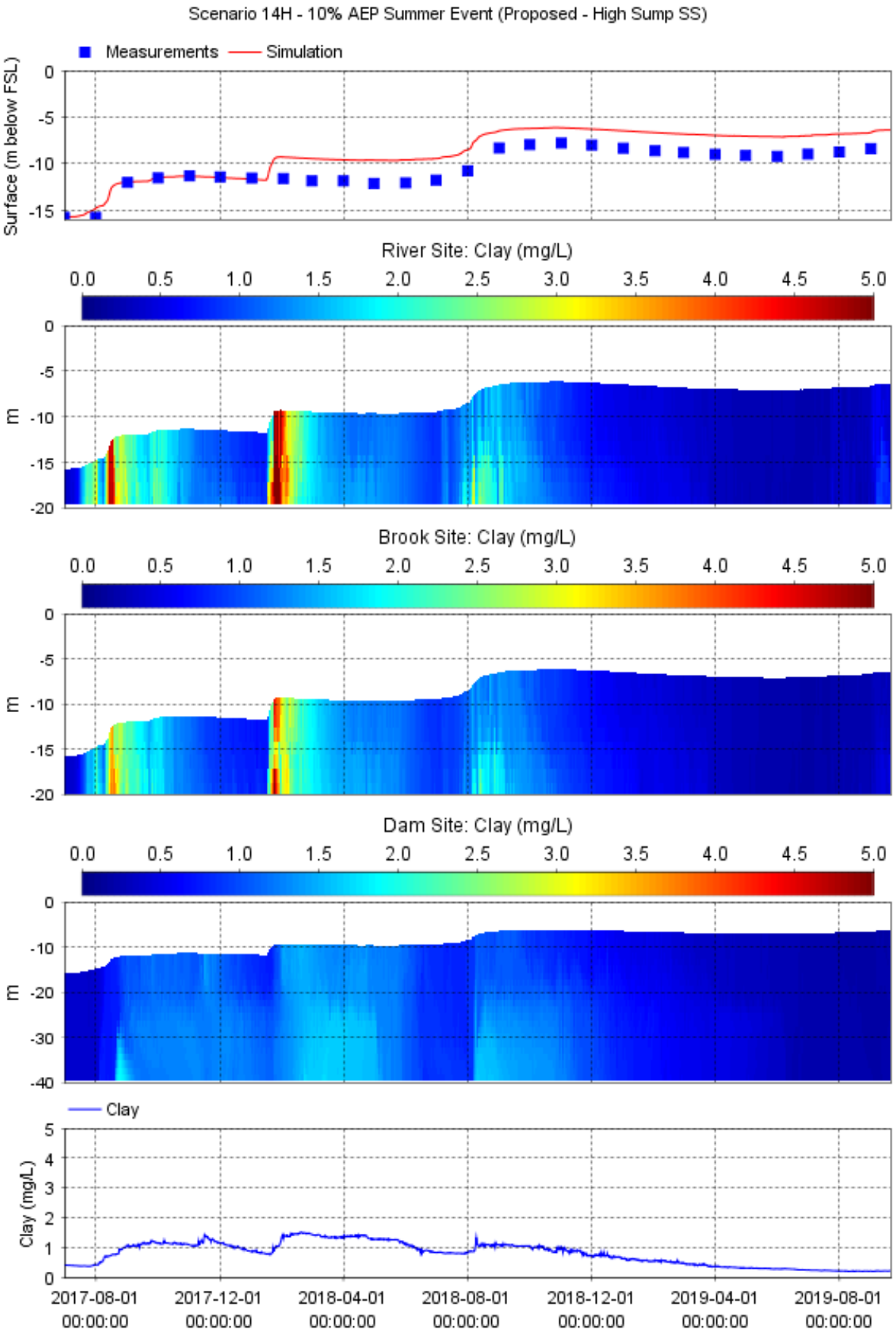


Figure 116 ***SMD simulated levels of clay for scenario 14H (summer proposed case 10% AEP flood event) with high drainage failure SS levels.***

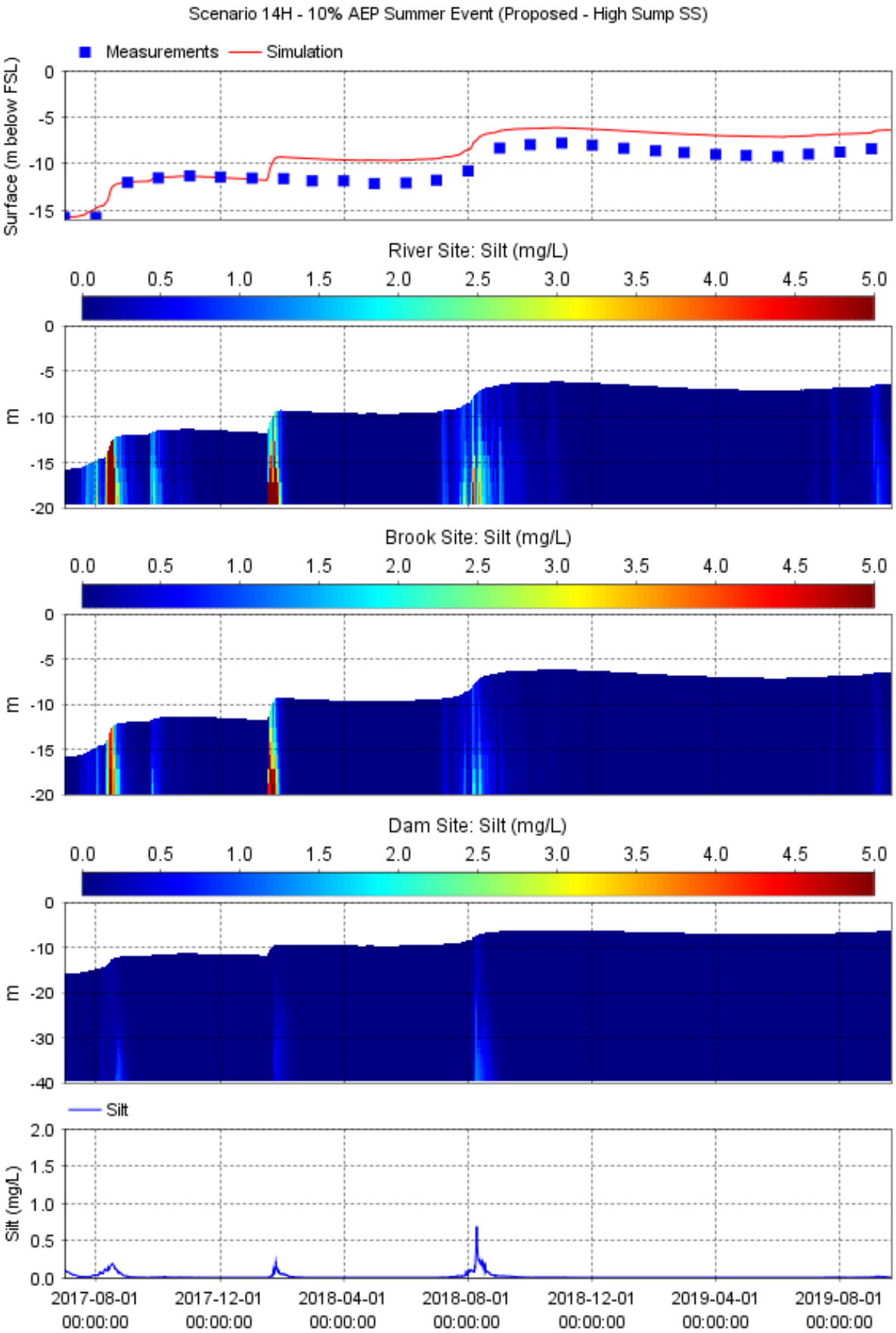


Figure 117 ***SMD simulated levels of silt for scenario 14H (summer proposed case 10% AEP flood event) with high drainage failure SS levels.***

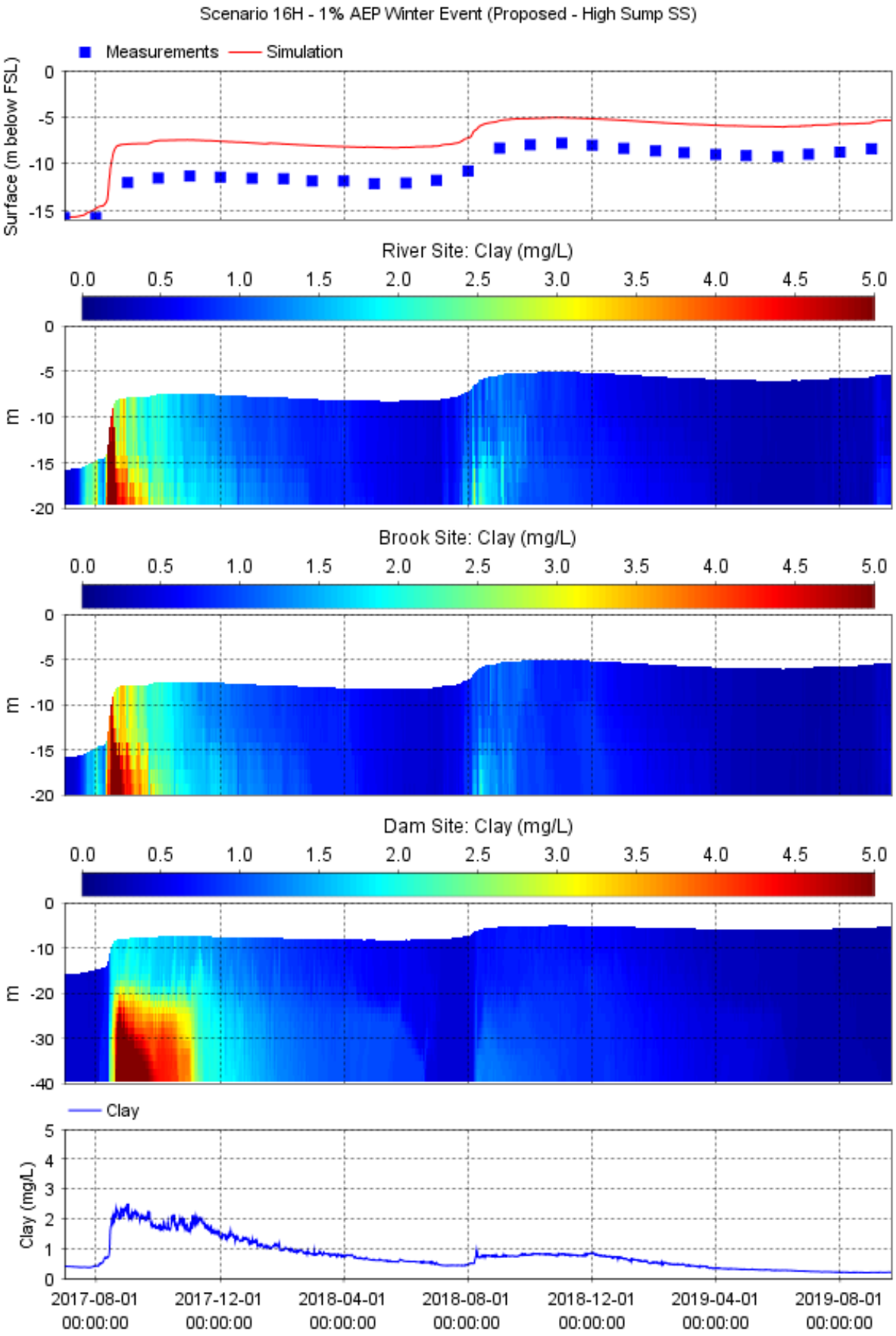


Figure 118 ***SMD simulated levels of clay for scenario 16H (winter proposed case 1% AEP flood event) with high drainage failure SS levels.***

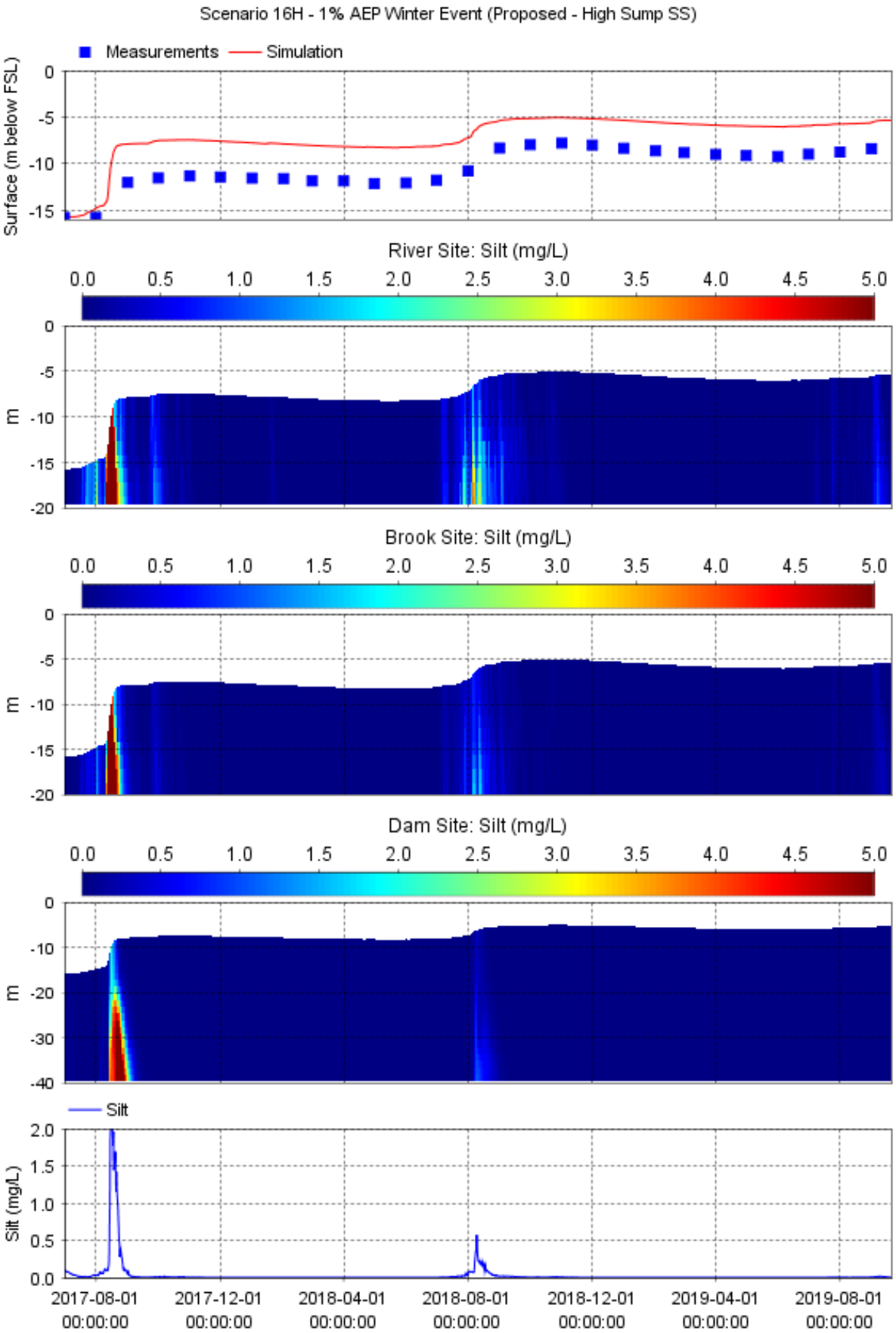


Figure 119 ***SMD simulated levels of silt for scenario 16H (winter proposed case 1% AEP flood event) with high drainage failure SS levels.***

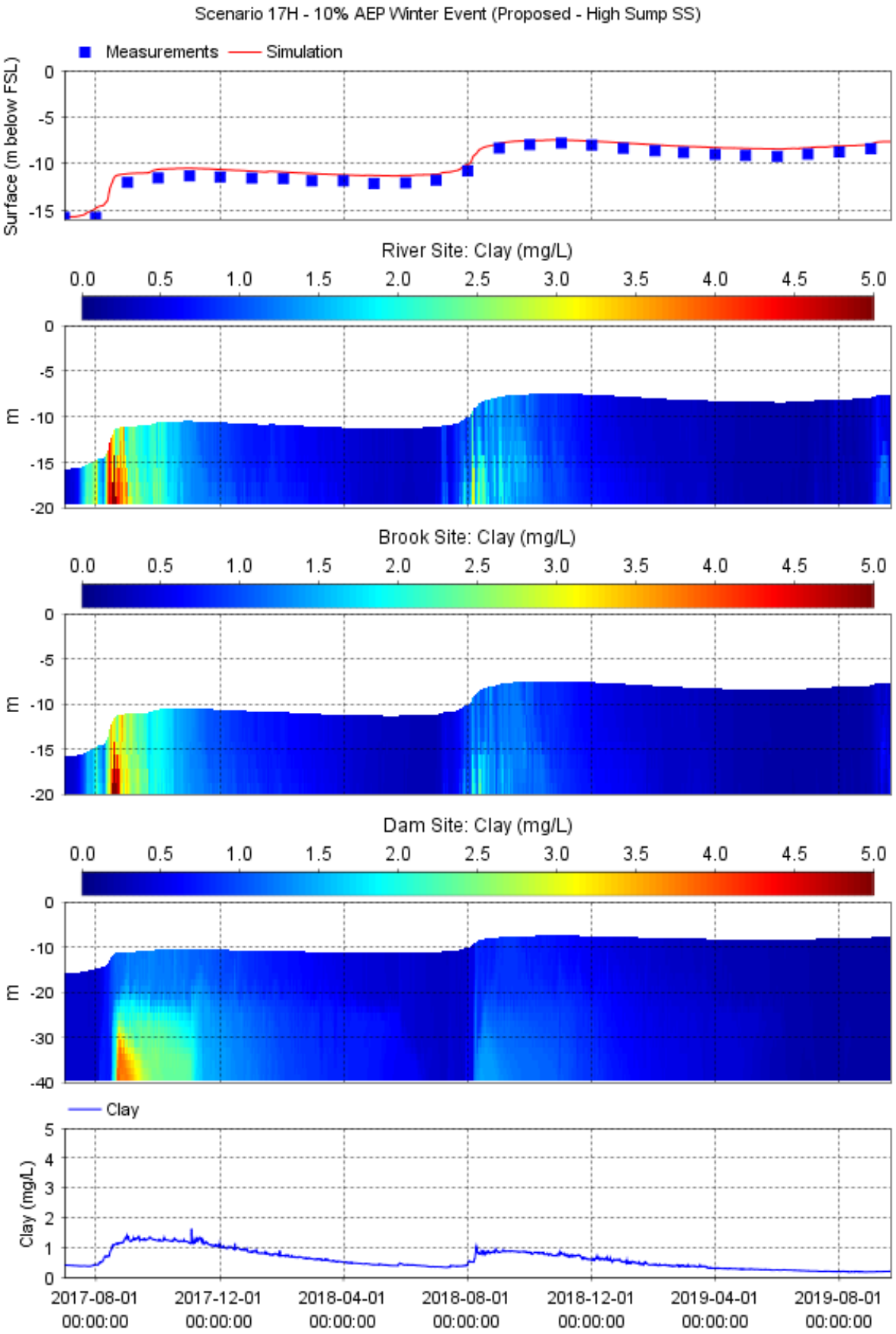


Figure 120 ***SMD simulated levels of clay for scenario 17H (winter proposed case 10% AEP flood event) with high drainage failure SS levels.***

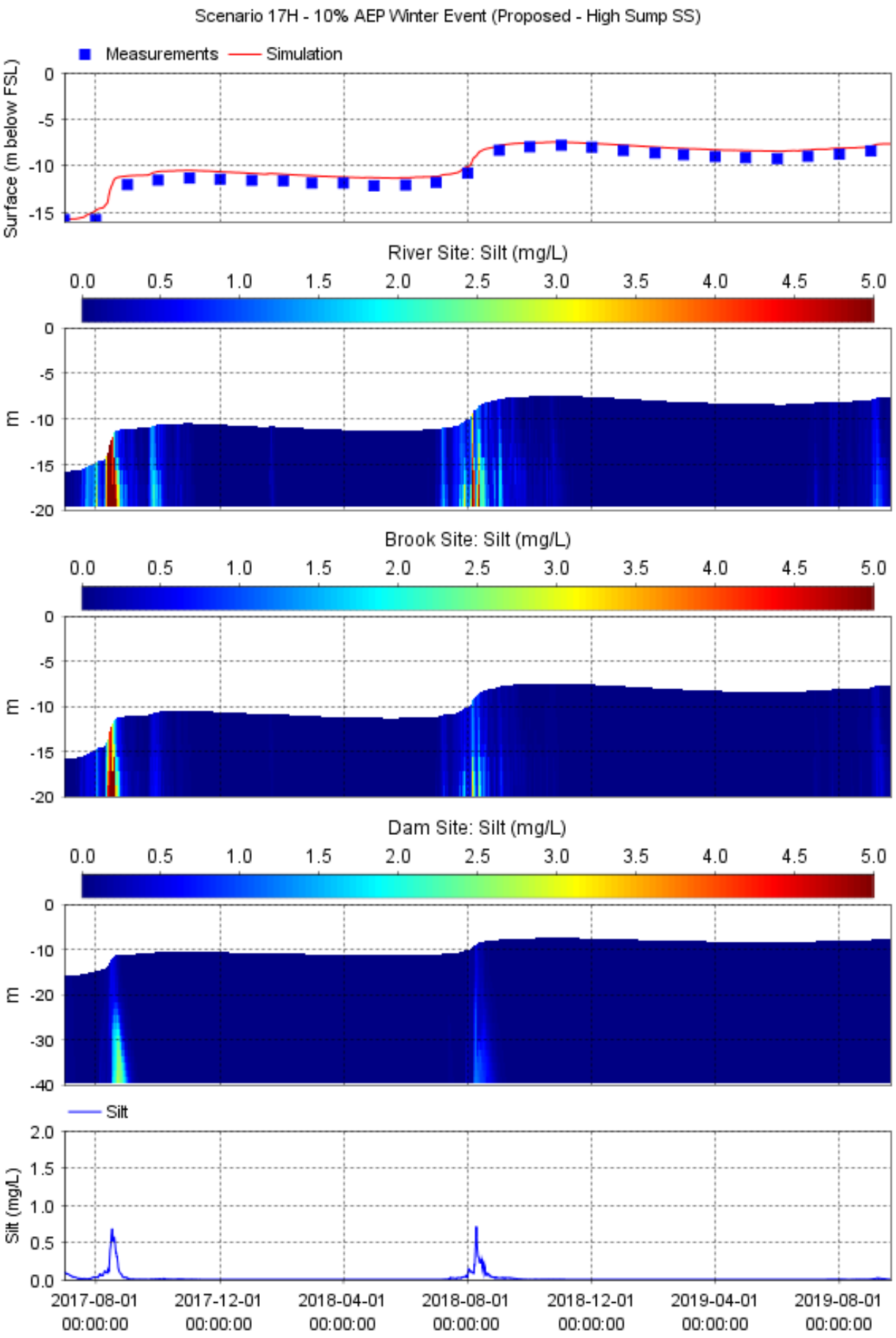


Figure 121 ***SMD simulated levels of silt for scenario 17H (winter proposed case 10% AEP flood event) with high drainage failure SS levels.***

Appendix E

SDD: 1% and 10% AEP Flood Event Inputs (Moderate Drainage Failure SS Levels)



Figure 122 SDD hydrology and suspended solids inputs for scenarios 1 and 4.

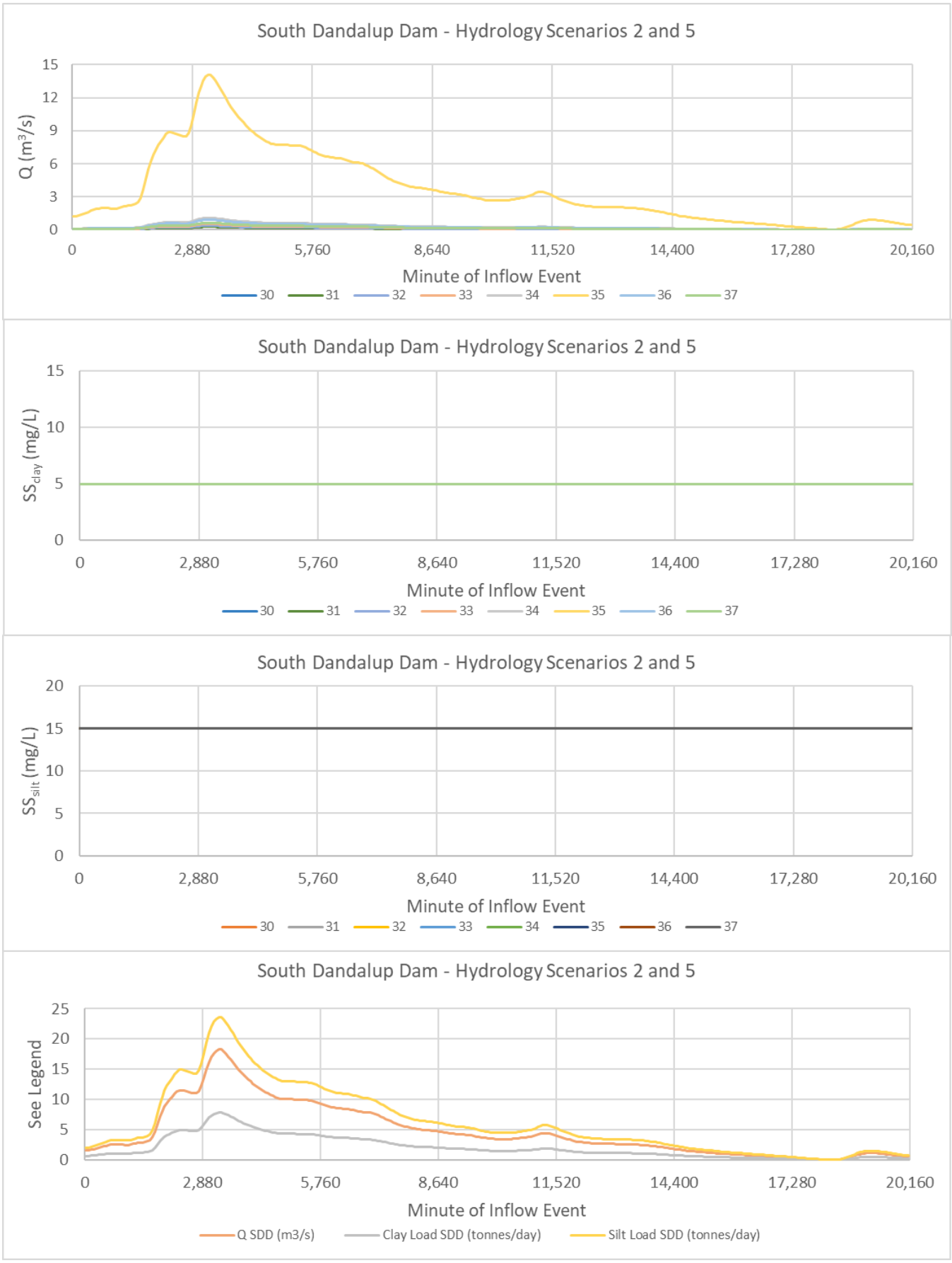


Figure 123 ***As Figure 122 for scenarios 2 and 5.***



Figure 124 ***As Figure 122 for scenarios 13 and 16 with moderate drainage failure SS levels.***



Figure 125 ***As Figure 122 for scenarios 14 and 17 with moderate drainage failure SS levels.***

Appendix F

SDD: 1% and 10% AEP Flood Event Simulations (Moderate Drainage Failure SS Levels)

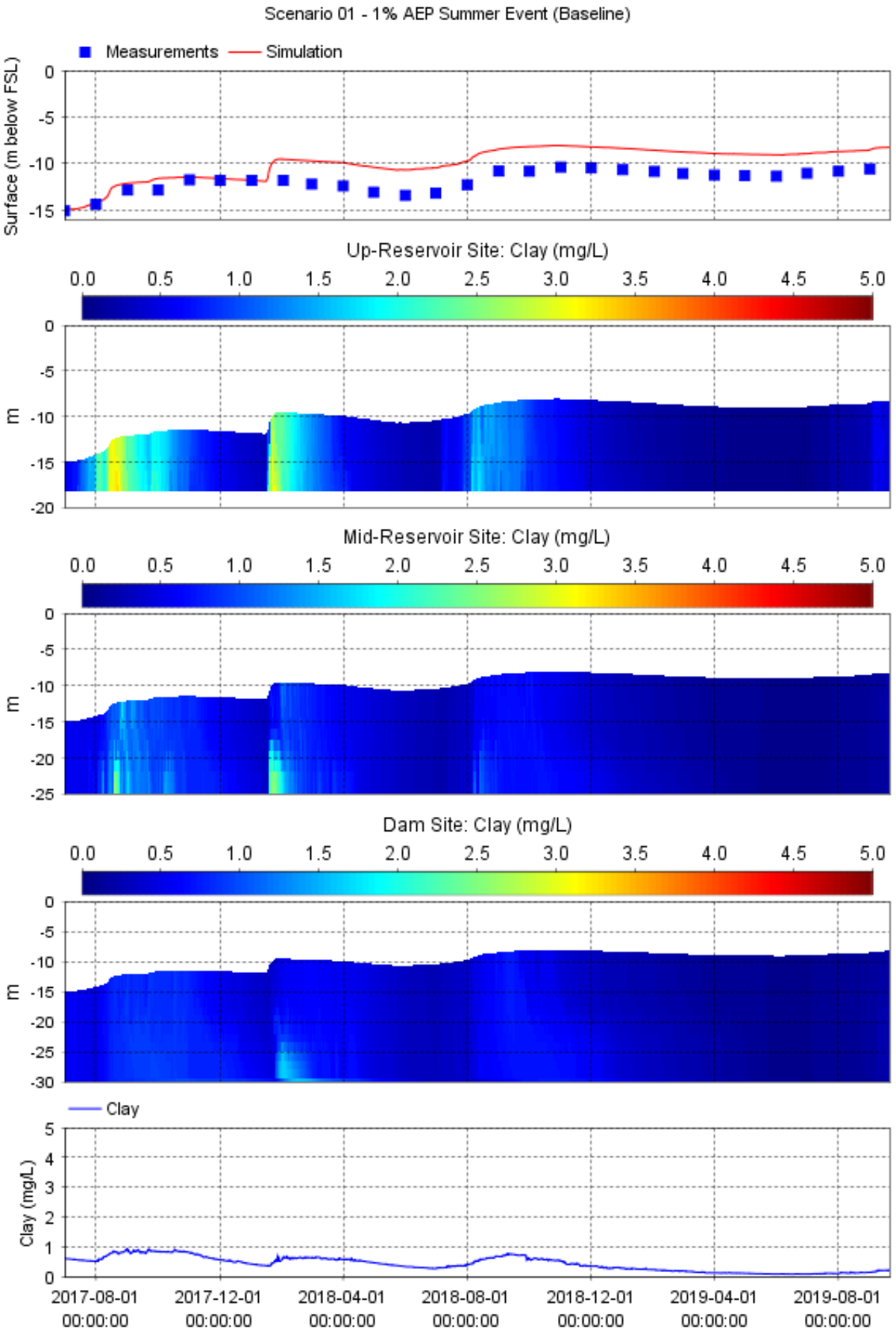


Figure 126 SDD simulated levels of clay for scenario 1 (summer baseline case 1% AEP flood event).

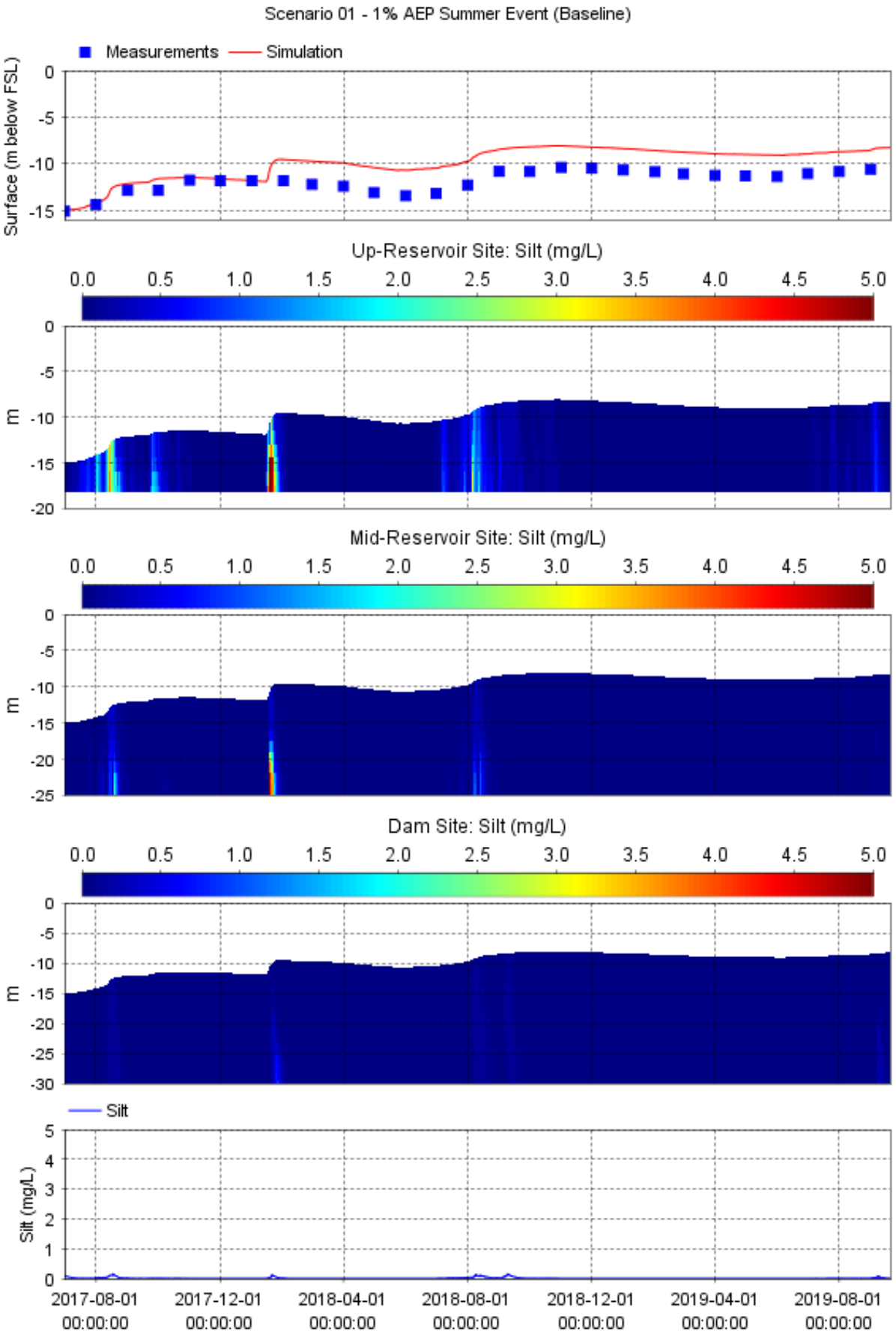


Figure 127 SDD simulated levels of silt for scenario 1 (summer baseline case 1% AEP flood event).

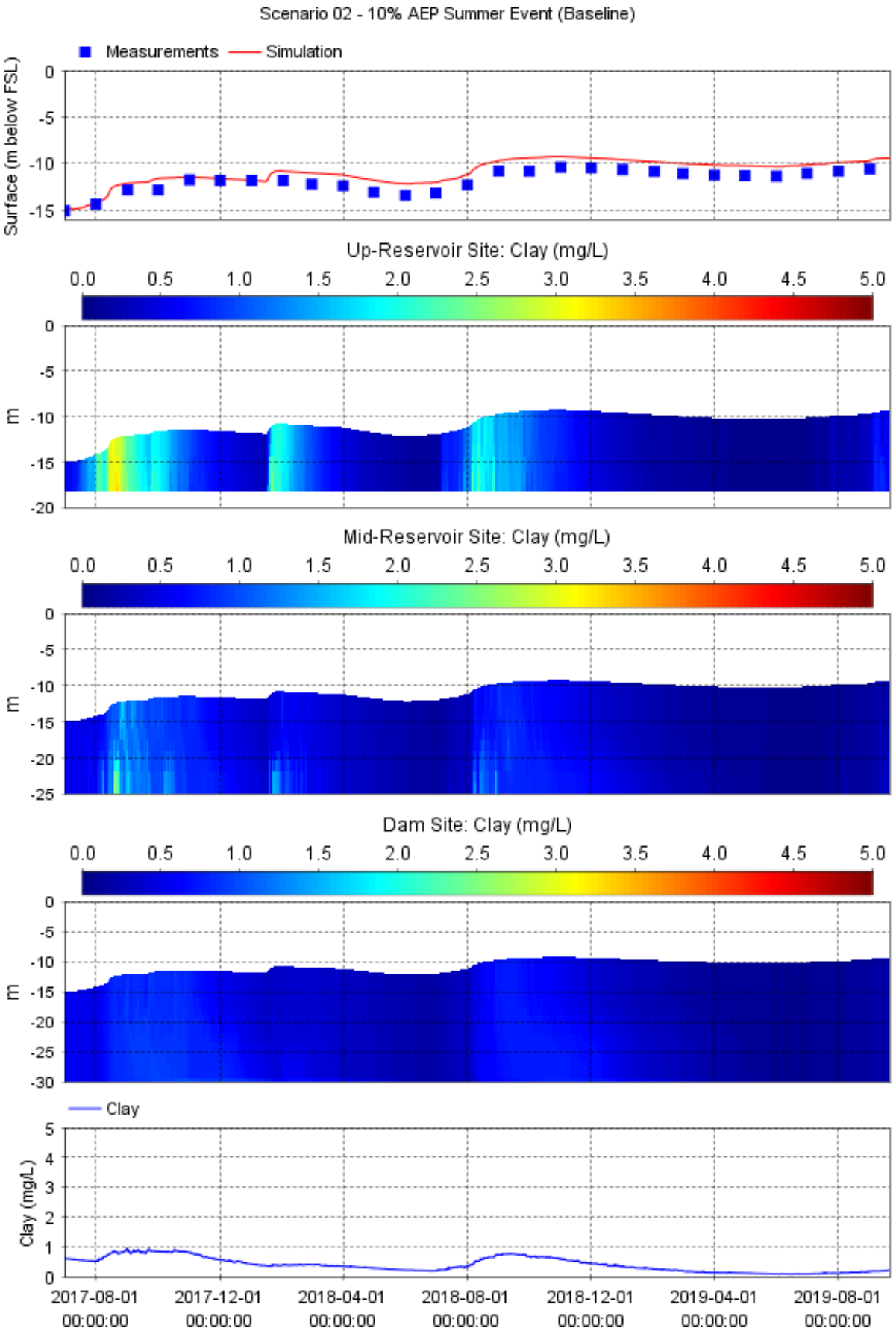


Figure 128 SDD simulated levels of clay for scenario 2 (summer baseline case 10% AEP flood event).

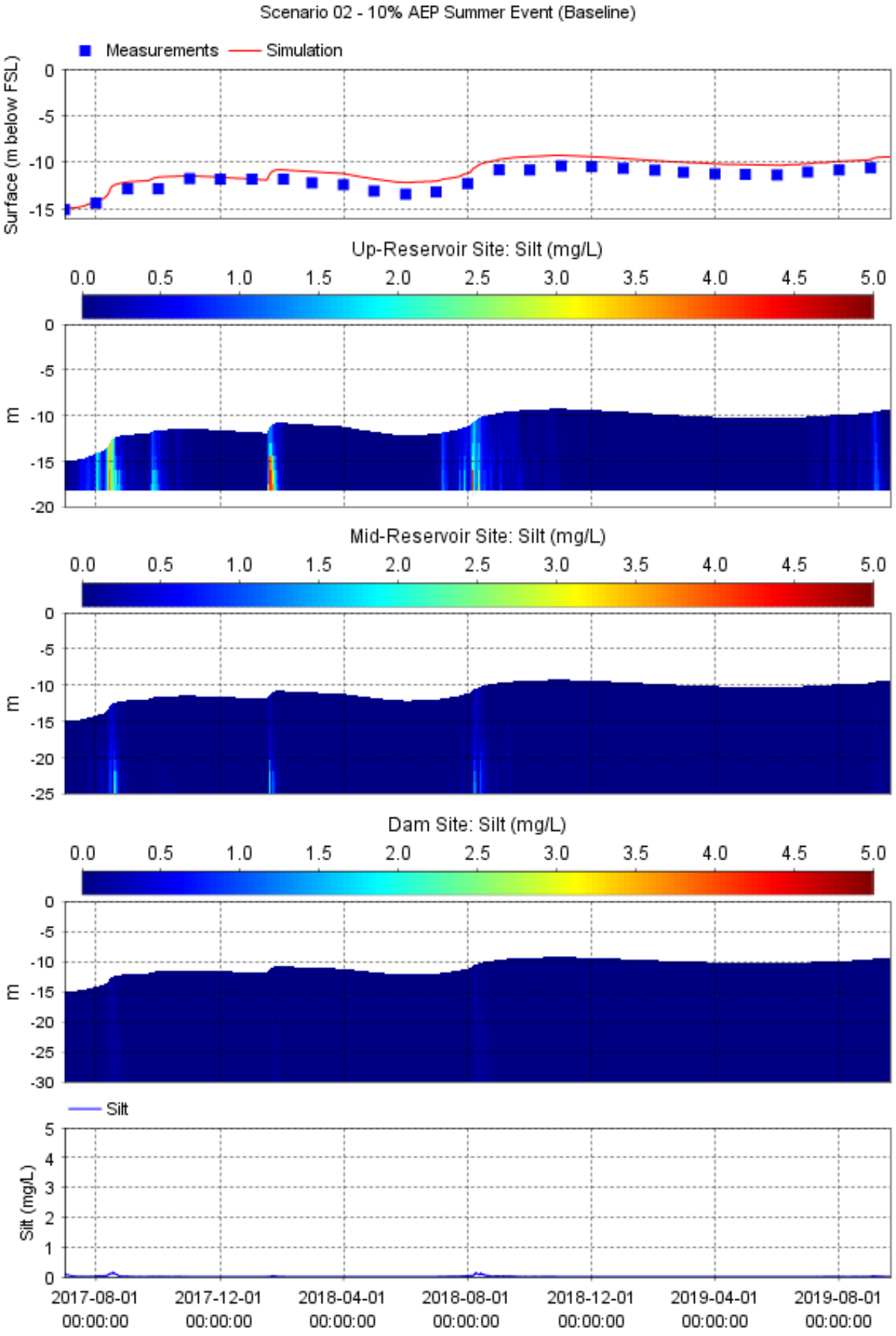


Figure 129 ***SDD simulated levels of silt for scenario 2 (summer baseline case 10% AEP flood event).***

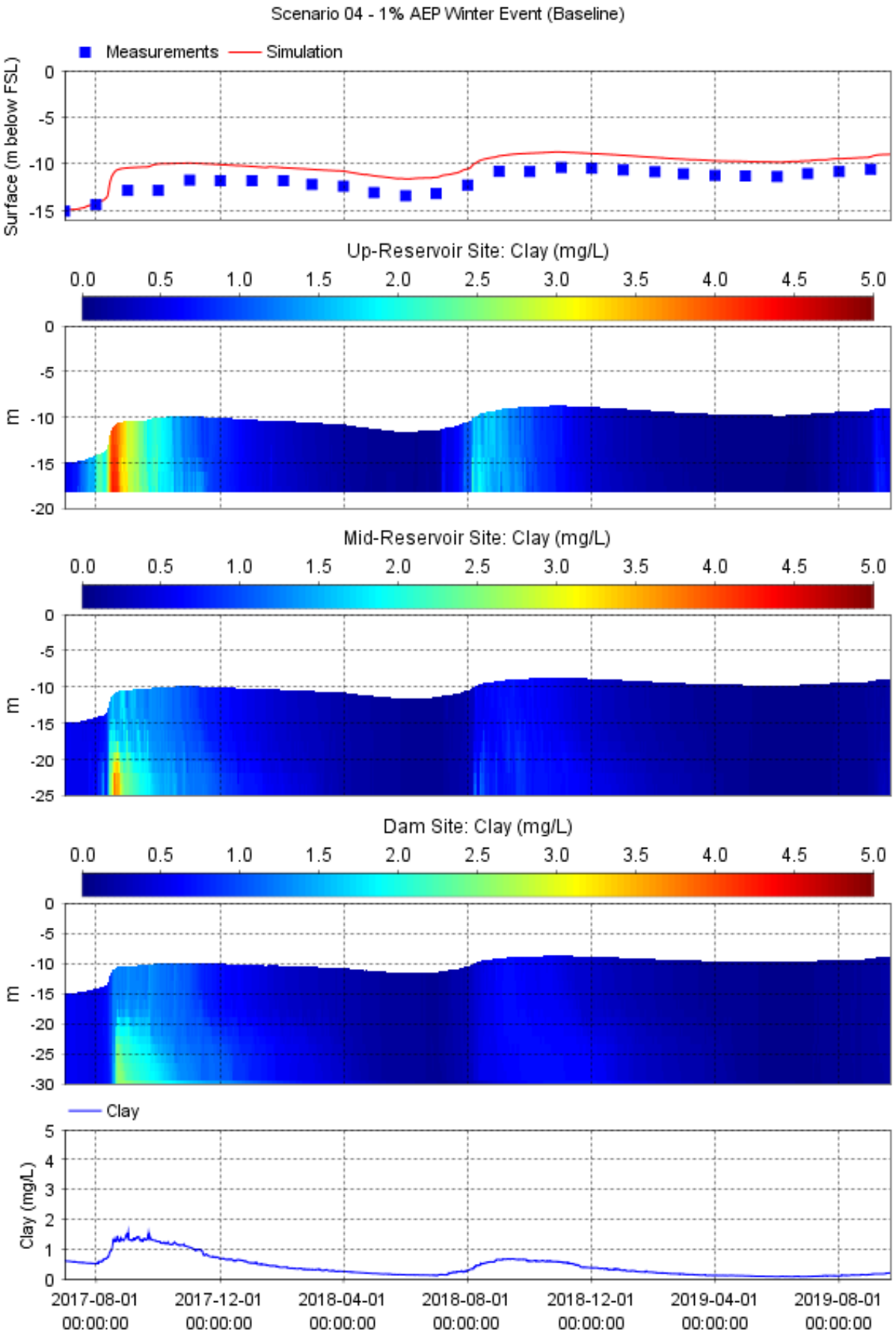


Figure 130 SDD simulated levels of clay for scenario 4 (winter baseline case 1% AEP flood event).

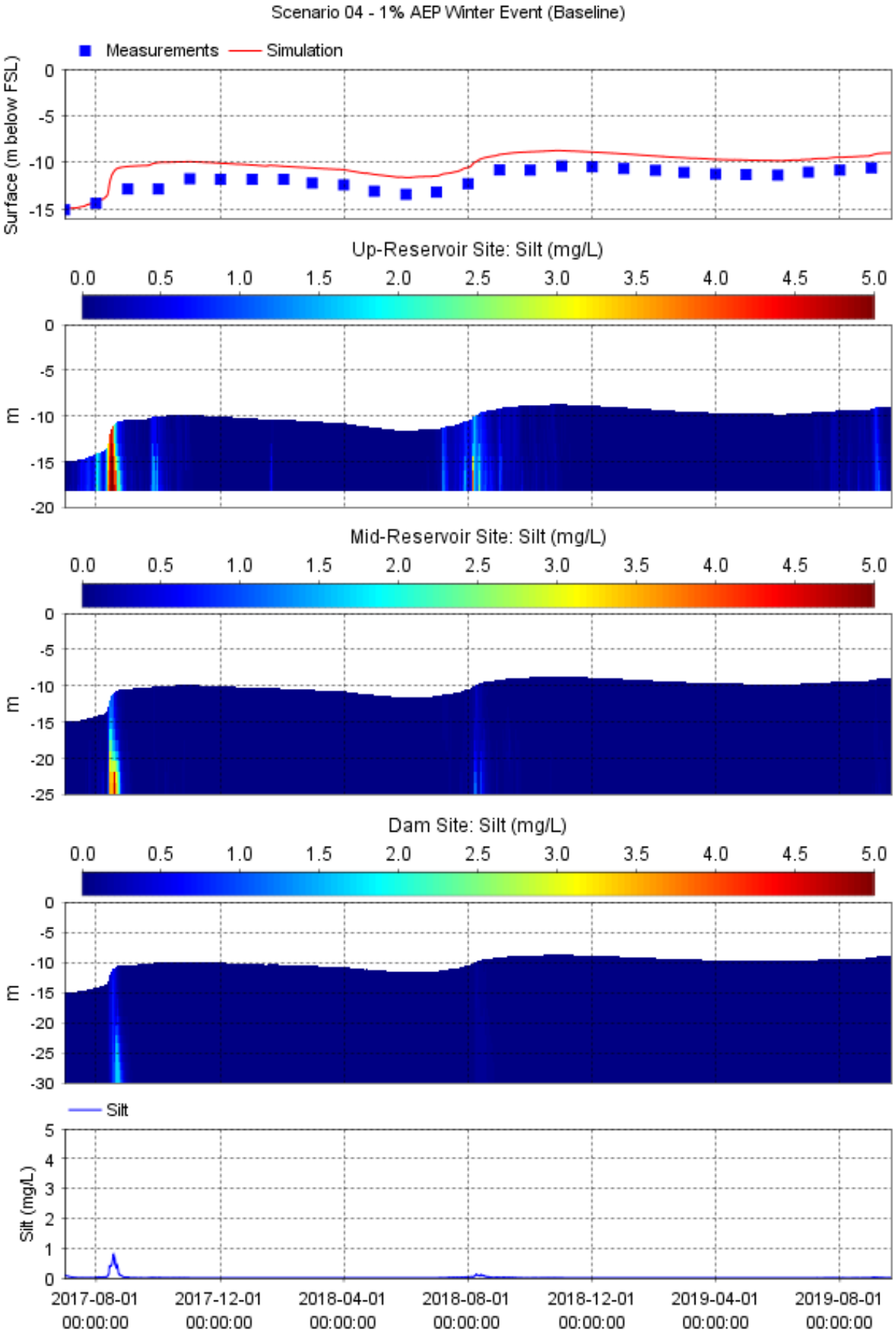


Figure 131 SDD simulated levels of silt for scenario 4 (winter baseline case 1% AEP flood event).

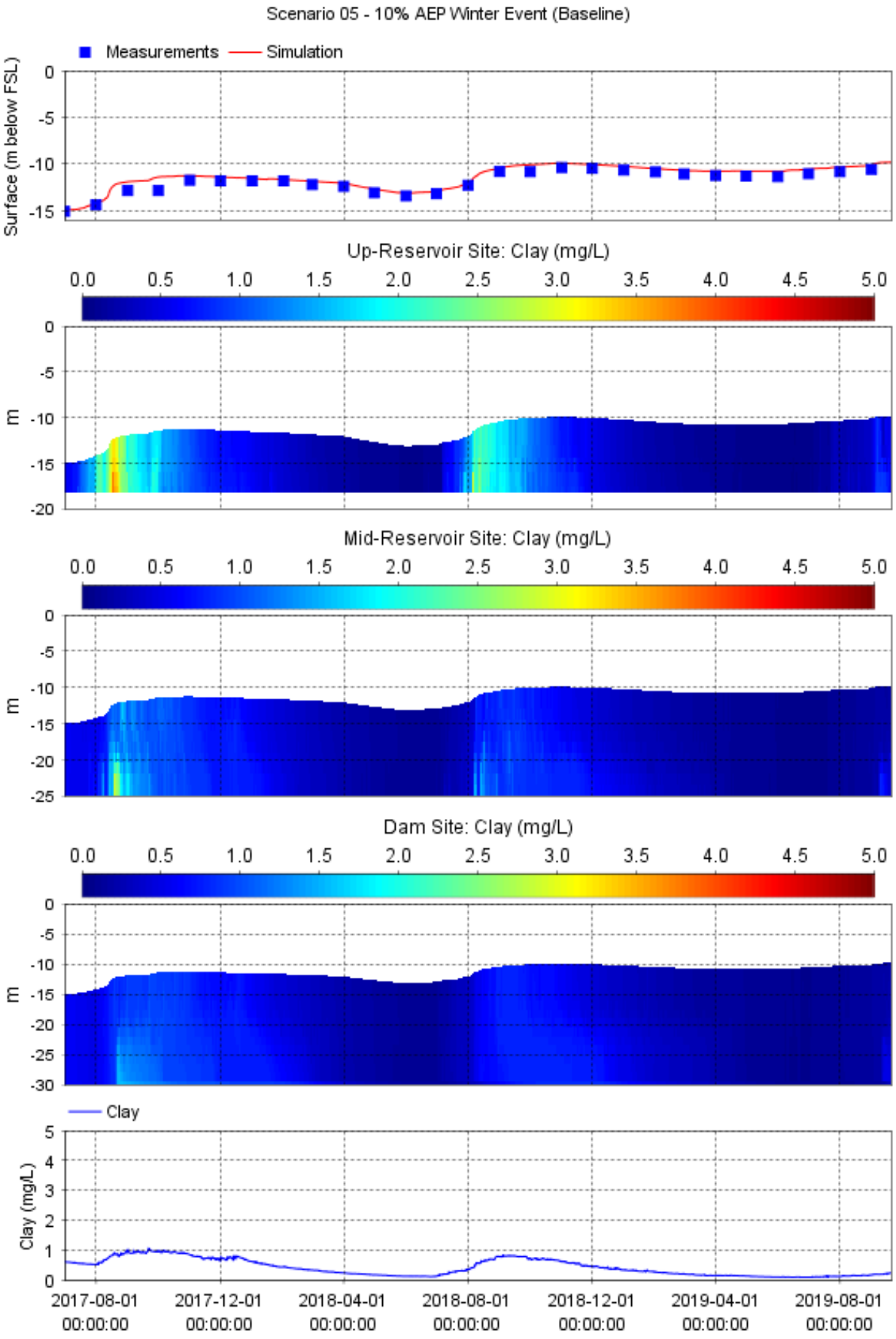


Figure 132 SDD simulated levels of clay for scenario 5 (winter baseline case 10% AEP flood event).

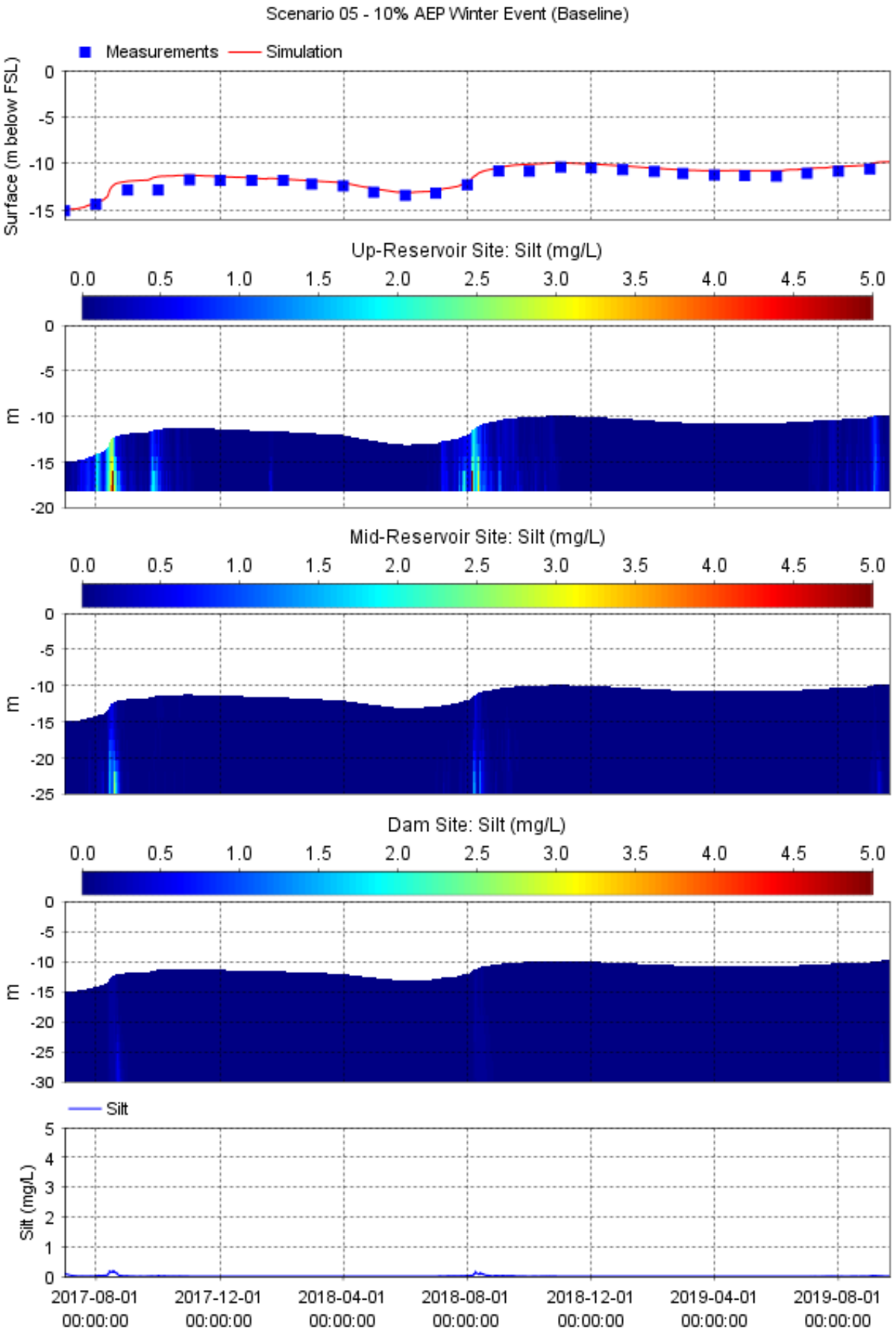


Figure 133 SDD simulated levels of silt for scenario 5 (winter baseline case 10% AEP flood event).

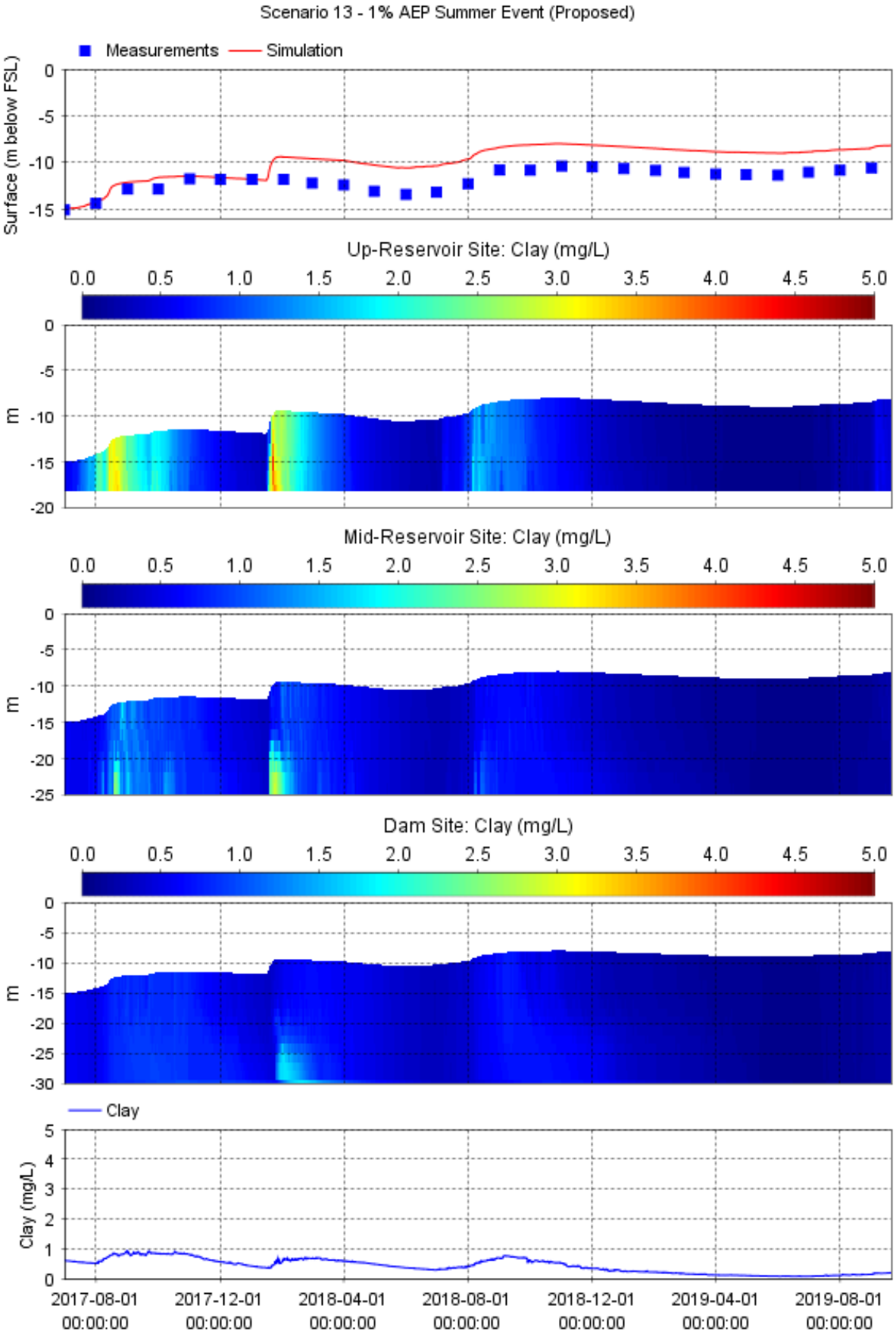


Figure 134 ***SDD simulated levels of clay for scenario 13 (summer proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

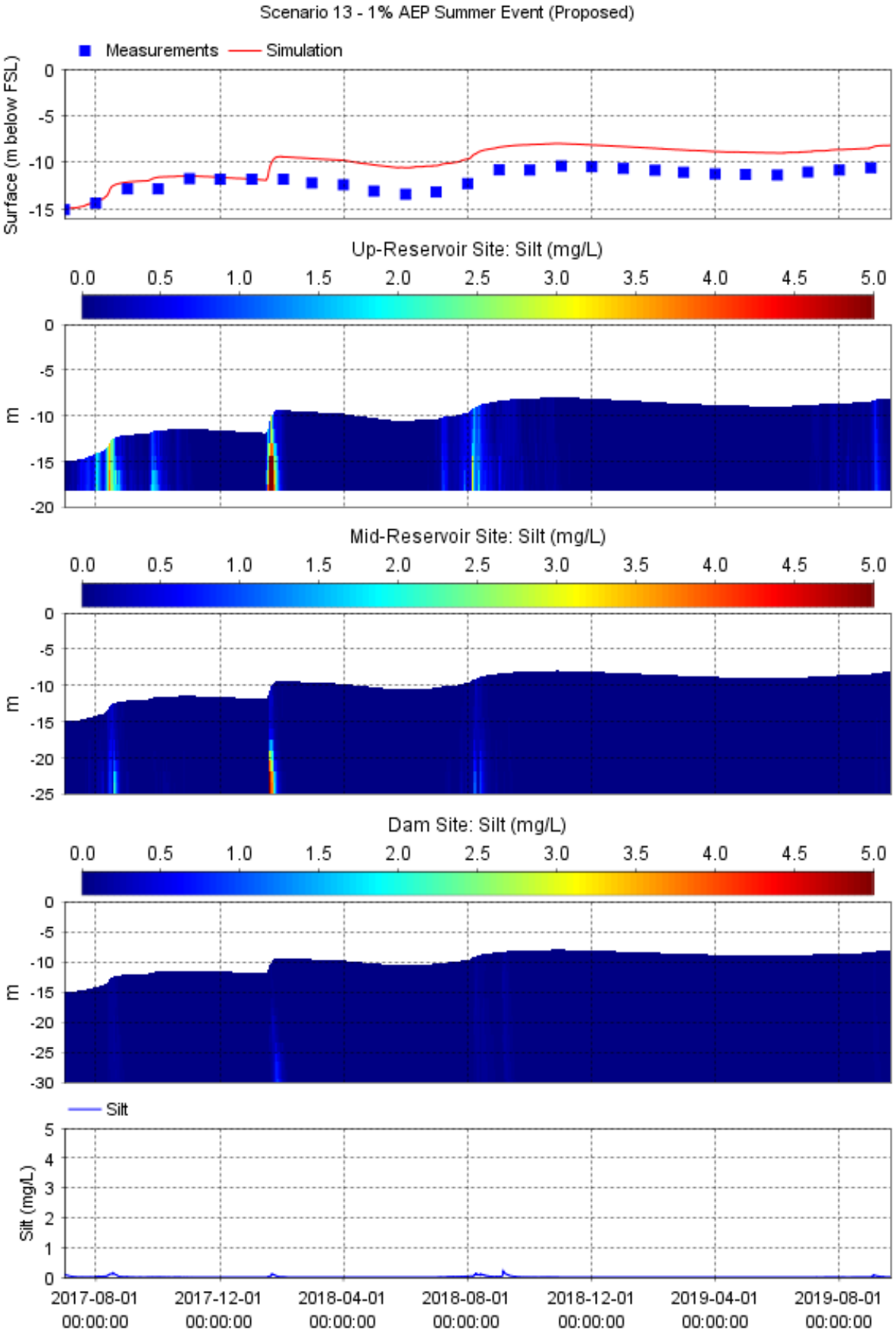


Figure 135 ***SDD simulated levels of silt for scenario 13 (summer proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

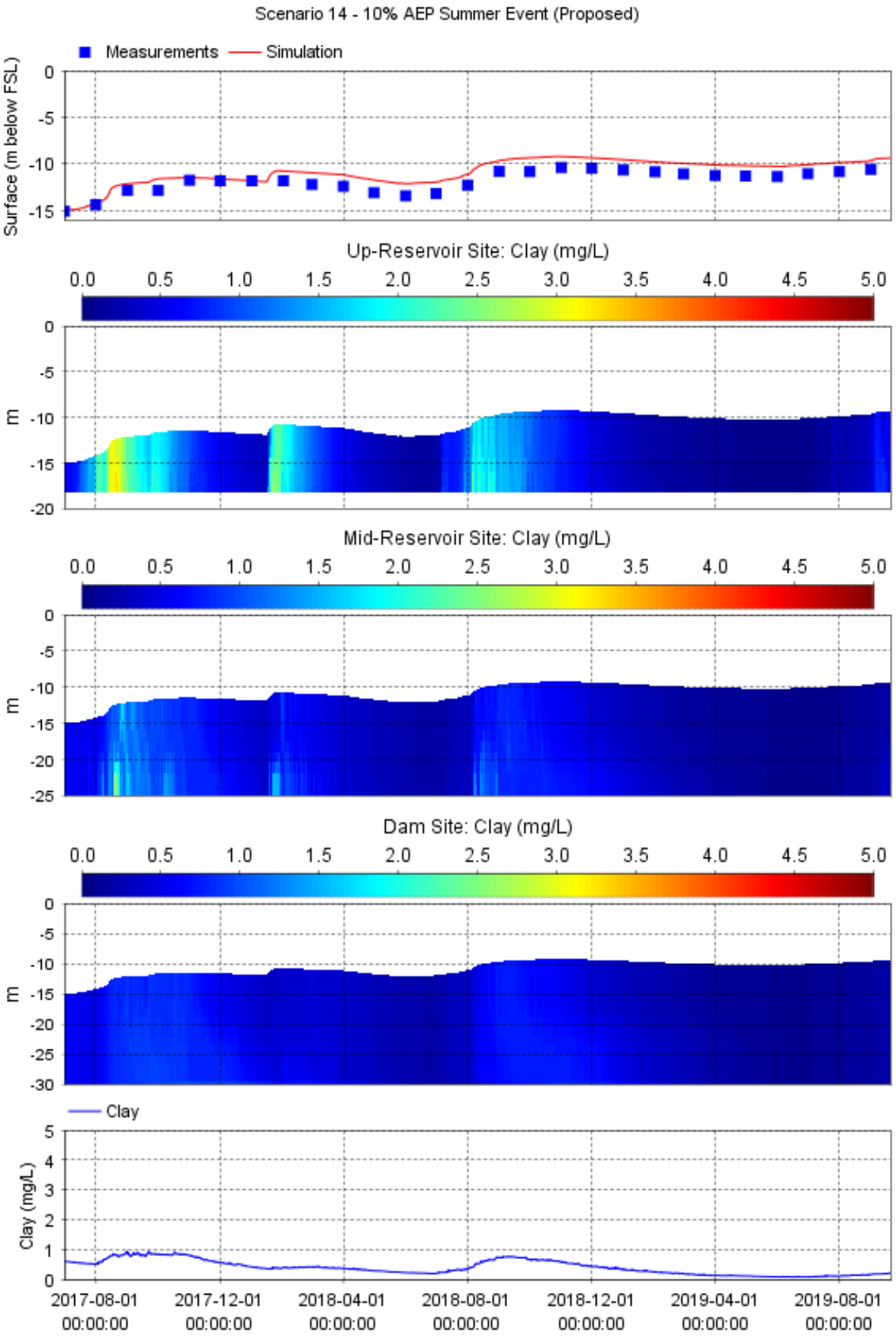


Figure 136 ***SDD simulated levels of clay for scenario 14 (summer proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

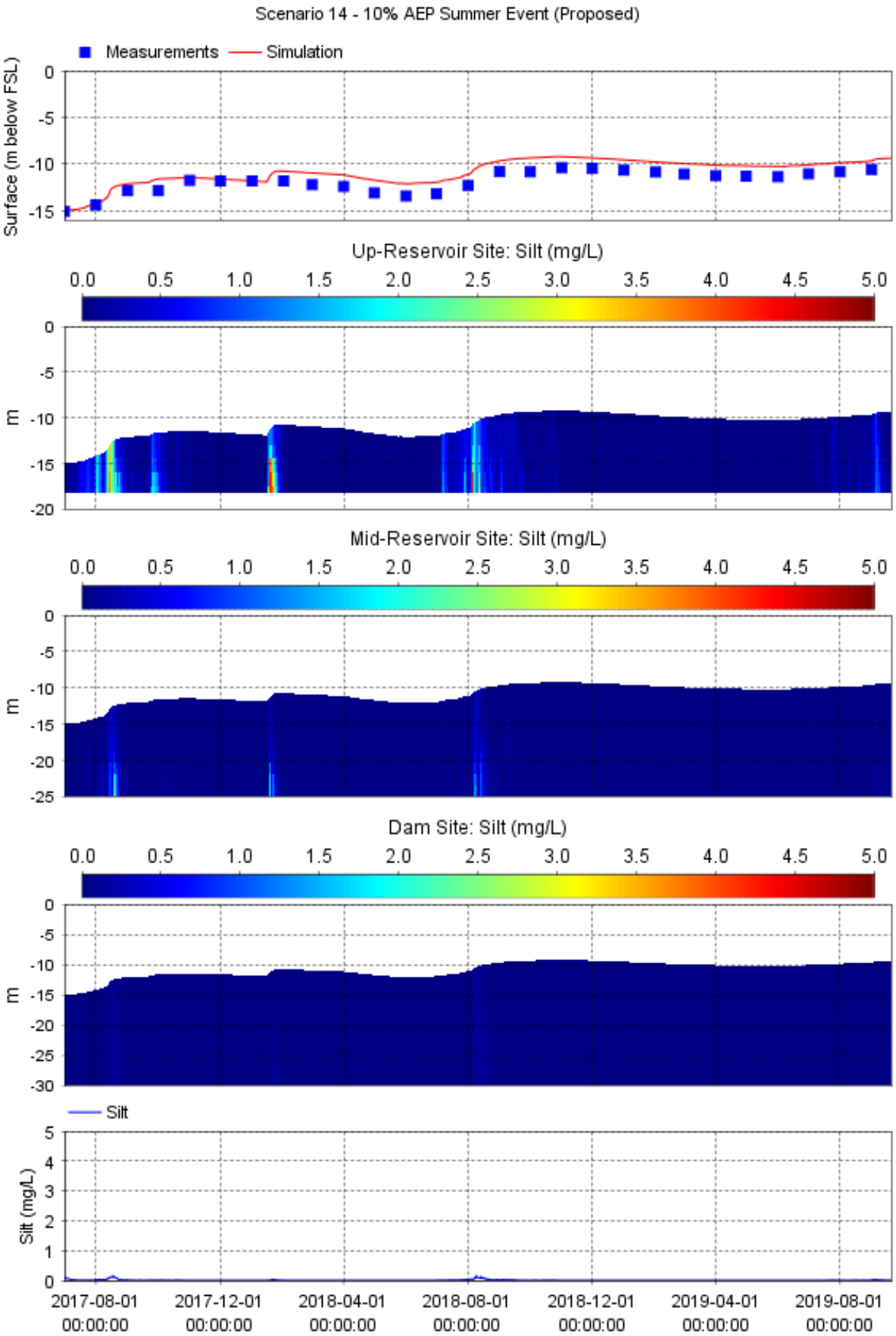


Figure 137 ***SDD simulated levels of silt for scenario 14 (summer proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

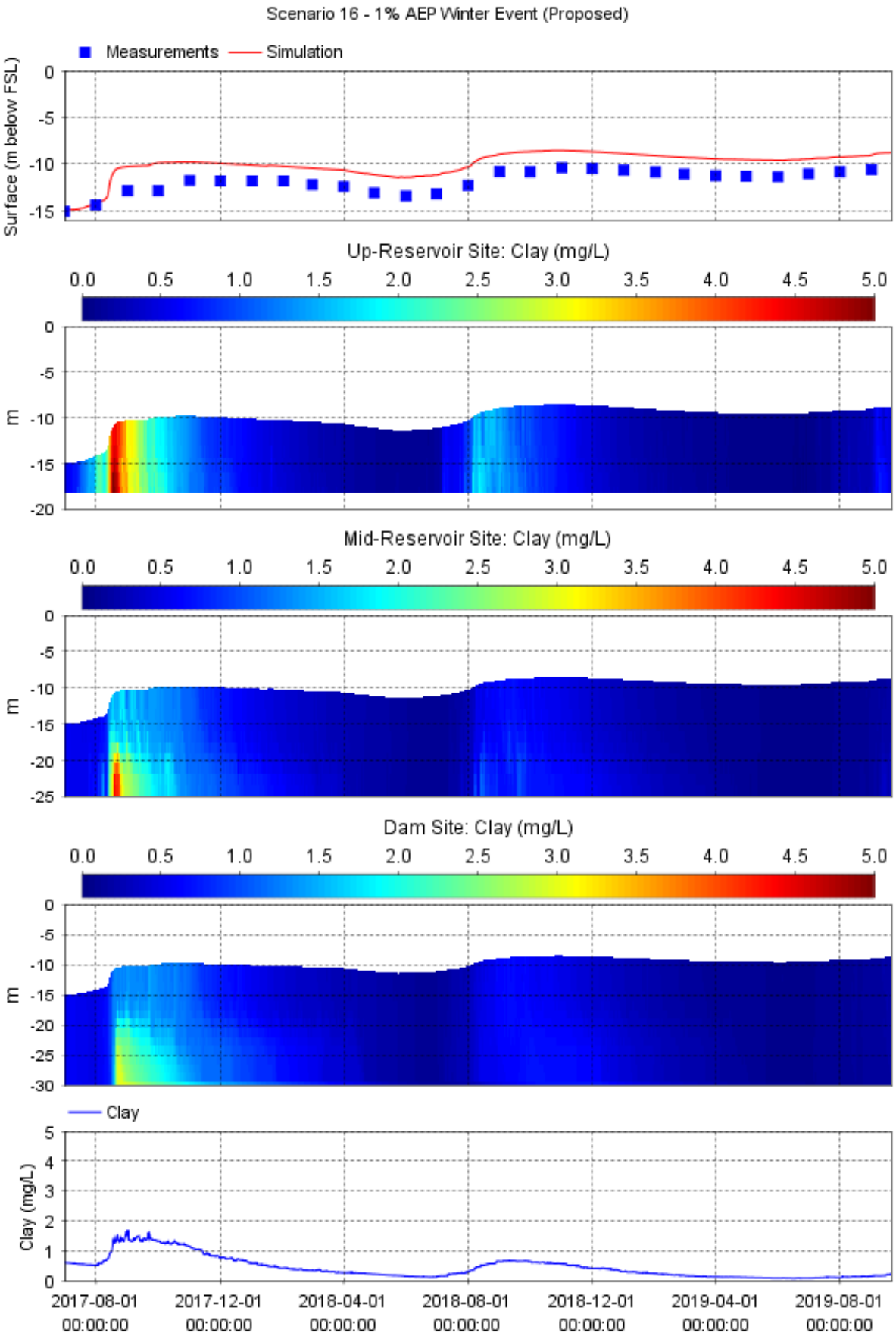


Figure 138 ***SDD simulated levels of clay for scenario 16 (winter proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

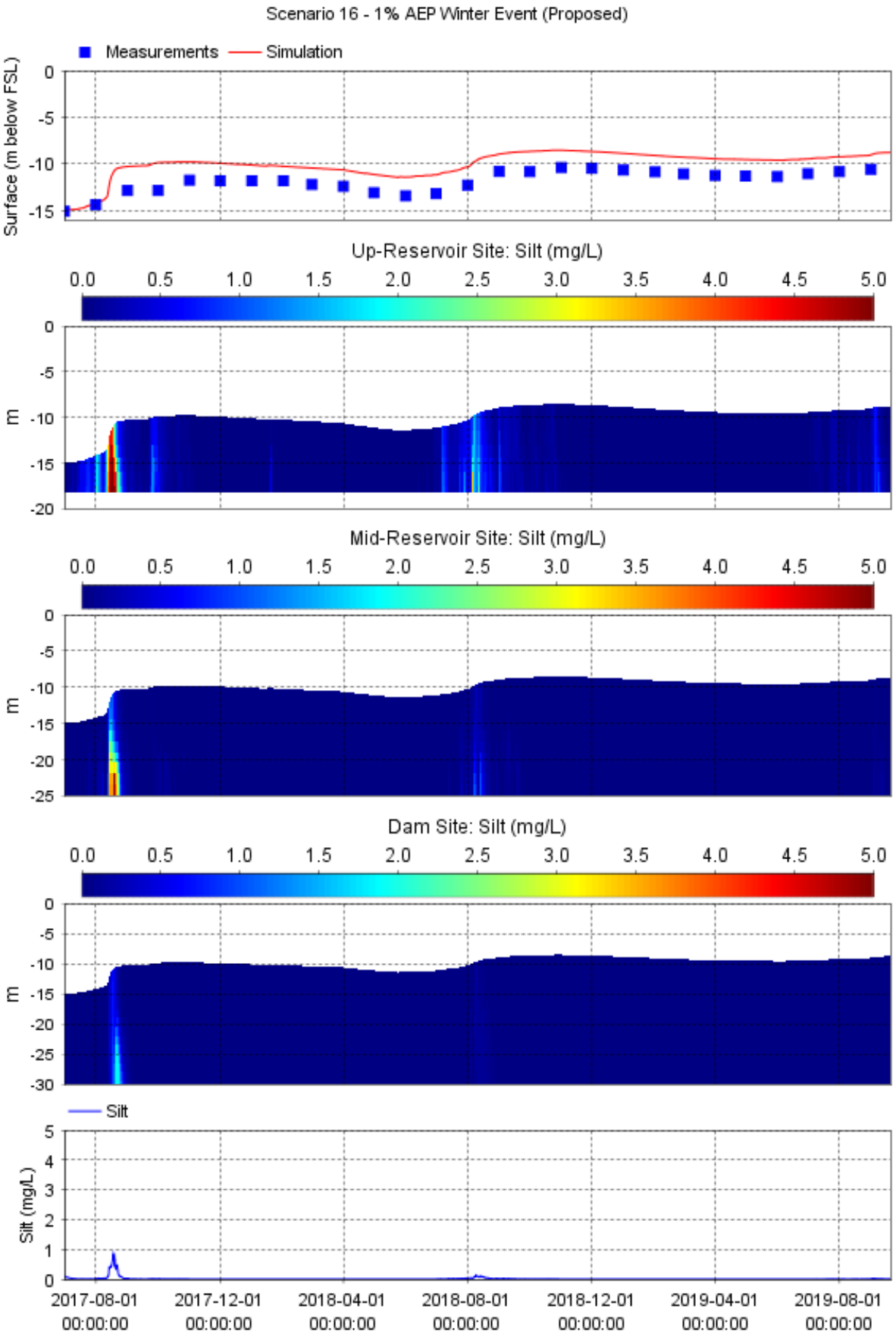


Figure 139 ***SDD simulated levels of silt for scenario 16 (winter proposed case 1% AEP flood event) with moderate drainage failure SS levels.***

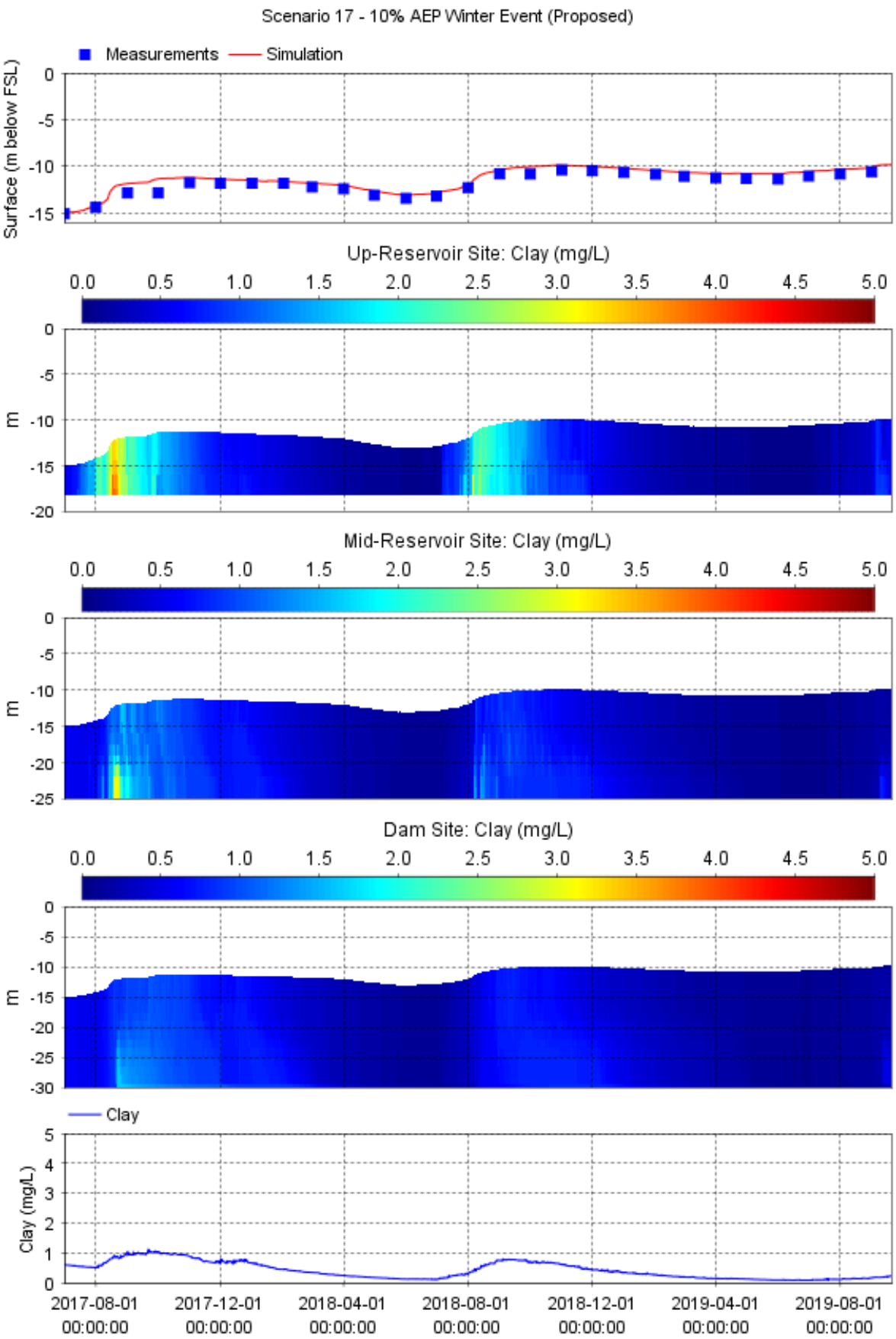


Figure 140 ***SDD simulated levels of clay for scenario 17 (winter proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

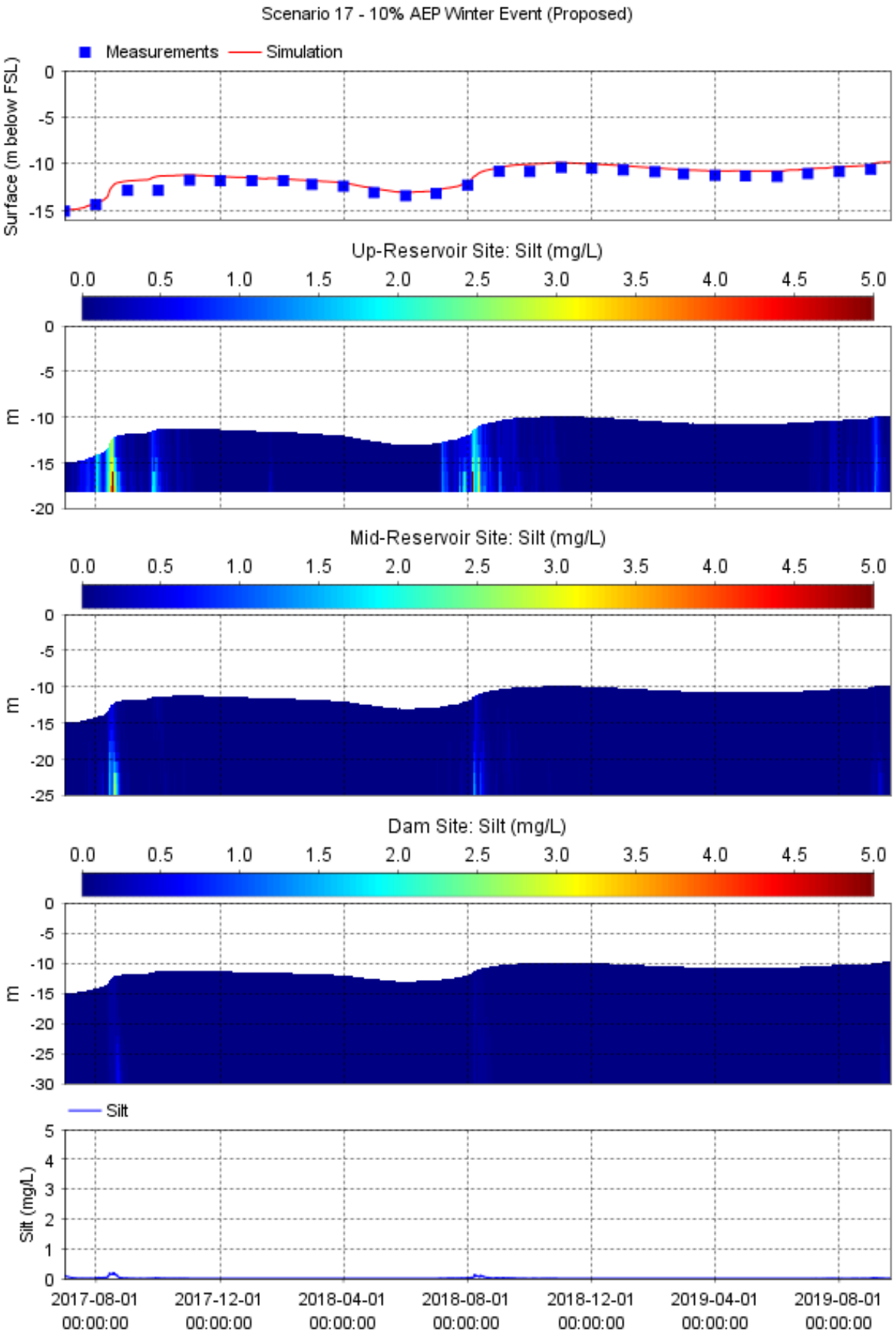


Figure 141 ***SDD simulated levels of silt for scenario 17 (winter proposed case 10% AEP flood event) with moderate drainage failure SS levels.***

Appendix G

SDD: 1% and 10% AEP Flood Event Inputs (High Drainage Failure SS Levels)

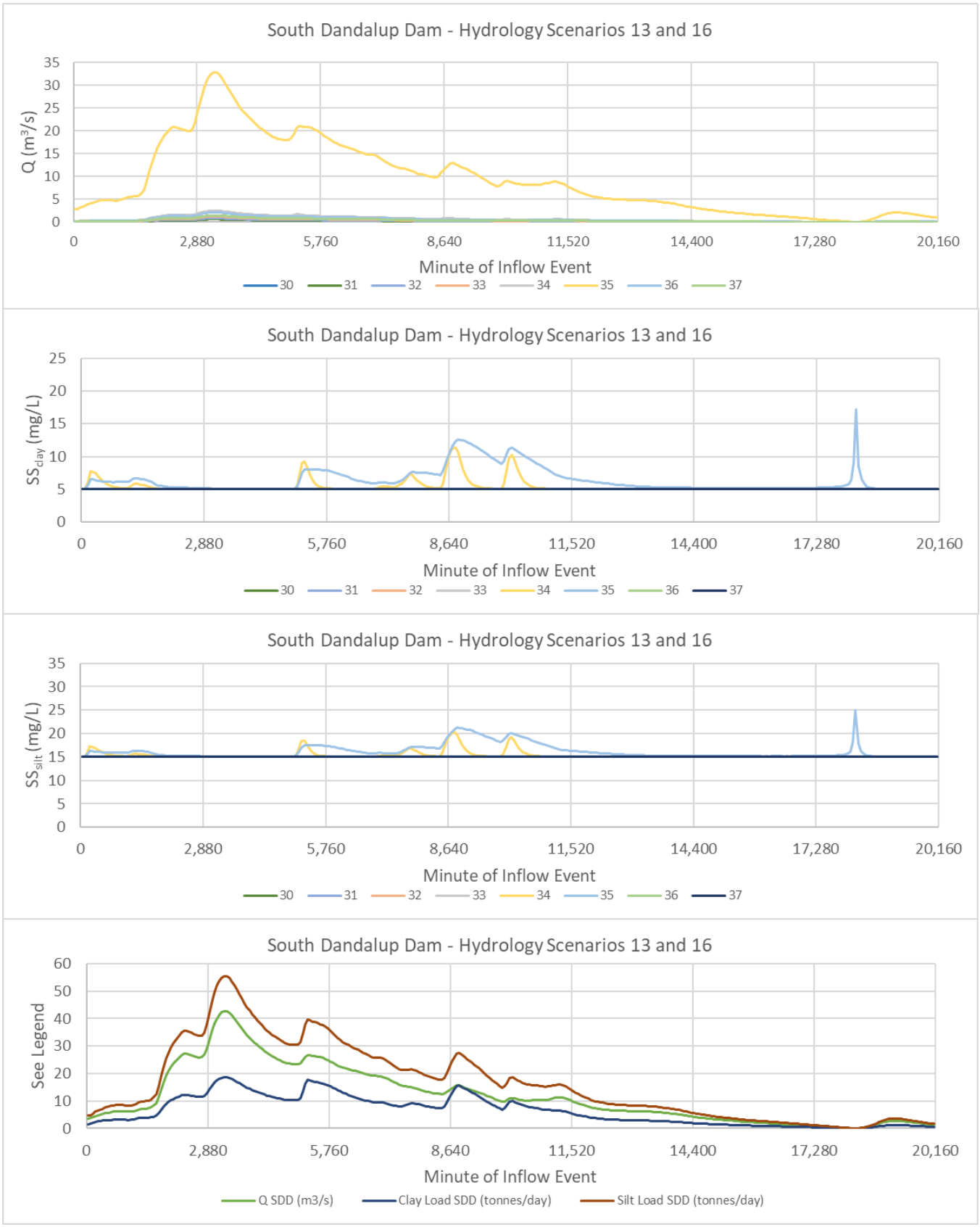


Figure 142 SDD hydrology and suspended solids inputs for scenarios 13H and 16H with high drainage failure SS levels.

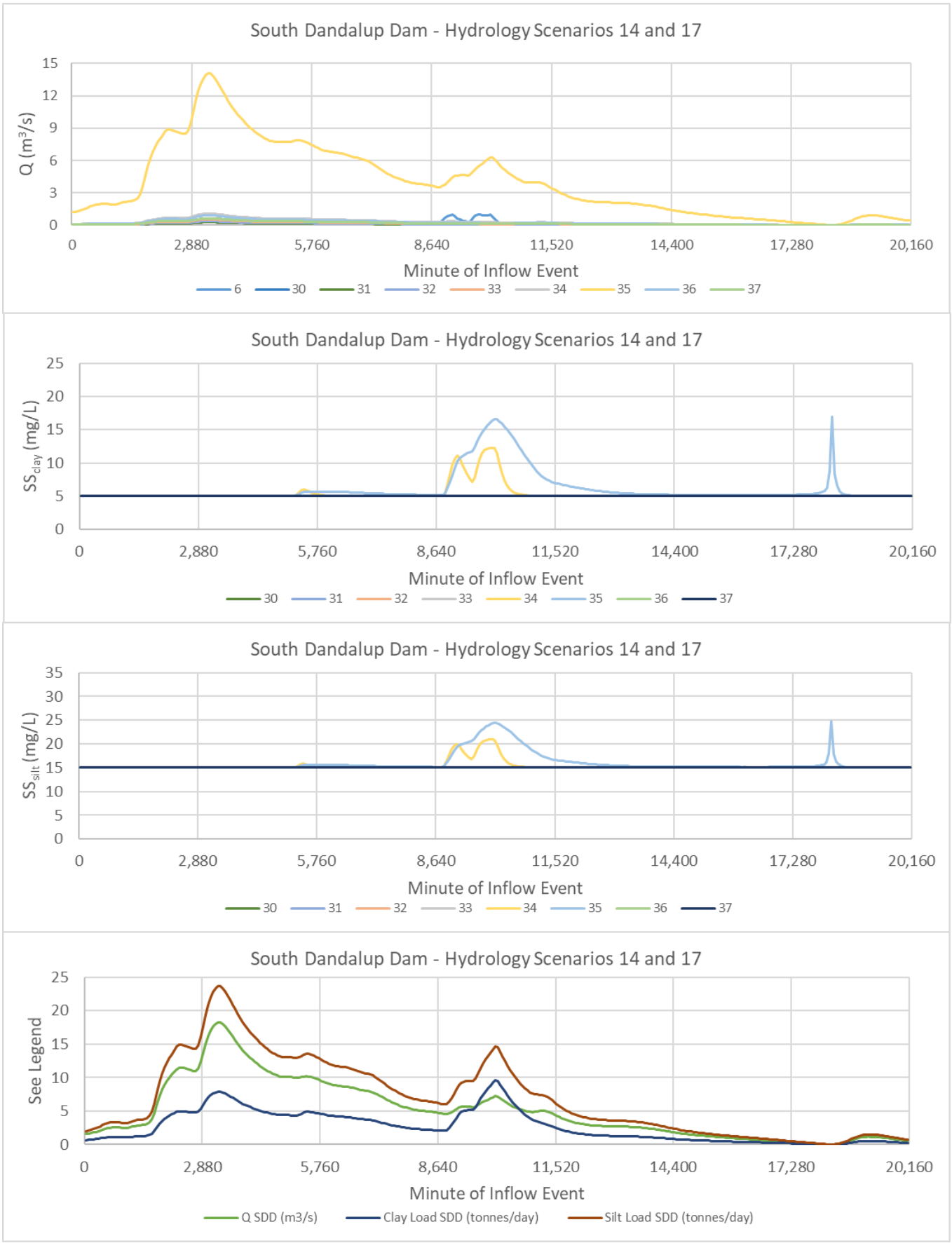


Figure 143 ***As Figure 122 for scenarios 14H and 17H with high drainage failure SS levels.***

Appendix H

SDD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)

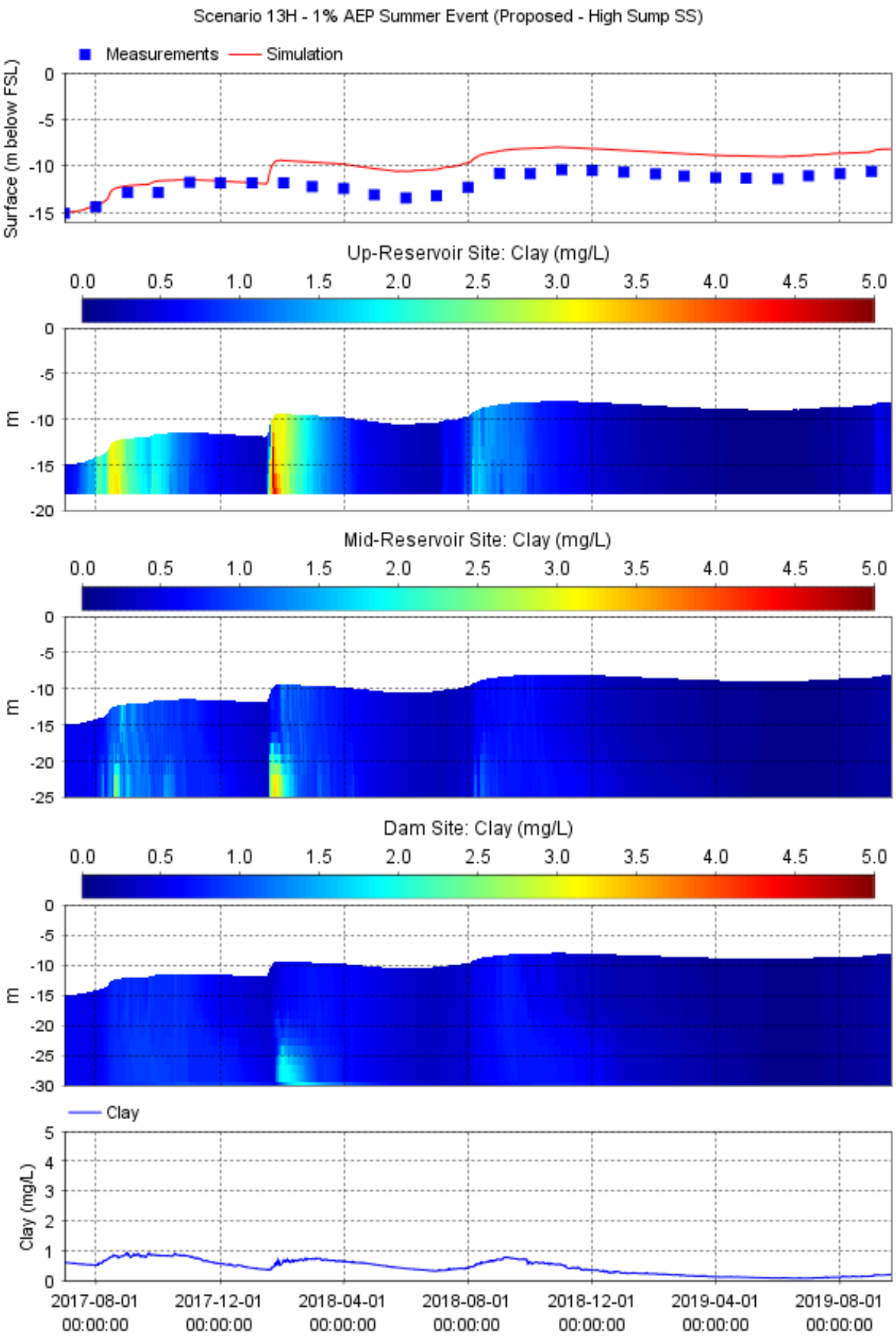


Figure 144 ***SDD simulated levels of clay for scenario 13H (summer proposed case 1% AEP flood event) with high drainage failure SS levels.***

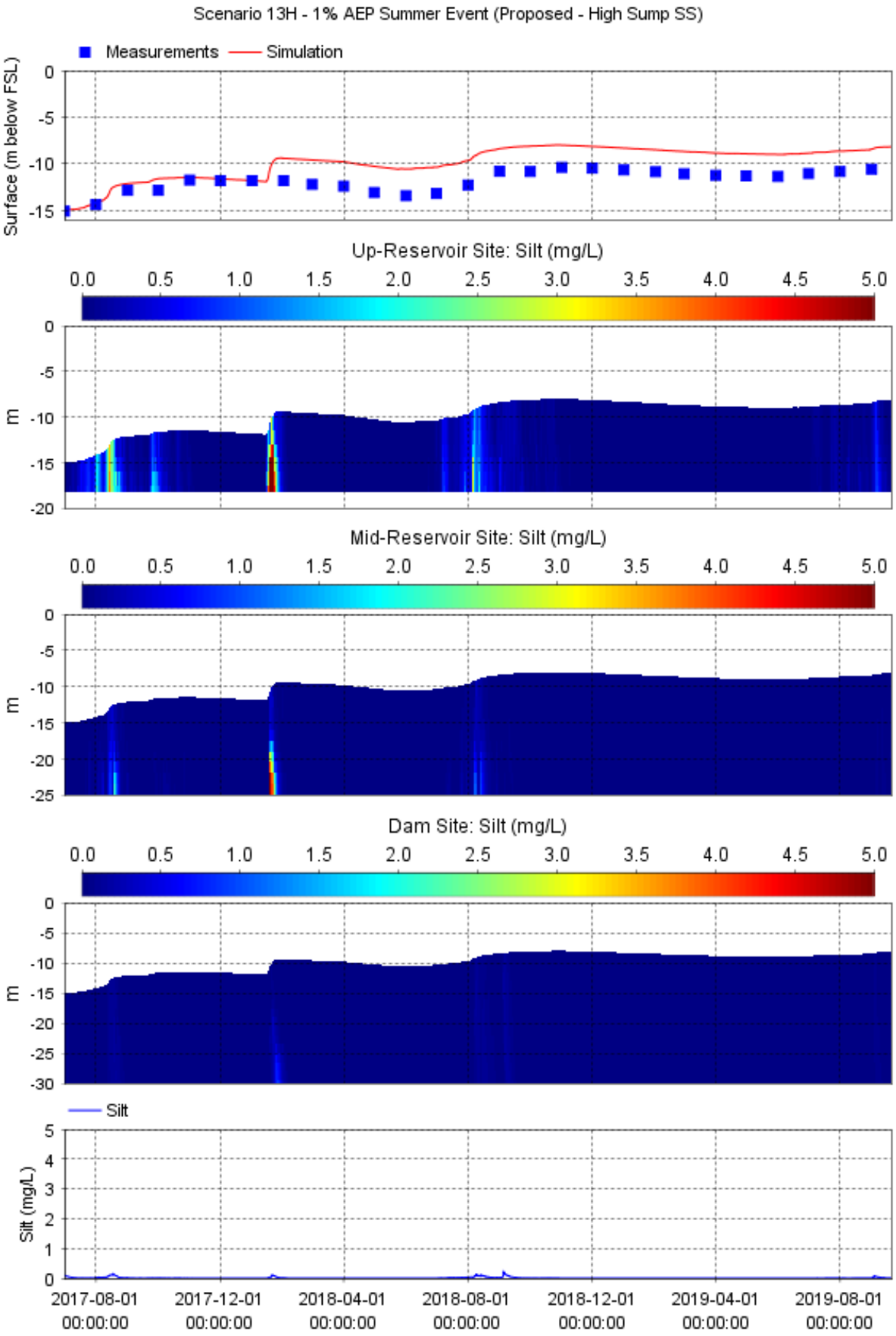


Figure 145 ***SDD simulated levels of silt for scenario 13H (summer proposed case 1% AEP flood event) with high drainage failure SS levels.***

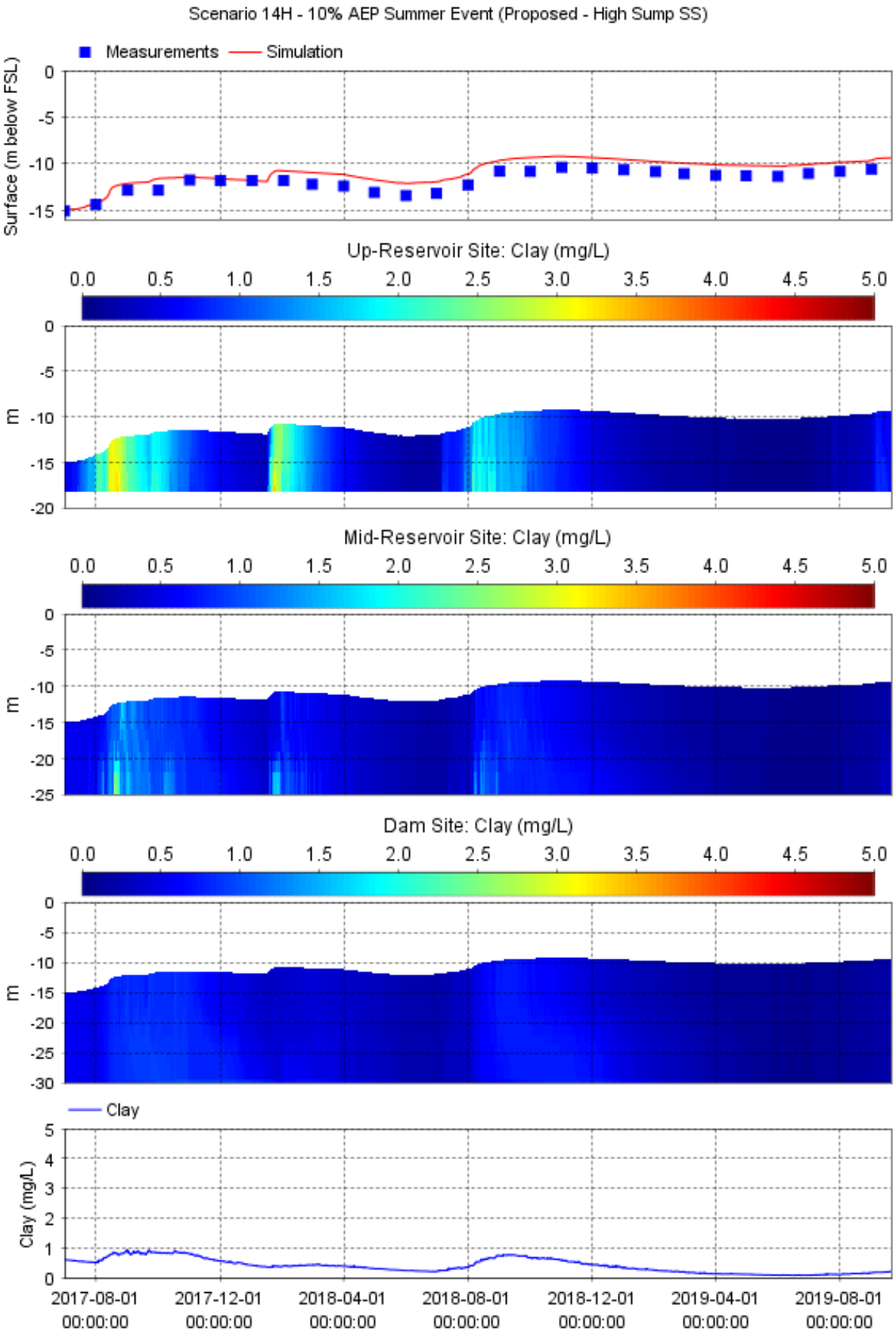


Figure 146 ***SDD simulated levels of clay for scenario 14H (summer proposed case 10% AEP flood event) with high drainage failure SS levels.***

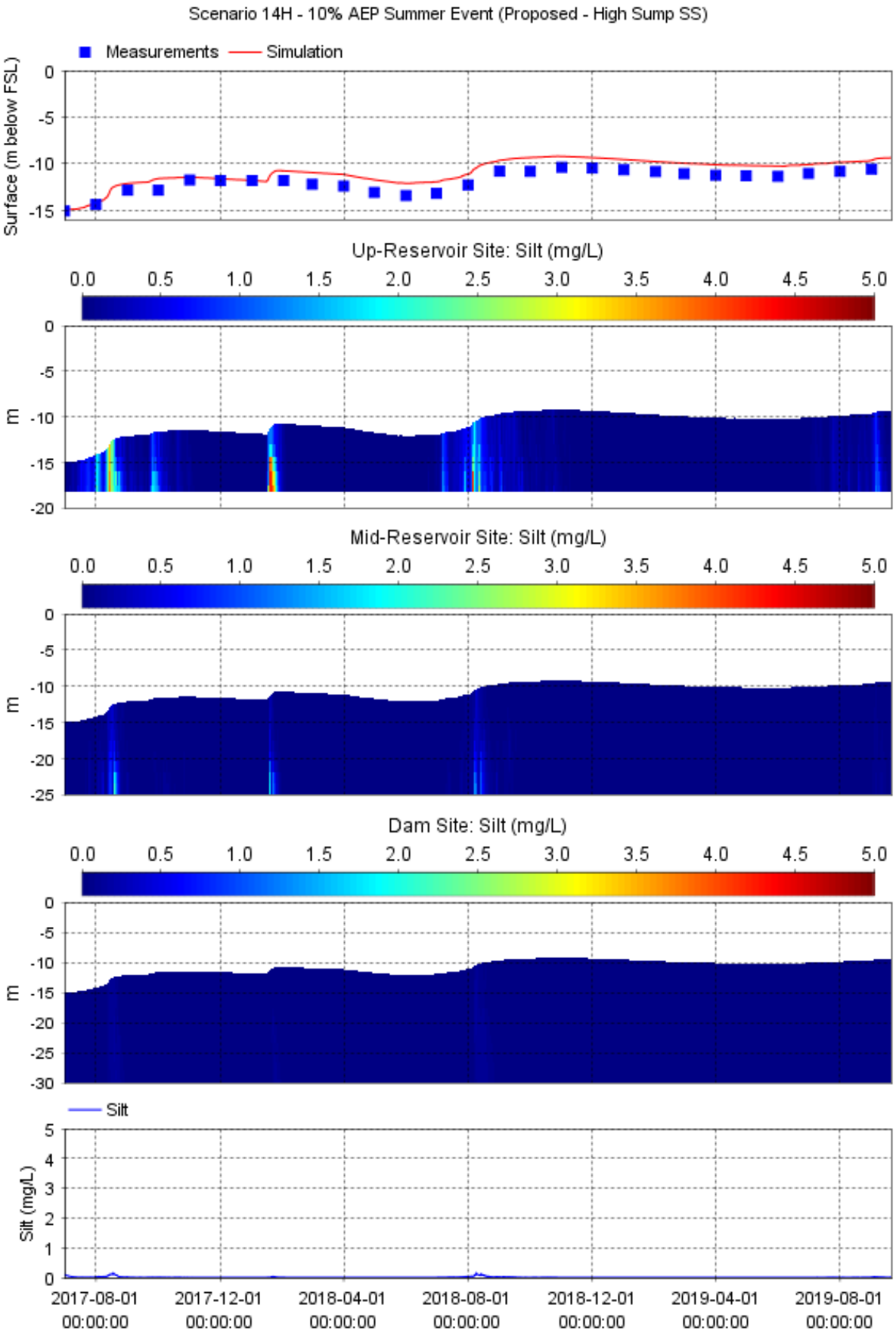


Figure 147 ***SDD simulated levels of silt for scenario 14H (summer proposed case 10% AEP flood event) with high drainage failure SS levels.***

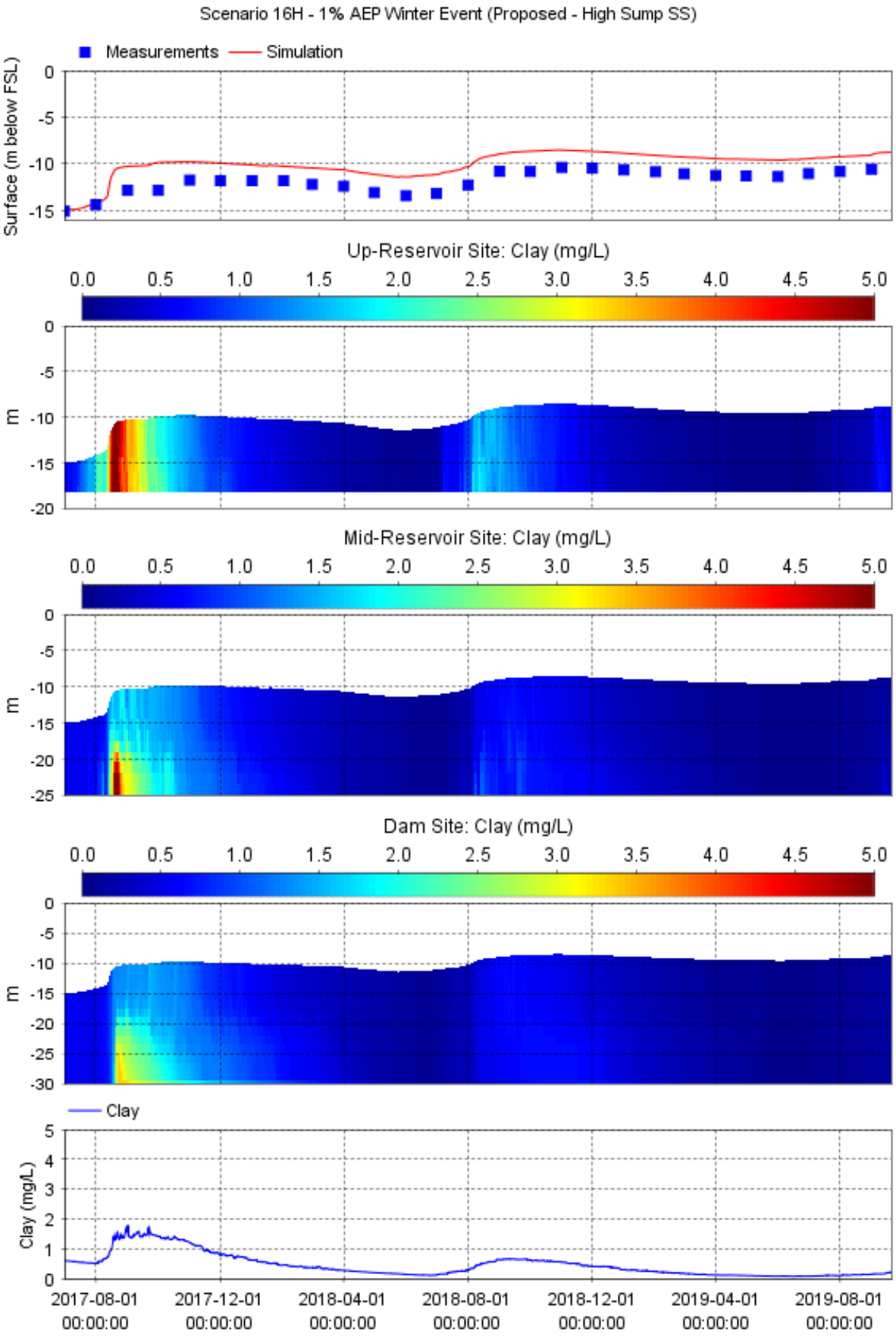


Figure 148 ***SDD simulated levels of clay for scenario 16H (winter proposed case 1% AEP flood event) with high drainage failure SS levels.***

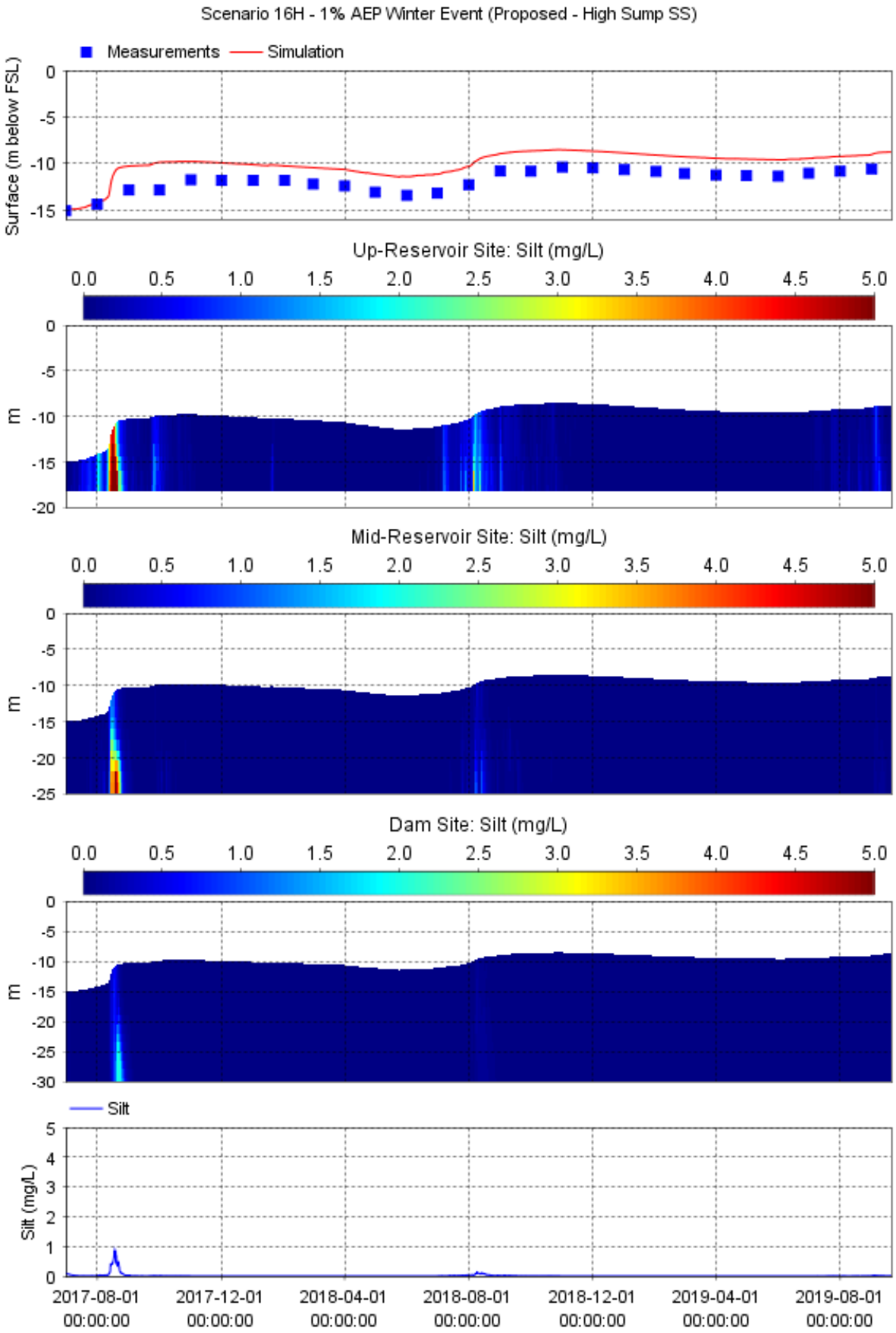


Figure 149 ***SDD simulated levels of silt for scenario 16H (winter proposed case 1% AEP flood event) with high drainage failure SS levels.***

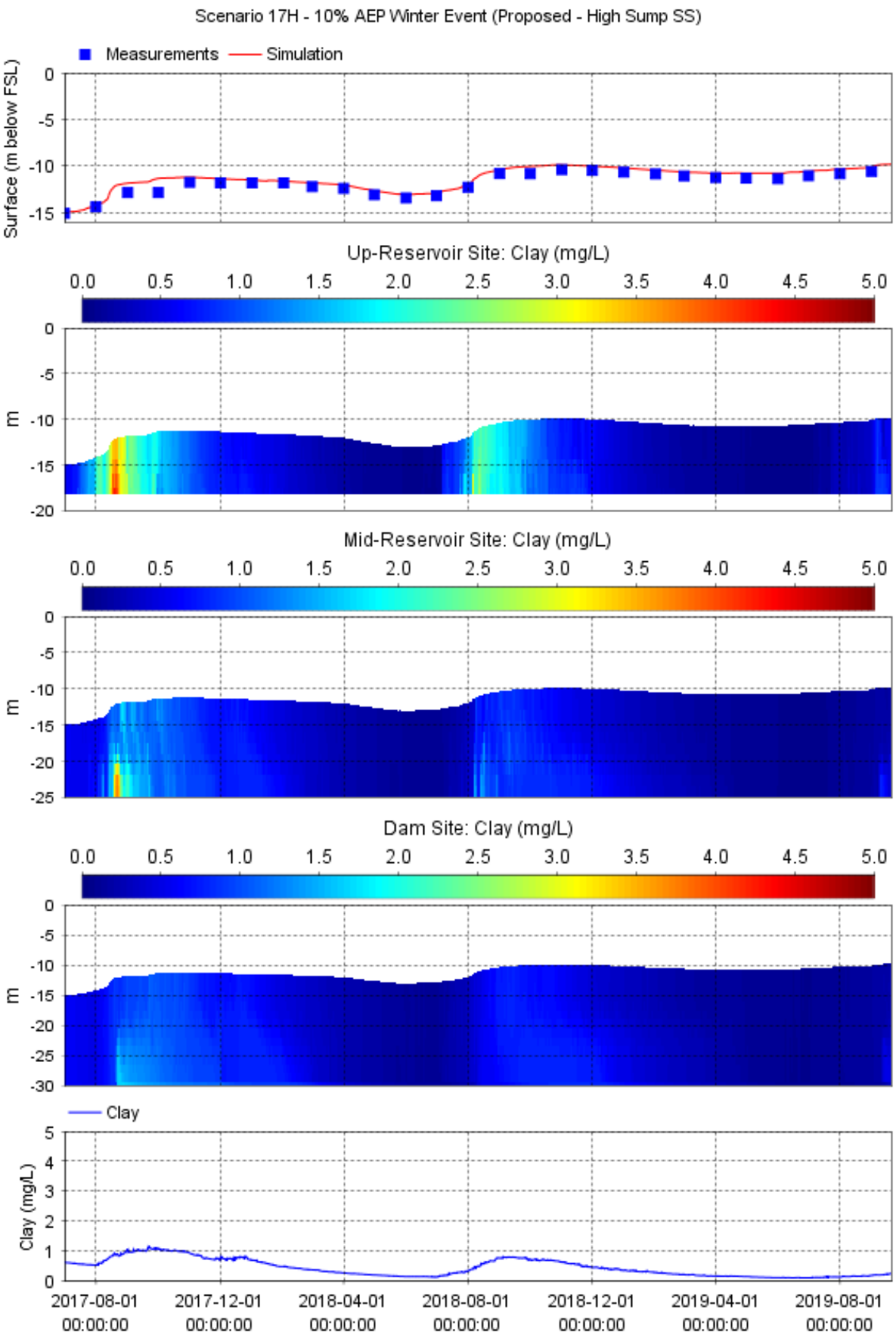


Figure 150 ***SDD simulated levels of clay for scenario 17H (winter proposed case 10% AEP flood event) with high drainage failure SS levels.***

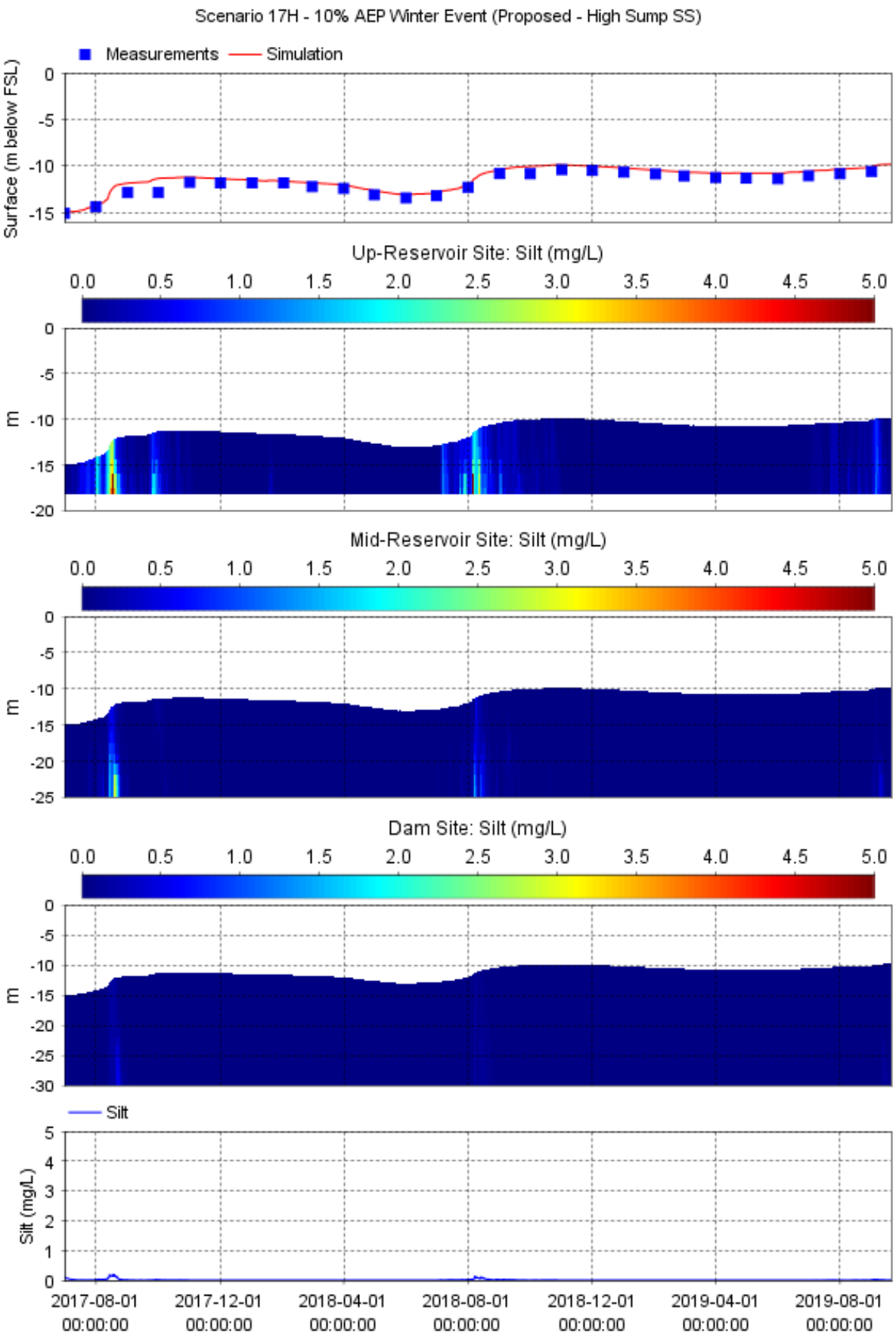


Figure 151 ***SDD simulated levels of silt for scenario 17H (winter proposed case 10% AEP flood event) with high drainage failure SS levels.***

Appendix I

SPD: 1% and 10% AEP Flood Event Inputs (Moderate Drainage Failure SS Levels)

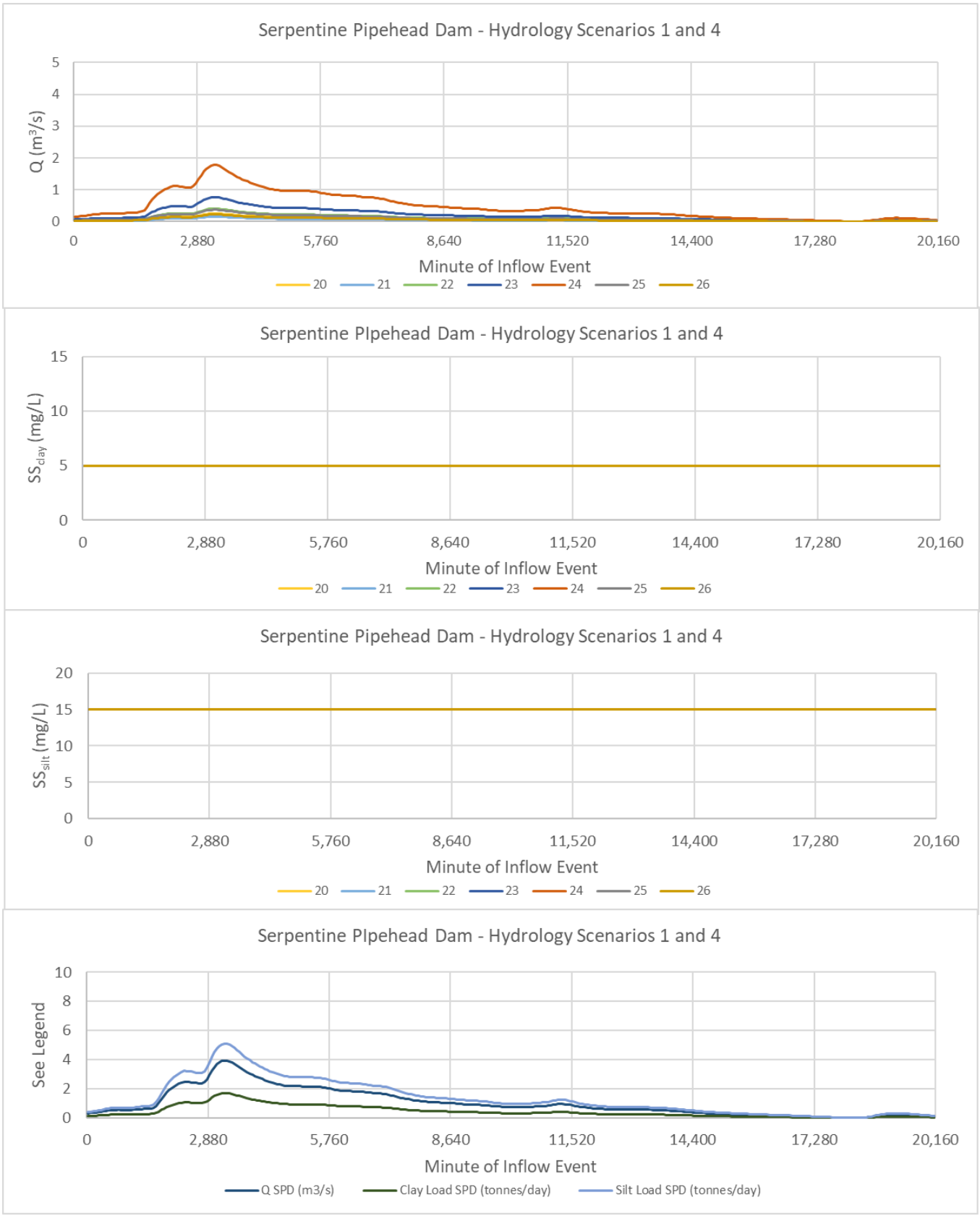


Figure 152 SPD hydrology and suspended solids inputs for scenarios 1 and 4.



Figure 153 ***SPD hydrology and suspended solids inputs for scenarios 2 and 5.***

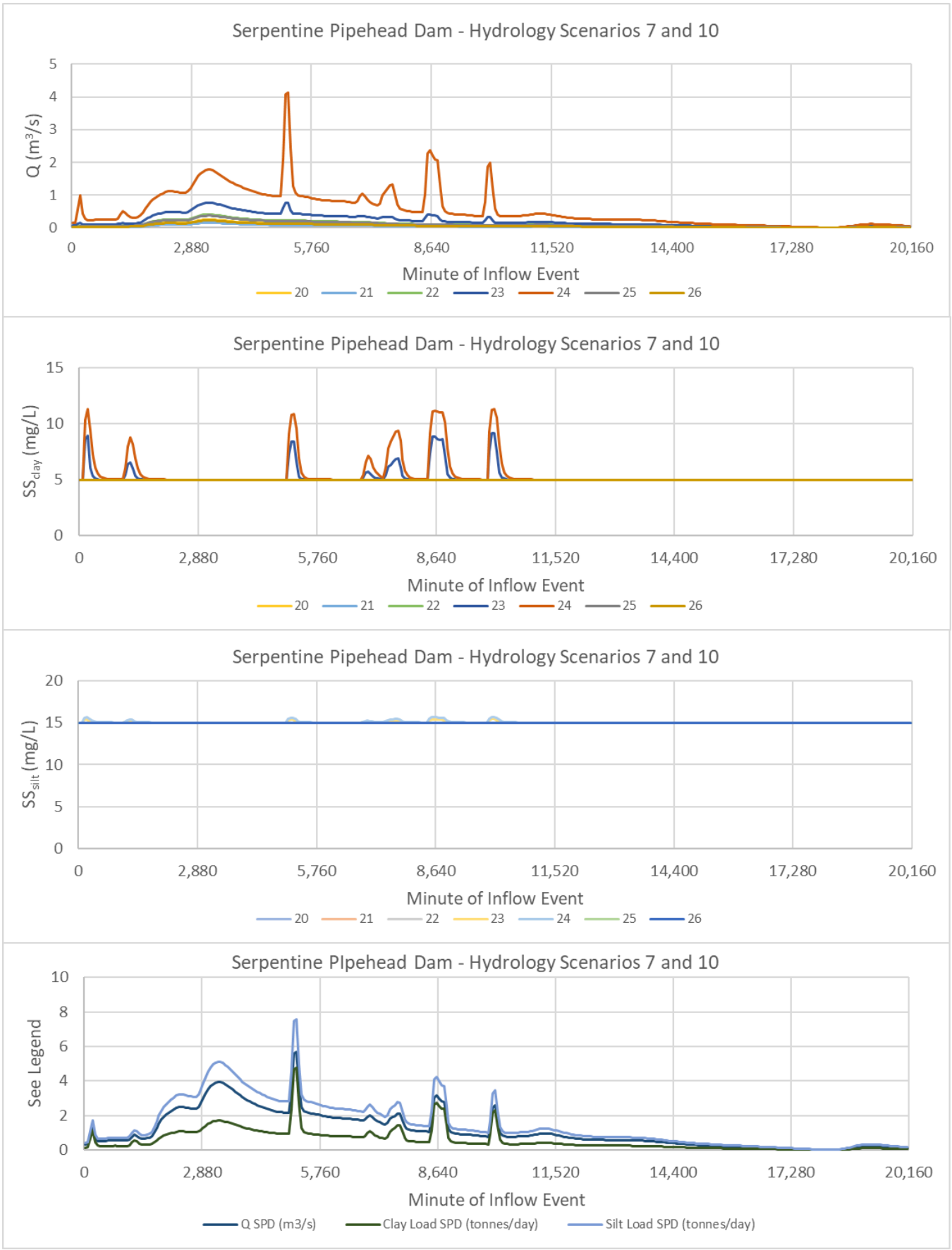


Figure 154 SPD hydrology and suspended solids inputs for scenarios 7 and 10 with moderate drainage failure SS levels.

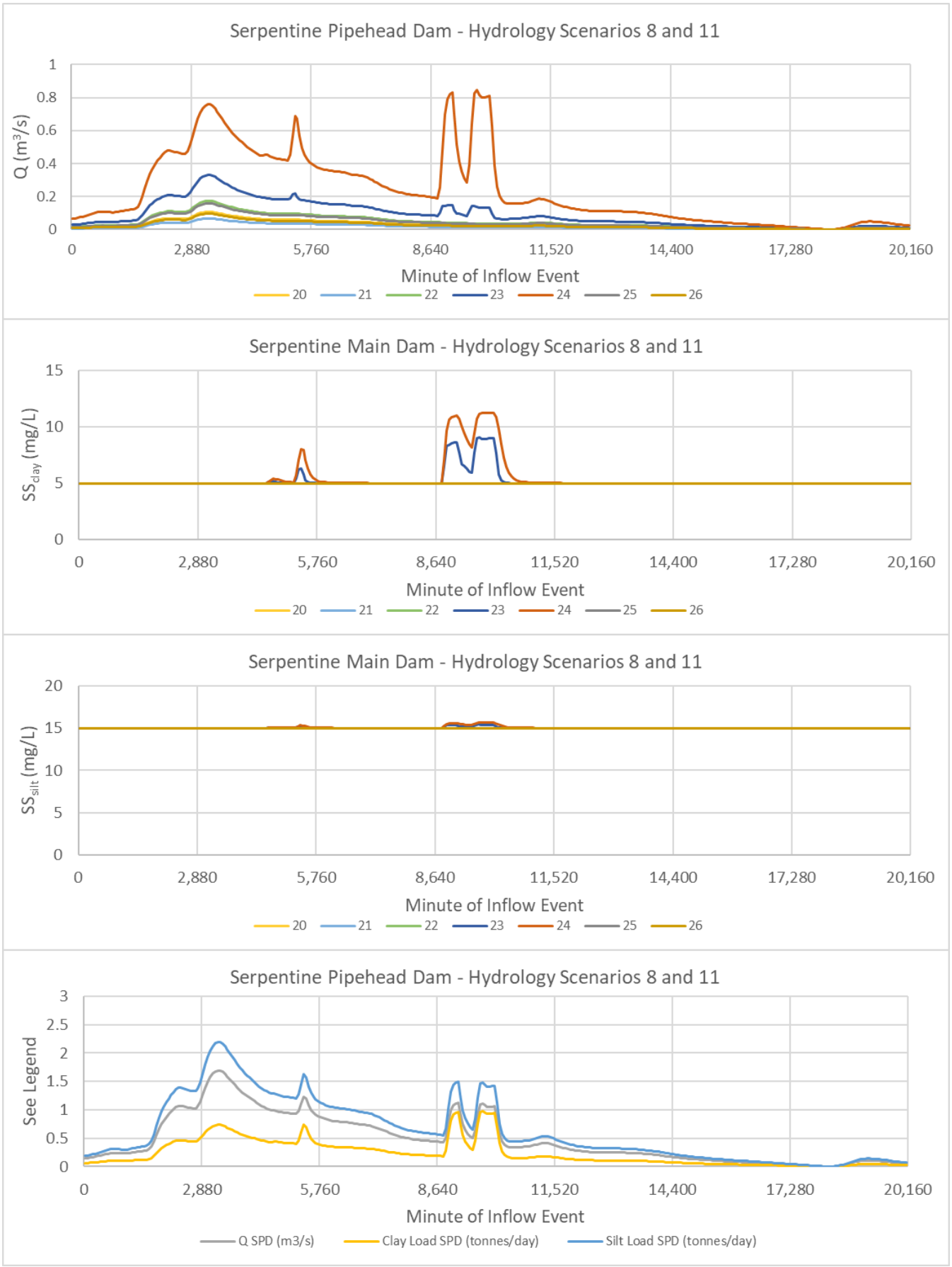


Figure 155 ***SPD hydrology and suspended solids inputs for scenarios 8 and 11 with moderate drainage failure SS levels.***

Appendix J

SPD: 1% and 10% AEP Flood Event Simulations (Moderate Drainage Failure SS Levels)

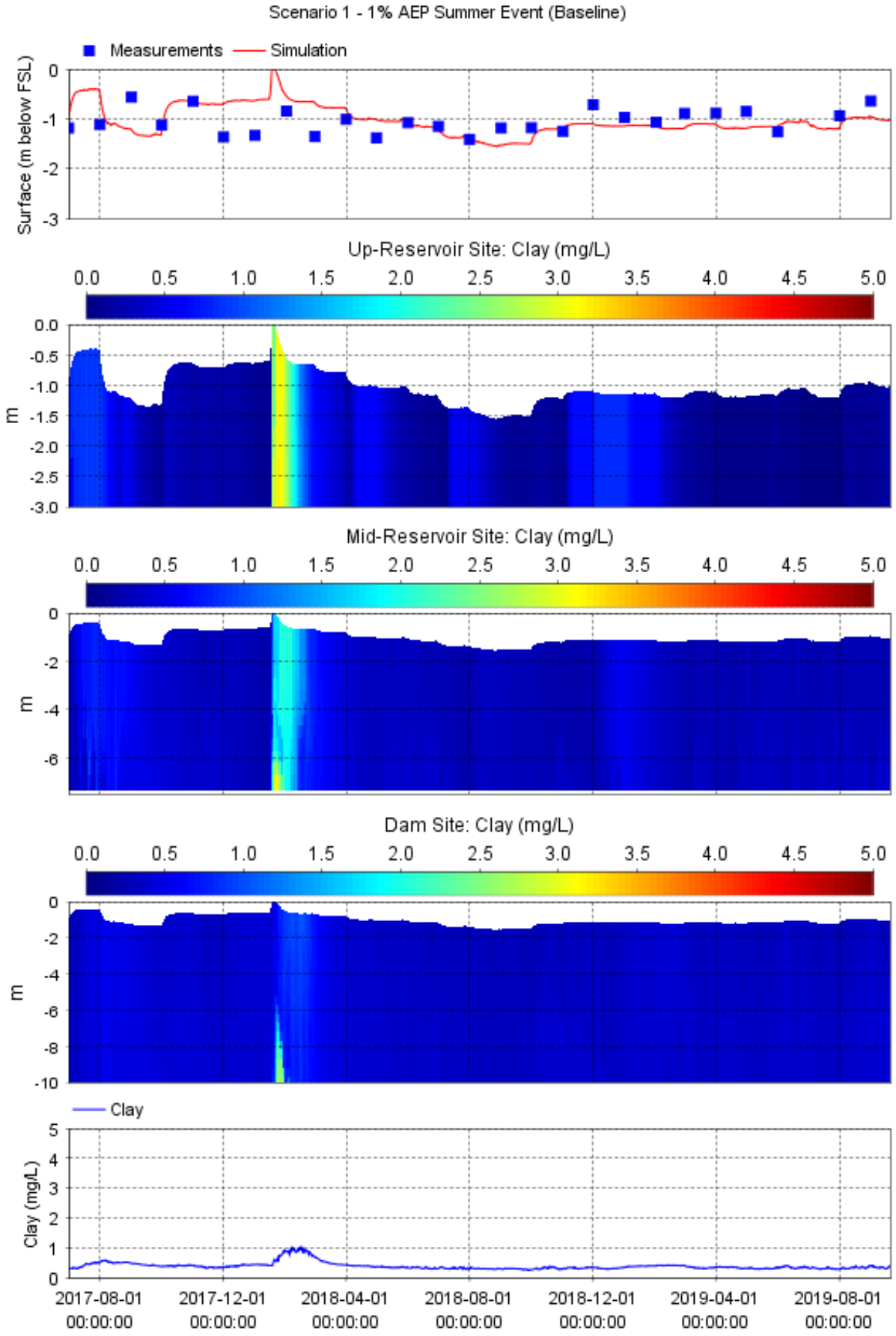


Figure 156 ***SPD simulated levels of clay for scenario 1 (summer baseline case 1% AEP flood event).***

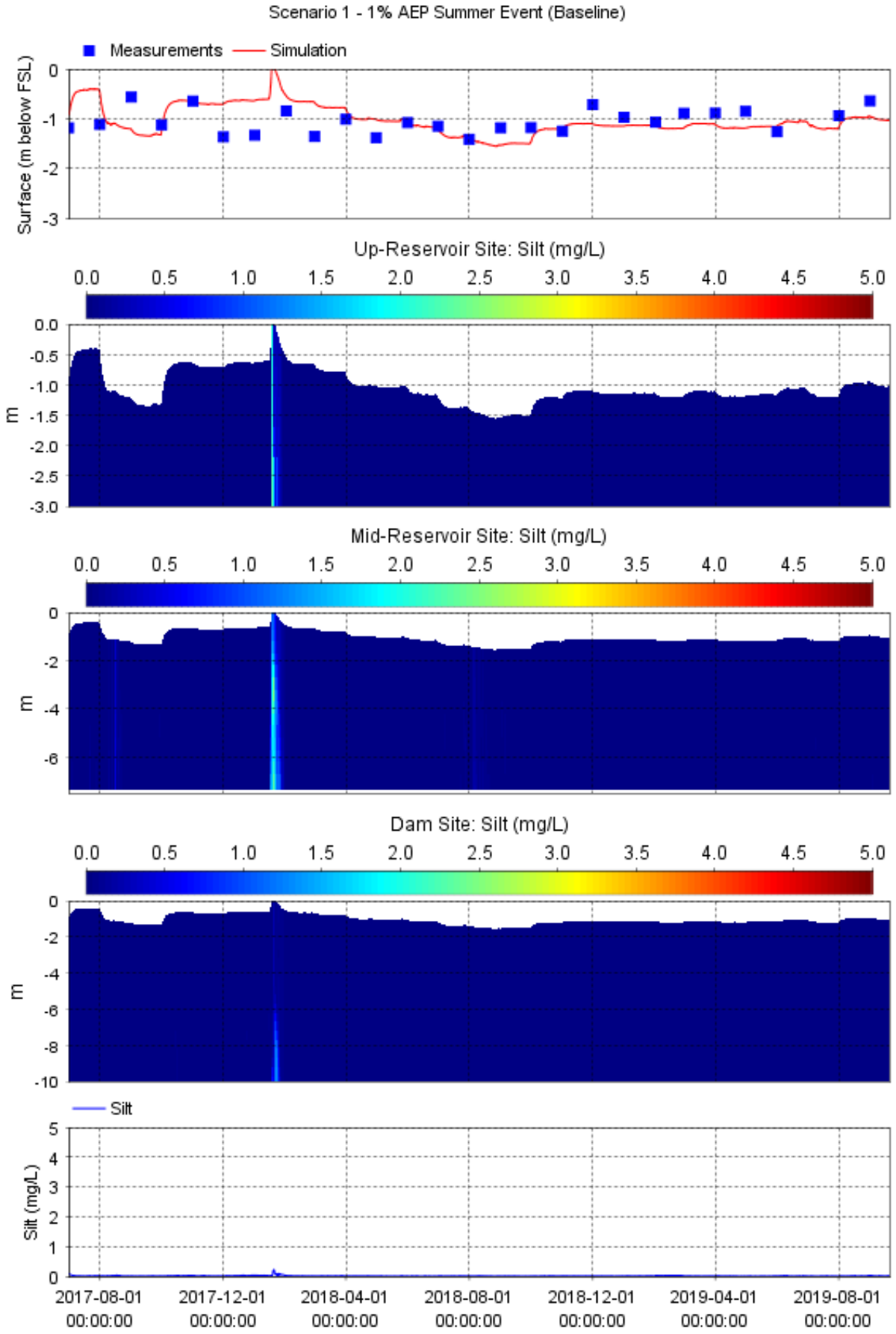


Figure 157 SPD simulated levels of silt for scenario 1 (summer baseline case 1% AEP flood event).

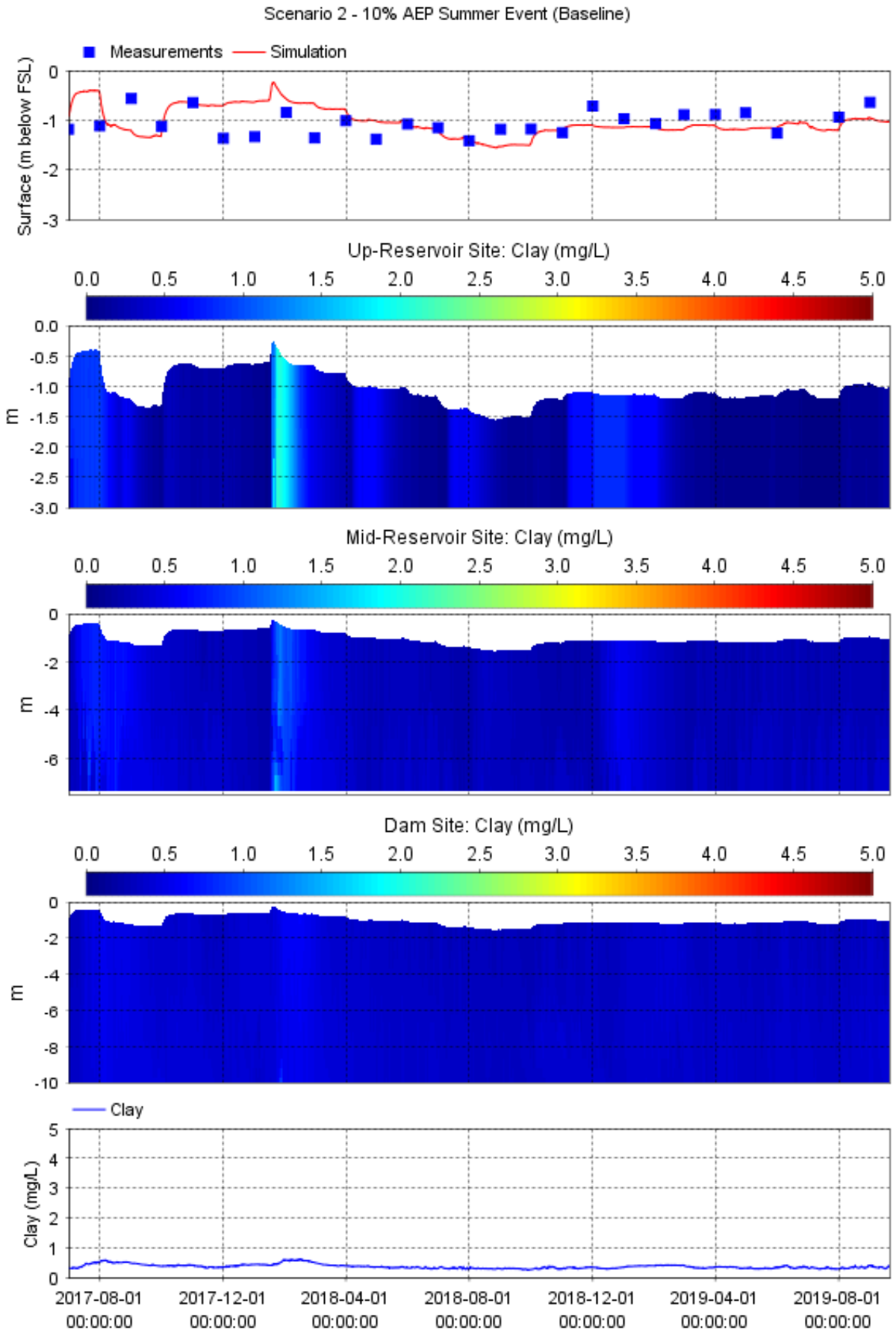


Figure 158 ***SPD simulated levels of clay for scenario 2 (summer baseline case 10% AEP flood event).***

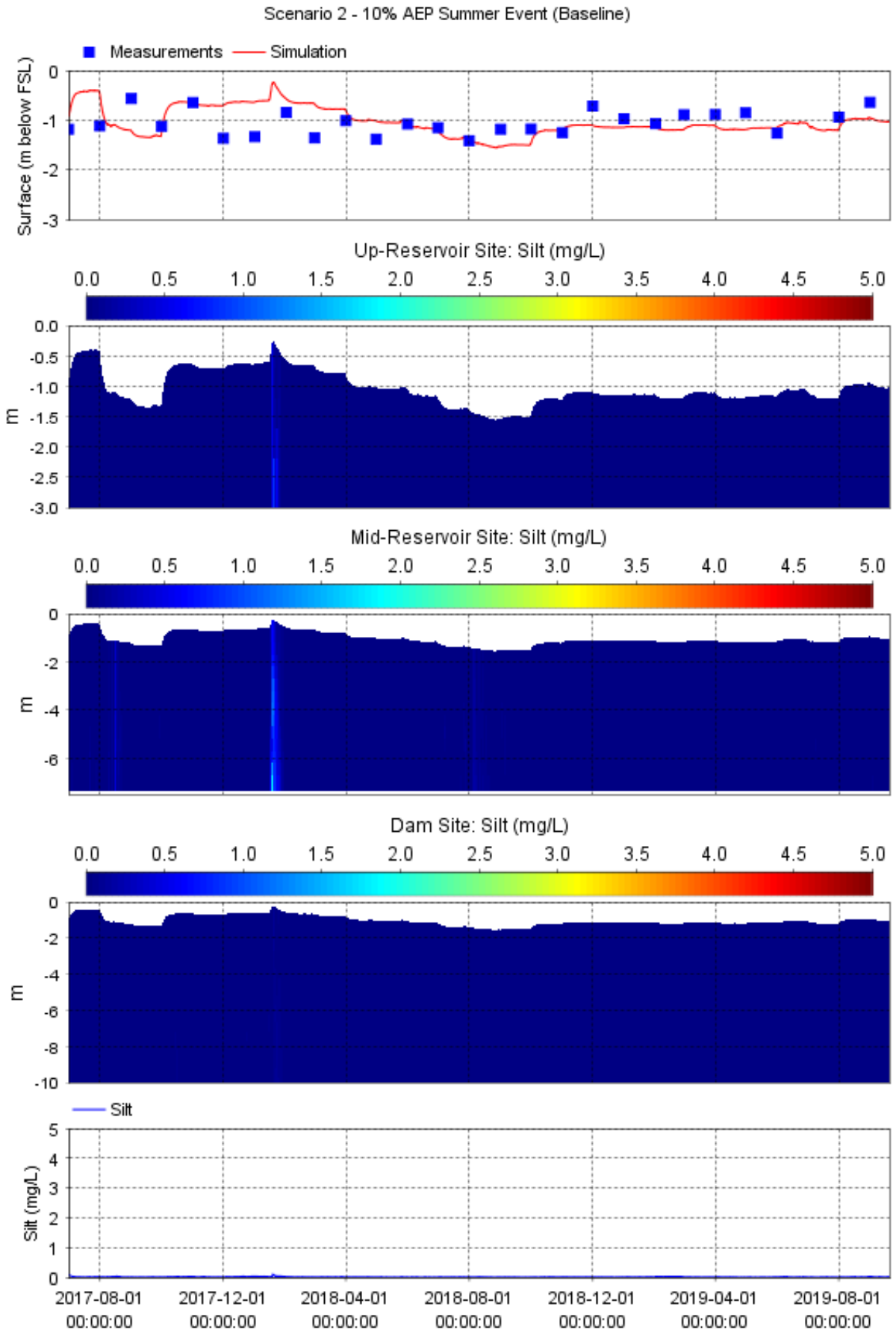


Figure 159 ***SPD simulated levels of silt for scenario 2 (summer baseline case 10% AEP flood event).***

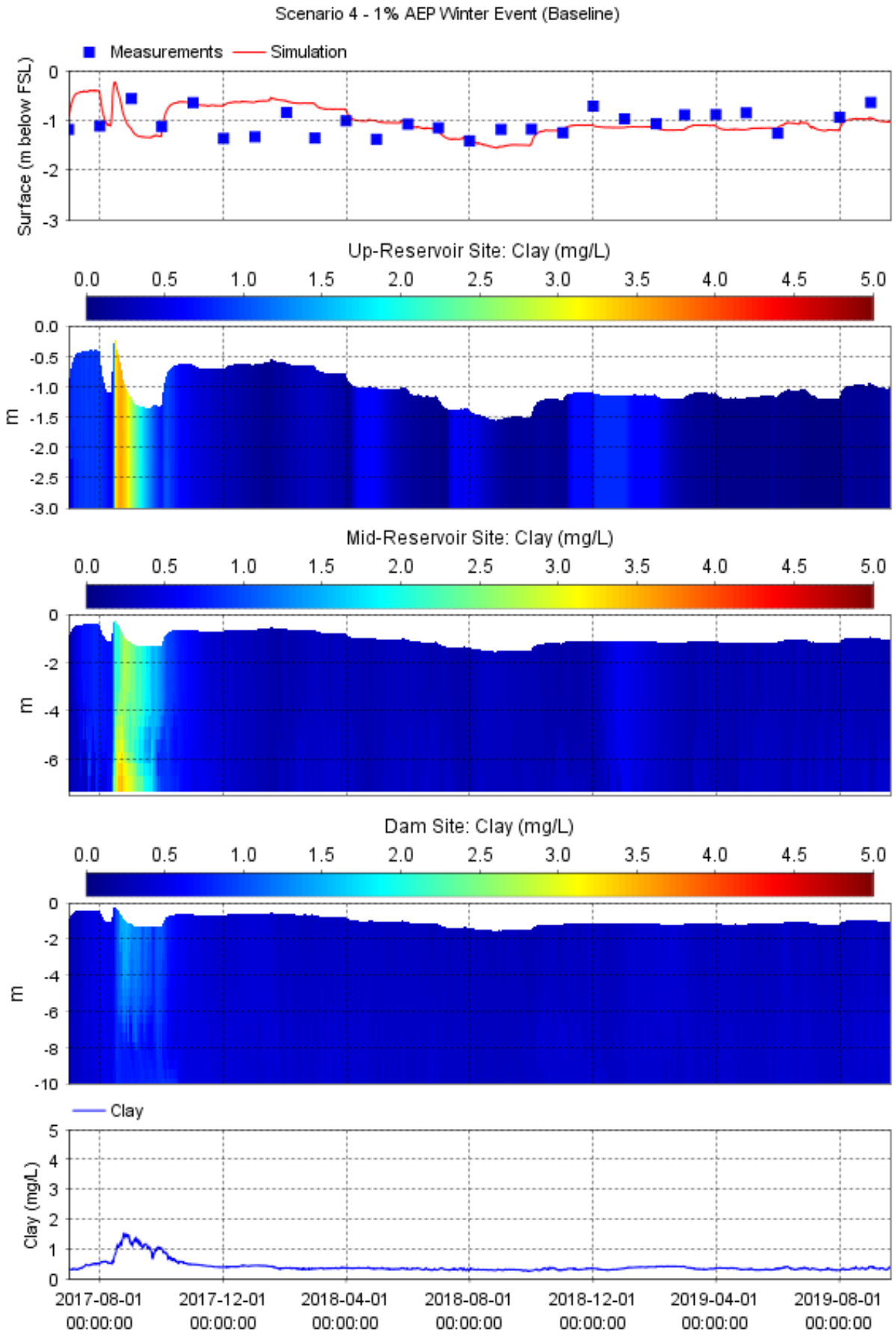


Figure 160 ***SPD simulated levels of clay for scenario 4 (winter baseline case 1% AEP flood event).***

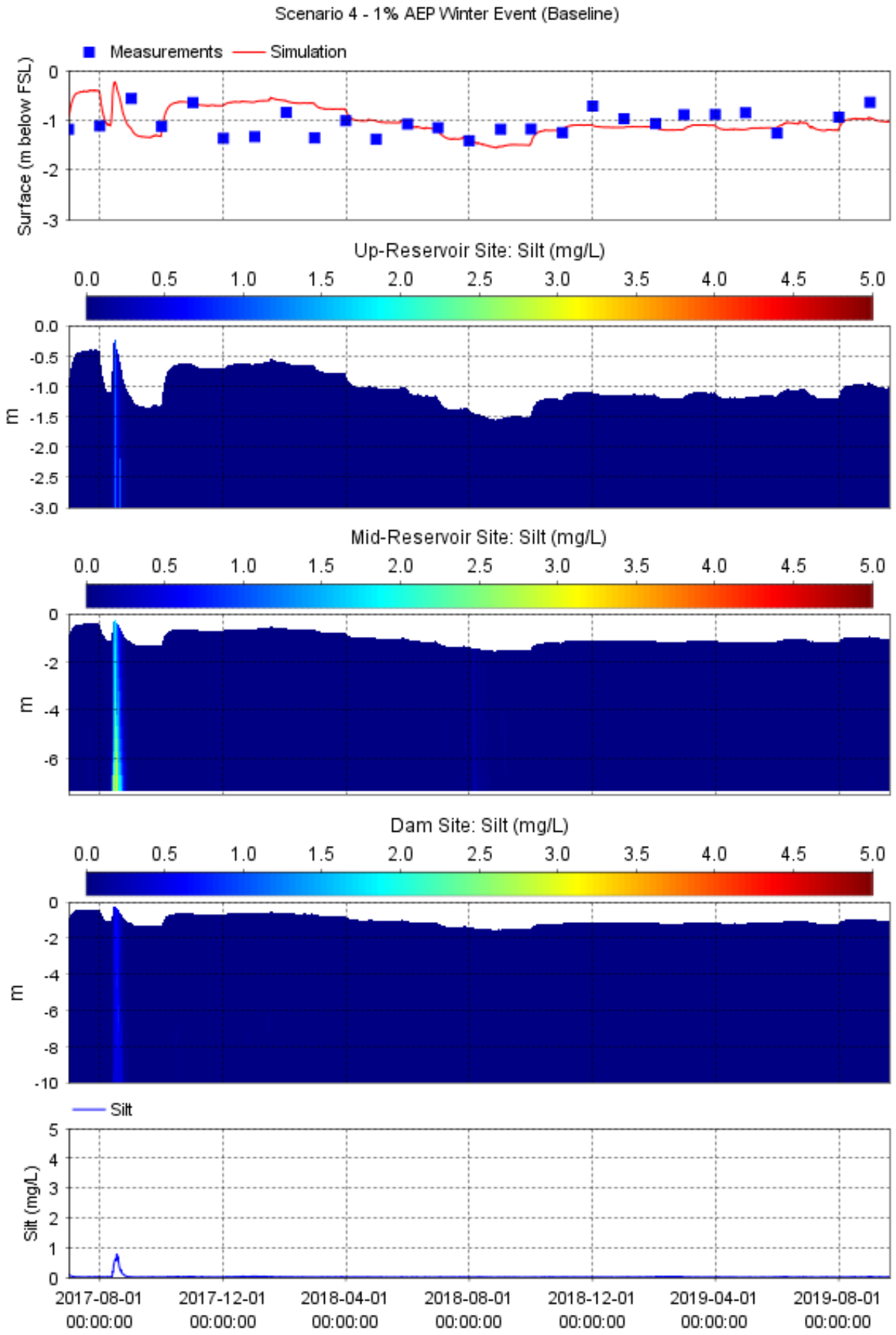


Figure 161 ***SPD simulated levels of silt for scenario 4 (winter baseline case 1% AEP flood event).***

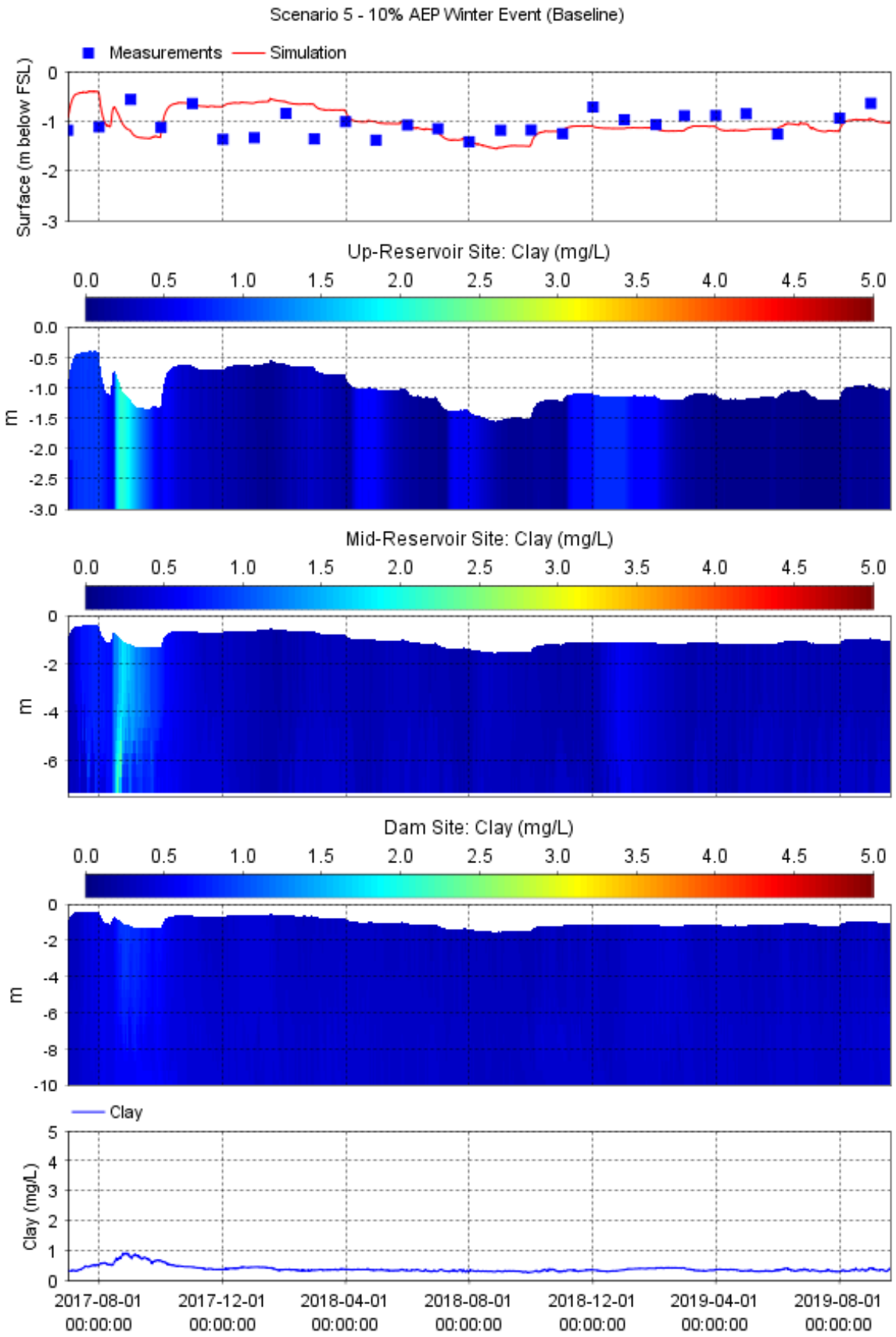


Figure 162 SPD simulated levels of clay for scenario 5 (winter baseline case 10% AEP flood event).

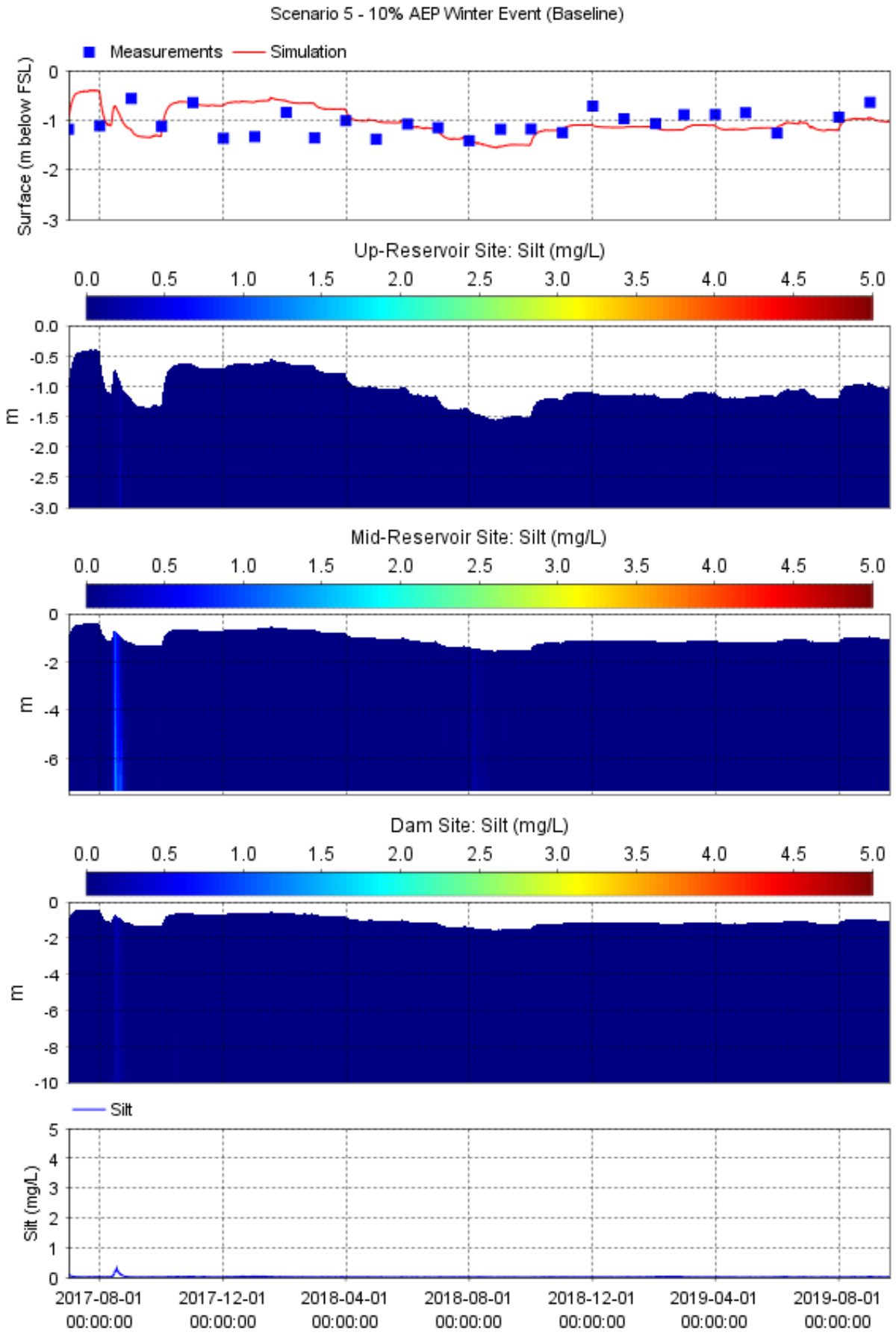


Figure 163 SPD simulated levels of silt for scenario 5 (winter baseline case 10% AEP flood event).

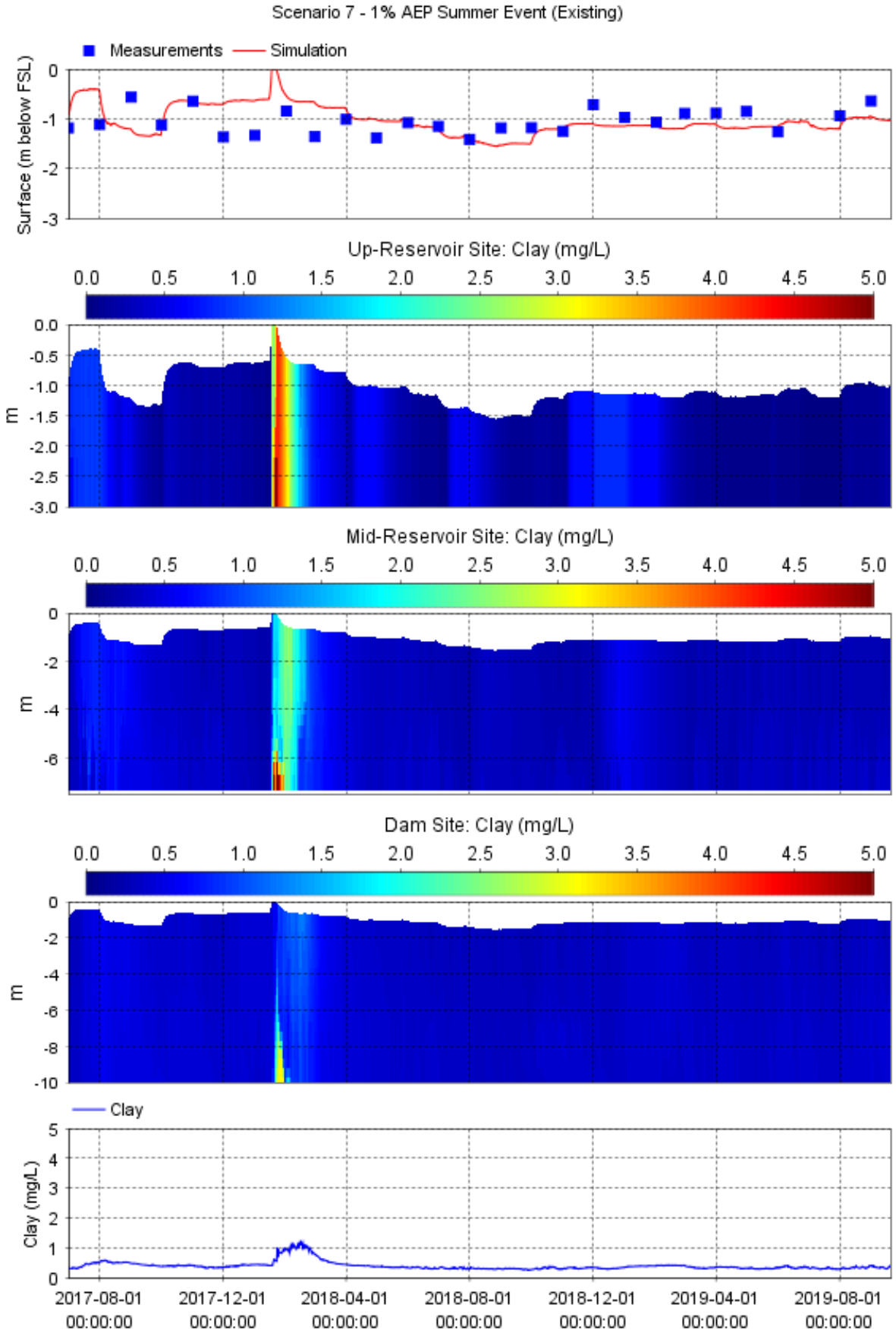


Figure 164 ***SPD simulated levels of clay for scenario 7 (summer existing case 1% AEP flood event) with moderate drainage failure SS levels.***

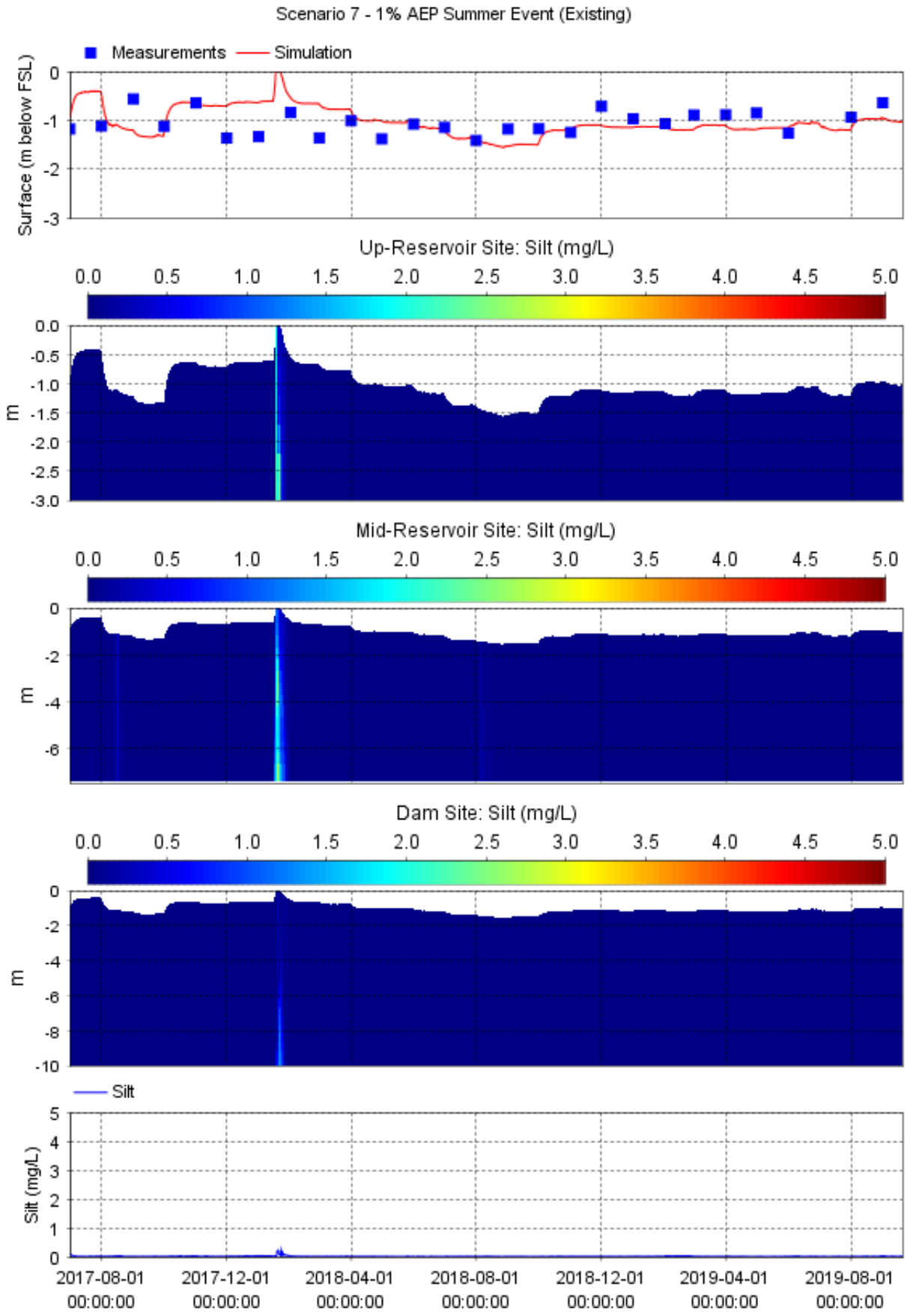


Figure 165 ***SPD simulated levels of silt for scenario 7 (summer existing case 1% AEP flood event) with moderate drainage failure SS levels.***

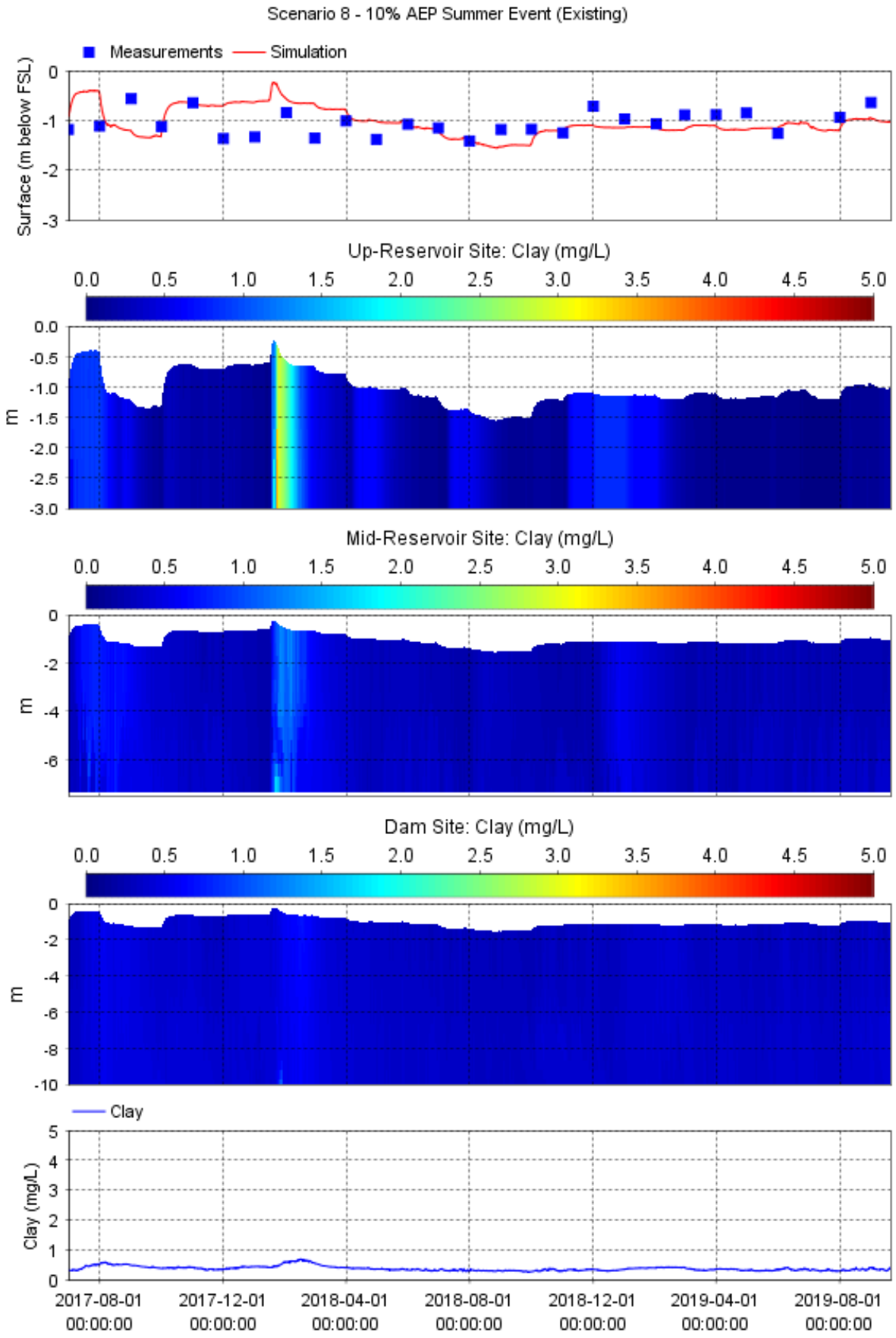


Figure 166 ***SPD simulated levels of clay for scenario 8 (summer existing case 10% AEP flood event) with moderate drainage failure SS levels.***

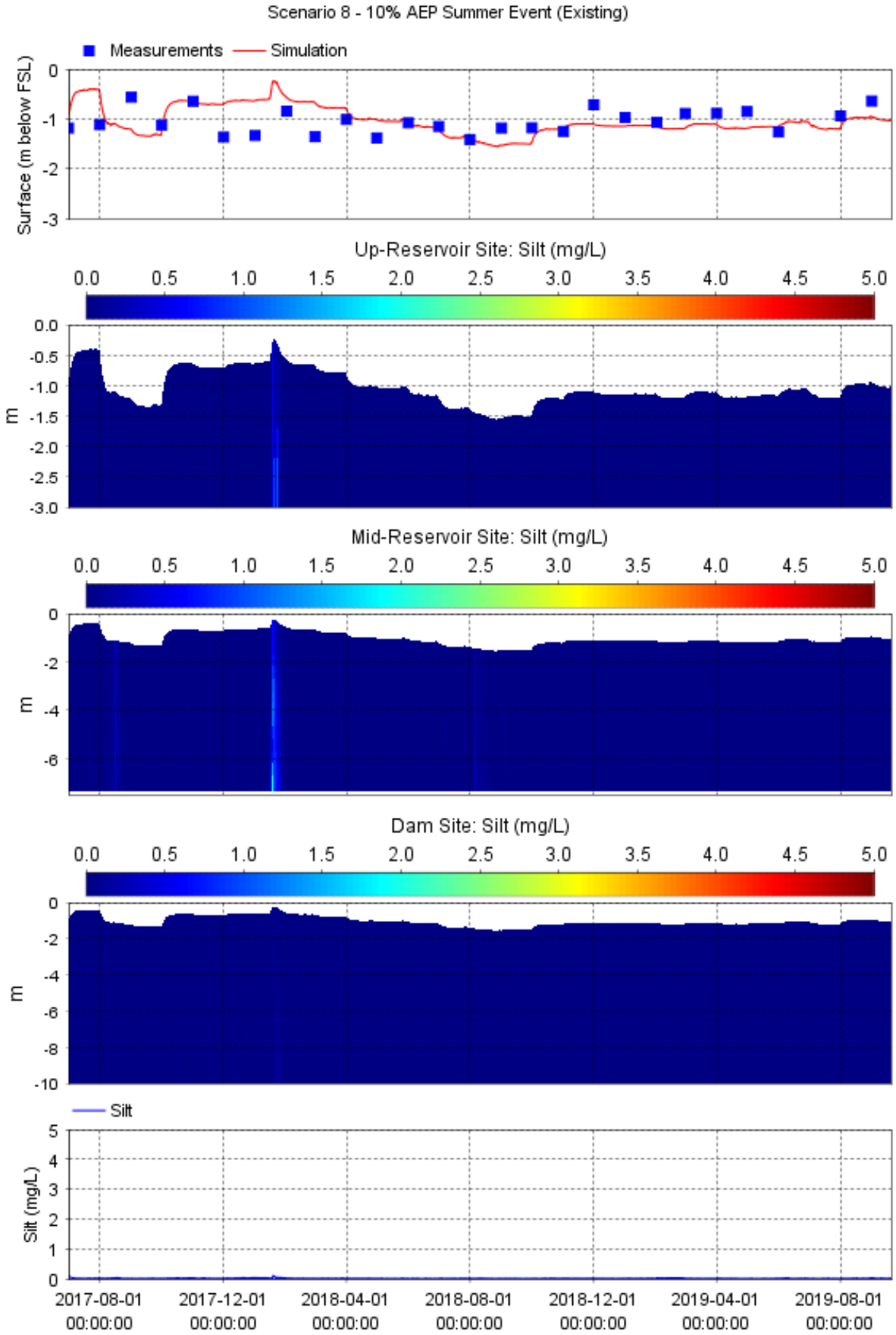


Figure 167 ***SPD simulated levels of silt for scenario 8 (summer existing case 10% AEP flood event) with moderate drainage failure SS levels.***

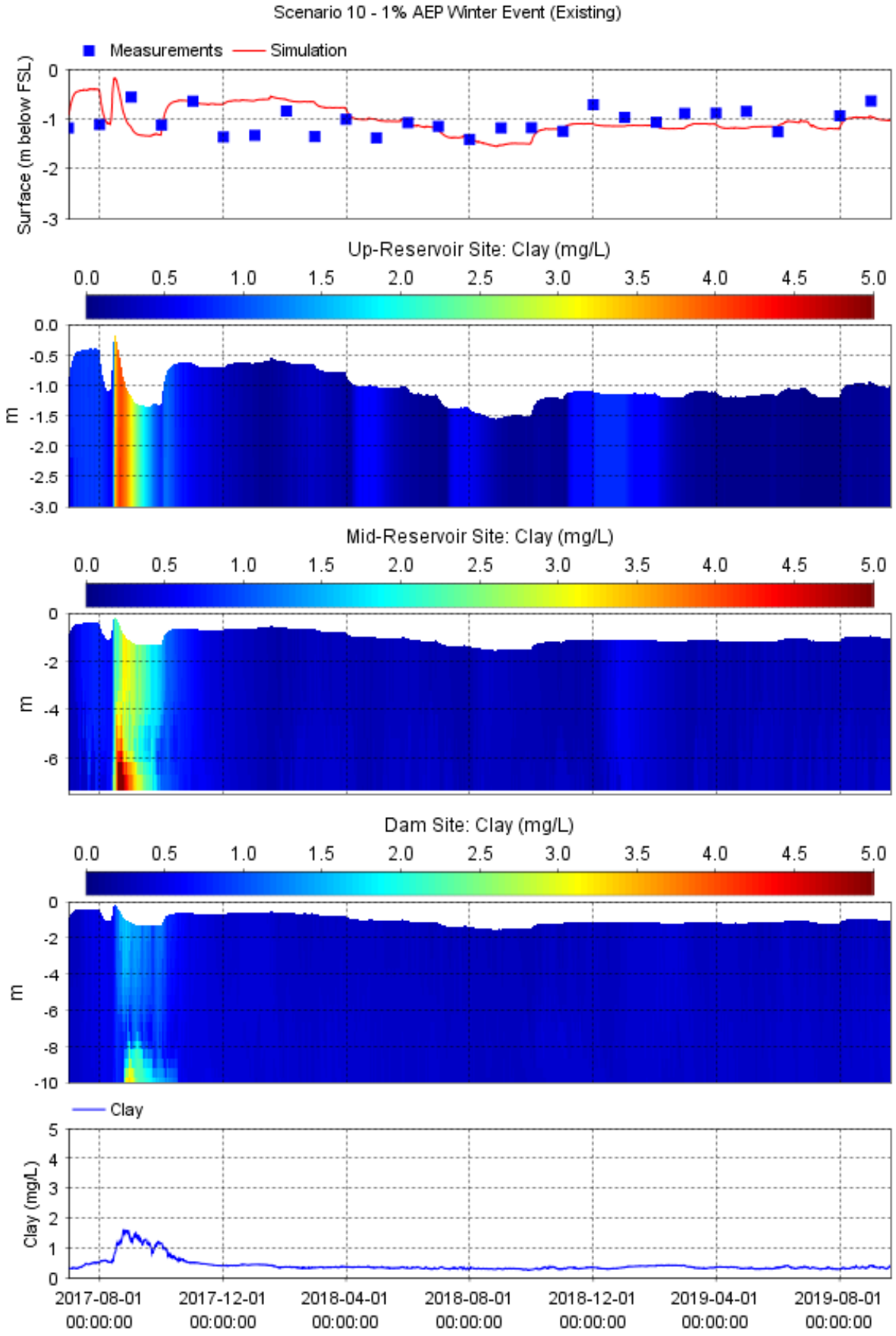


Figure 168 ***SPD simulated levels of clay for scenario 10 (winter existing case 1% AEP flood event) with moderate drainage failure SS levels.***

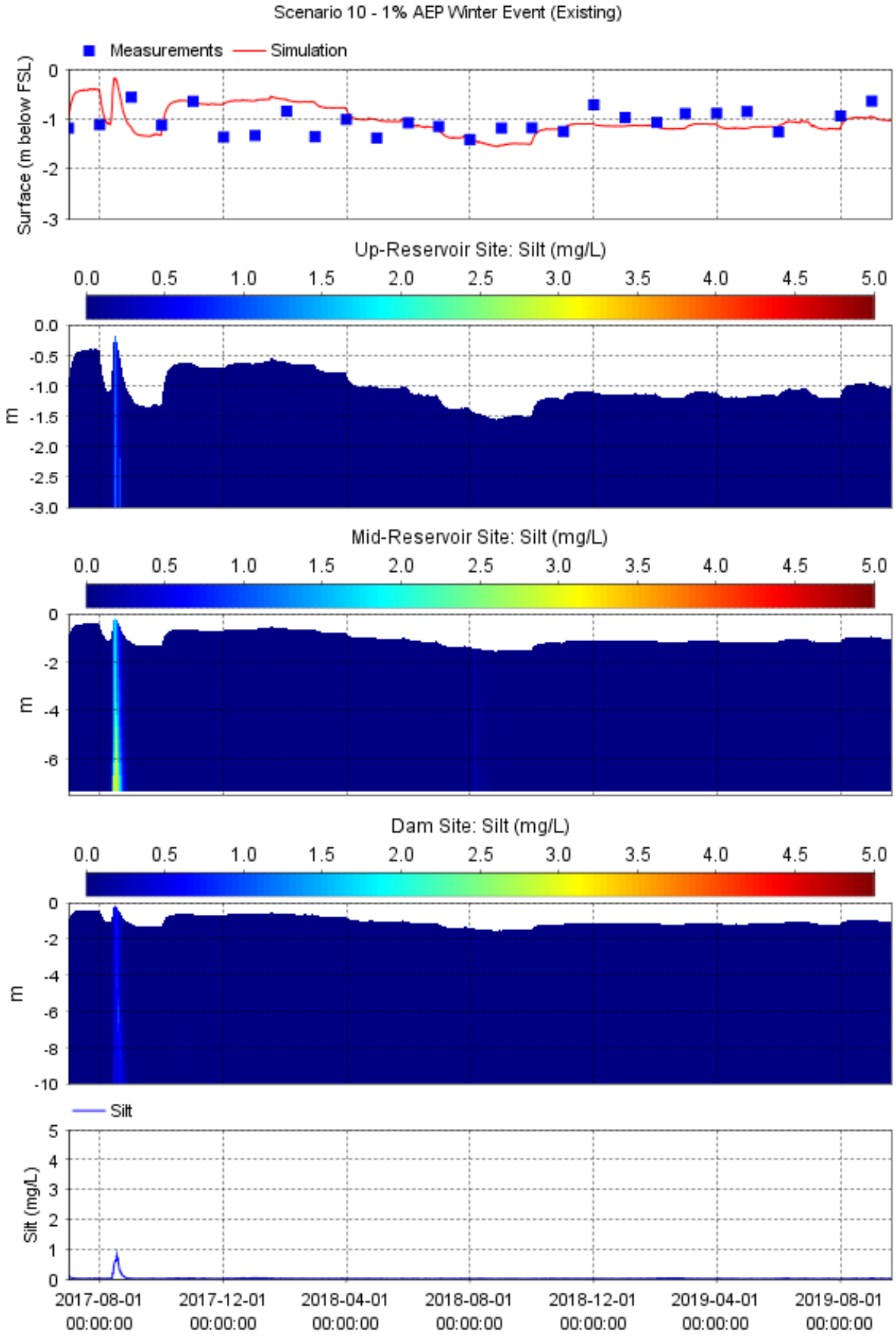


Figure 169 ***SPD simulated levels of silt for scenario 10 (winter existing case 1% AEP flood event) with moderate drainage failure SS levels.***

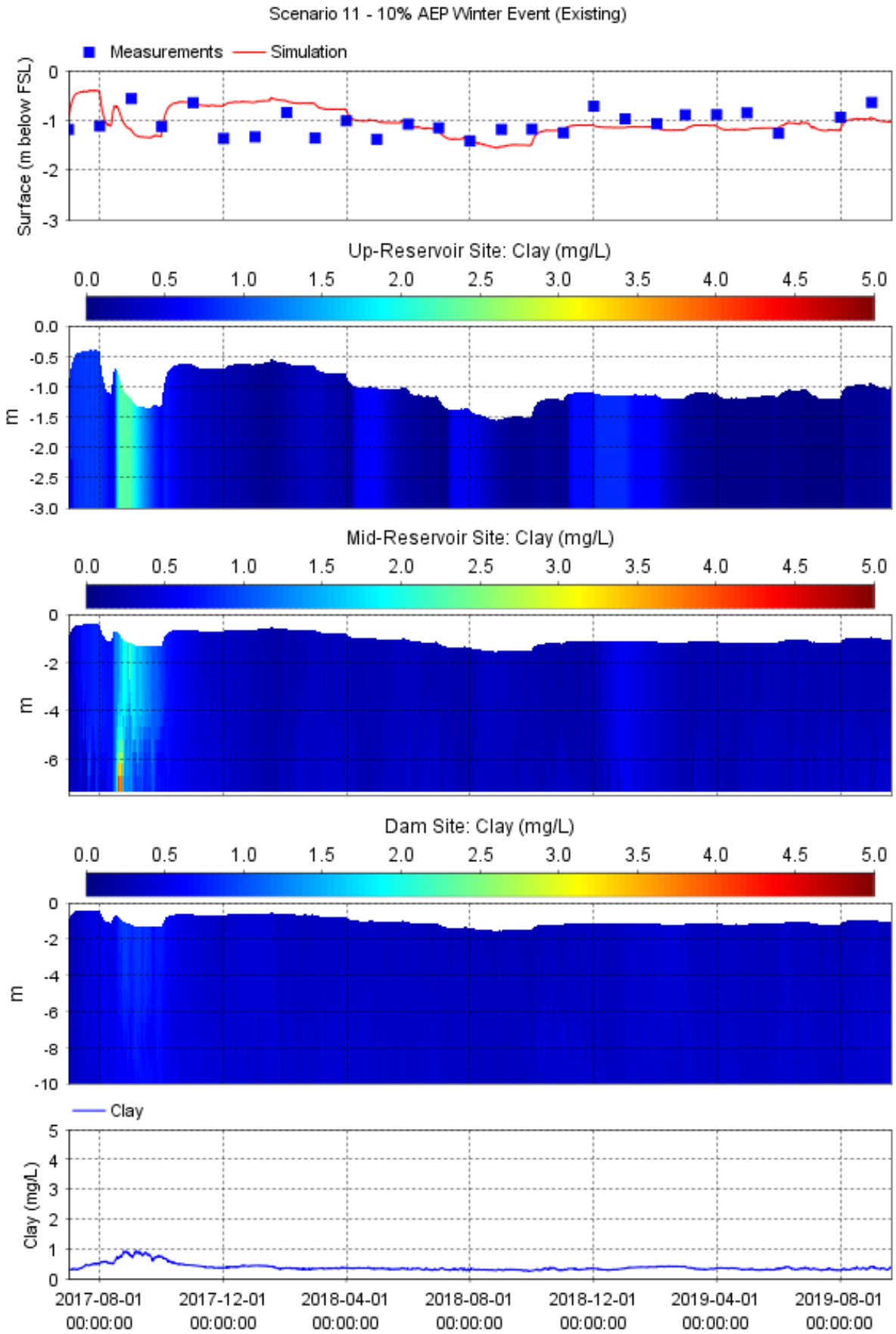


Figure 170 ***SPD simulated levels of clay for scenario 11 (winter existing case 10% AEP flood event) with moderate drainage failure SS levels.***

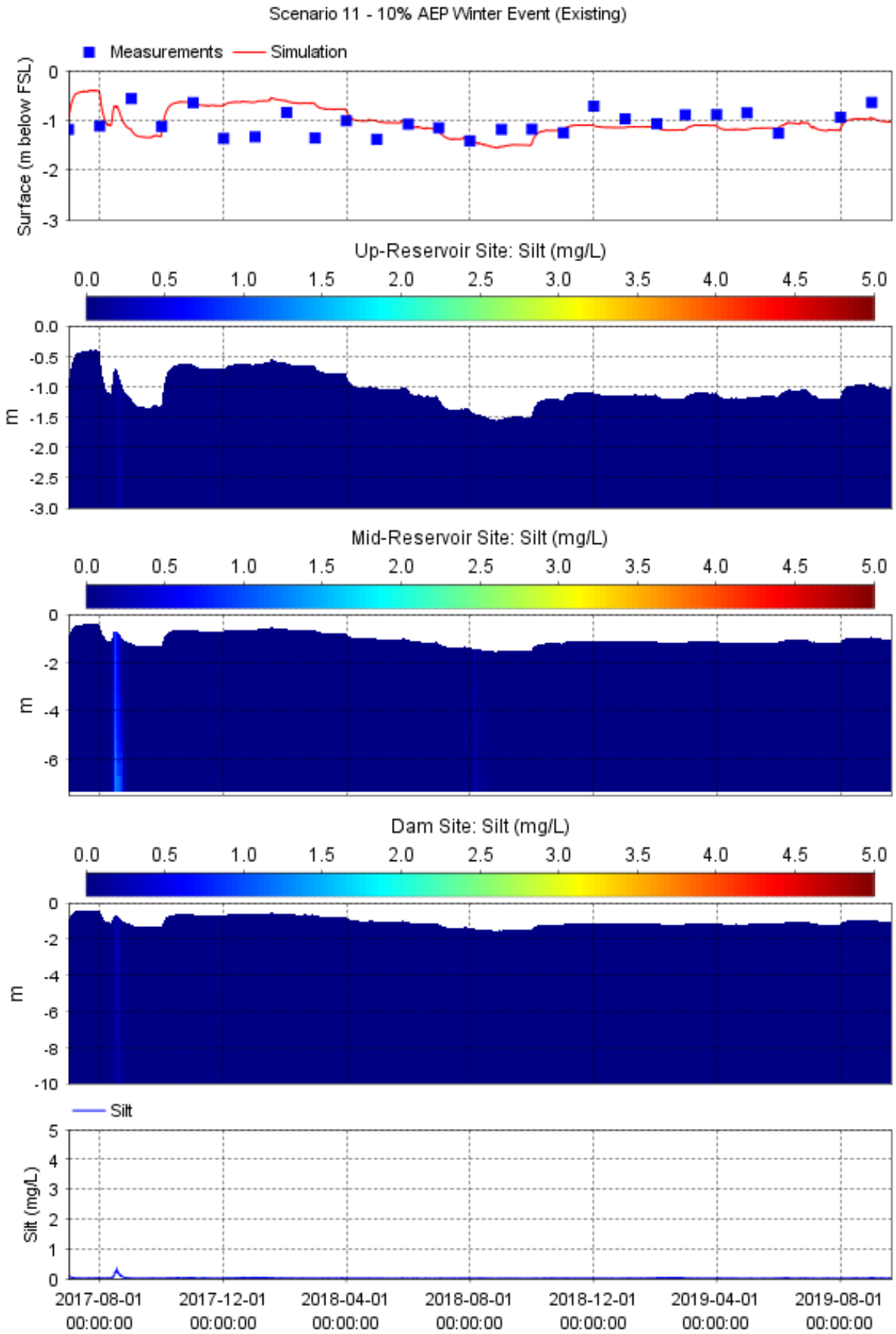


Figure 171 ***SPD simulated levels of silt for scenario 11 (winter existing case 10% AEP flood event) with moderate drainage failure SS levels.***

Appendix K

SPD: 1% and 10% AEP Flood Event Inputs (High Drainage Failure SS Levels)

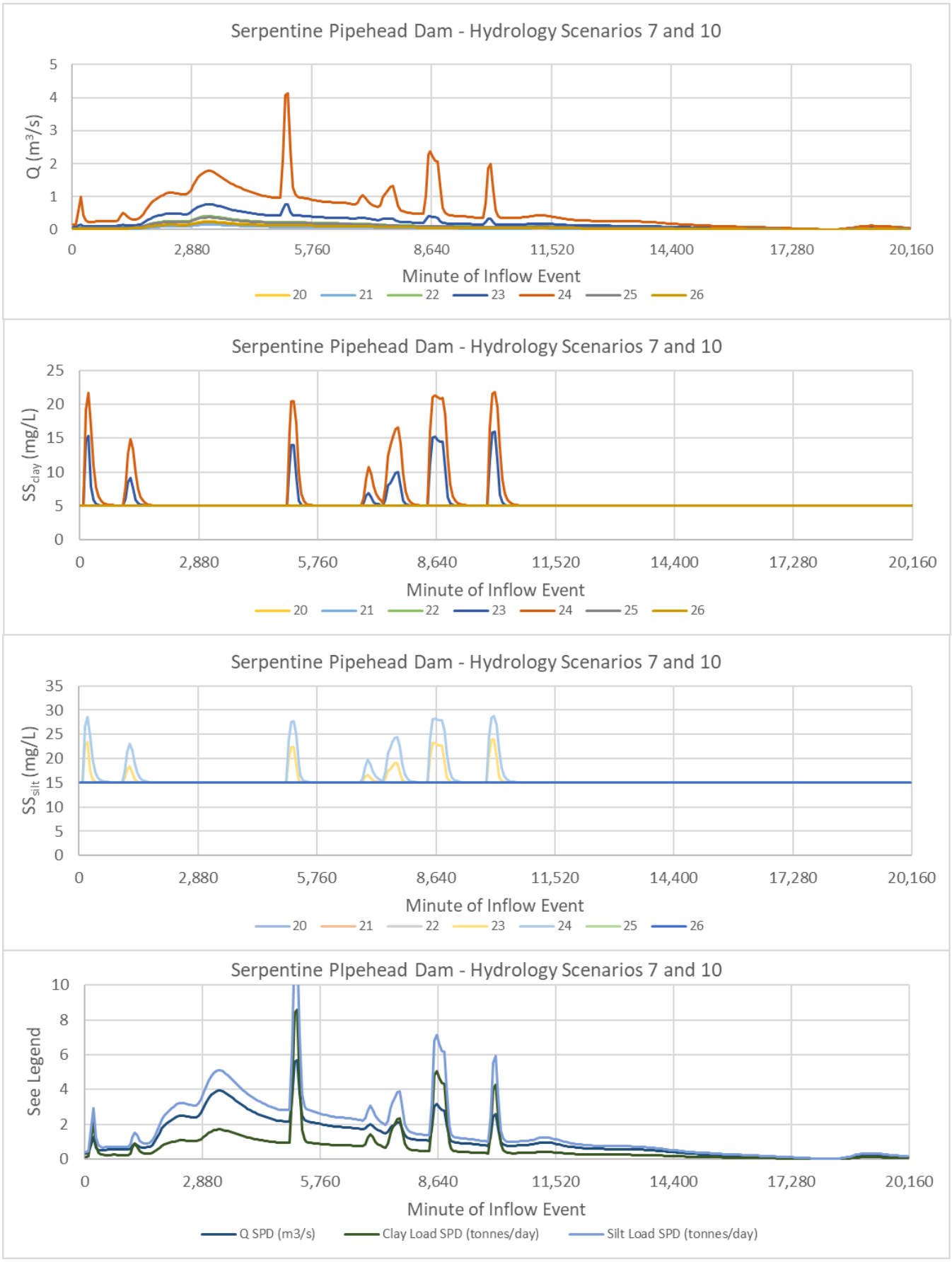


Figure 172 SPD hydrology and suspended solids inputs for scenarios 7H and 10H with high drainage failure SS levels.

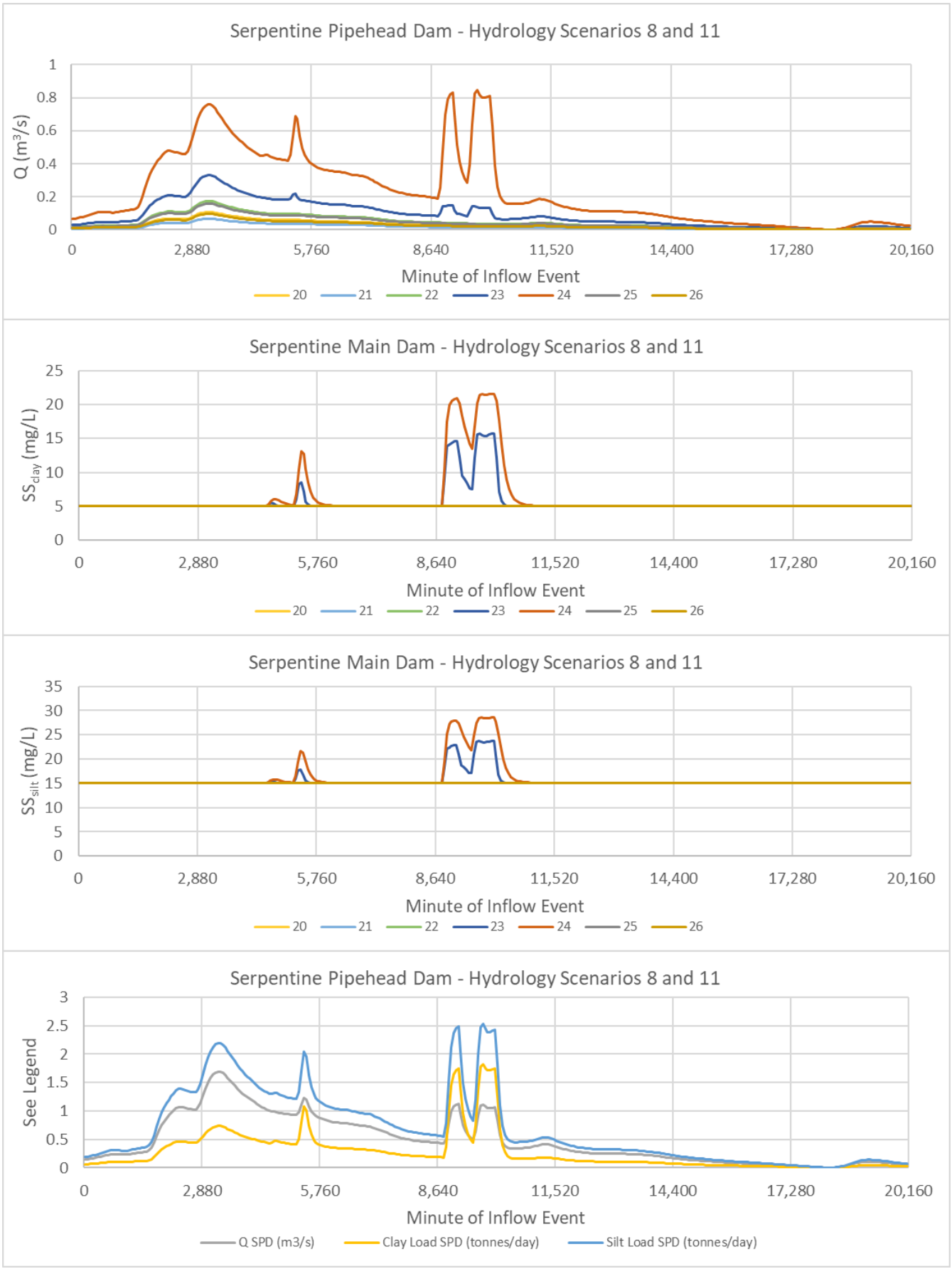


Figure 173 ***SPD hydrology and suspended solids inputs for scenarios 8H and 11H with high drainage failure SS levels.***

Appendix L

SPD: 1% and 10% AEP Flood Event Simulations (High Drainage Failure SS Levels)

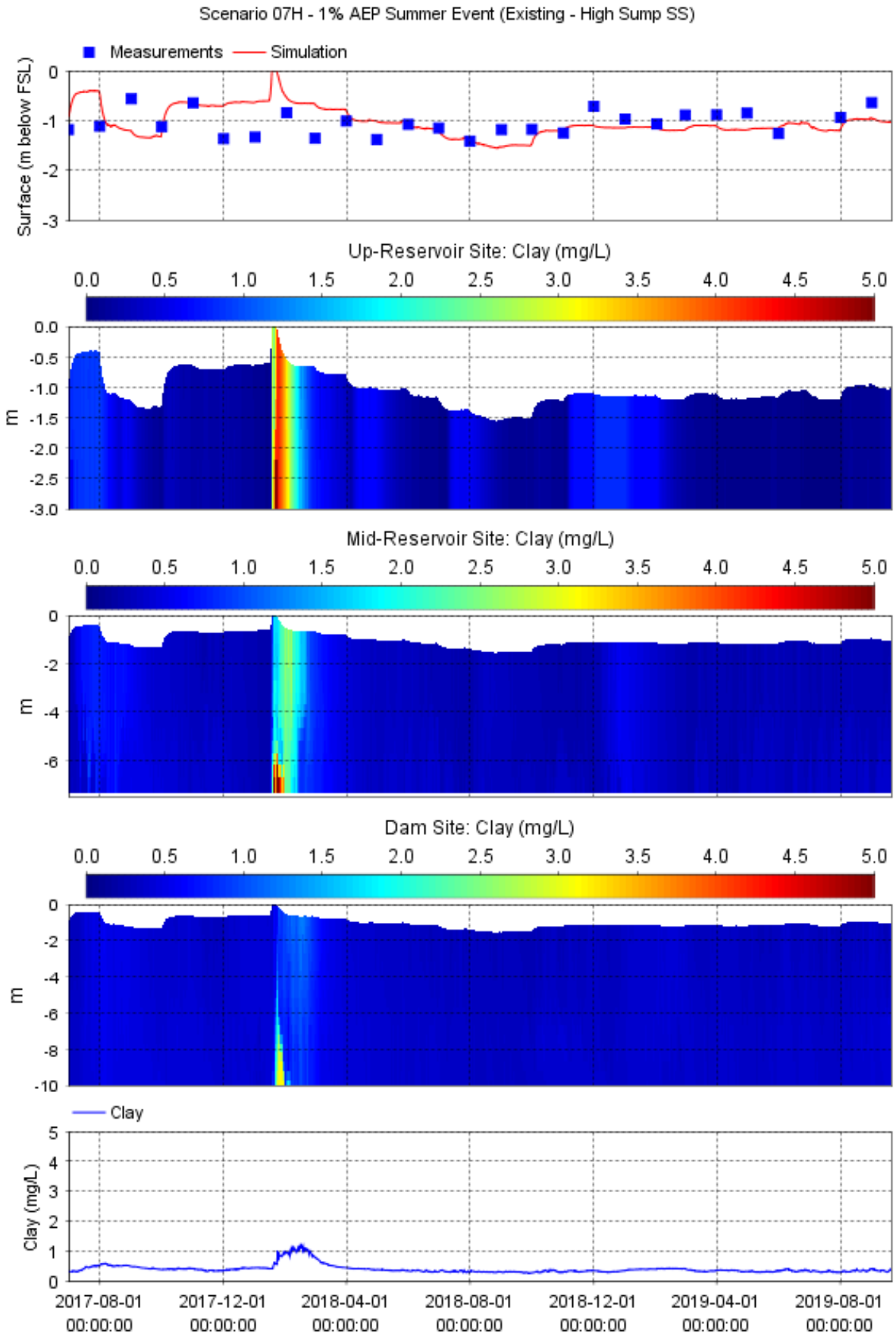


Figure 174 ***SPD simulated levels of clay for scenario 7H (summer existing case 1% AEP flood event) with high drainage failure SS levels.***

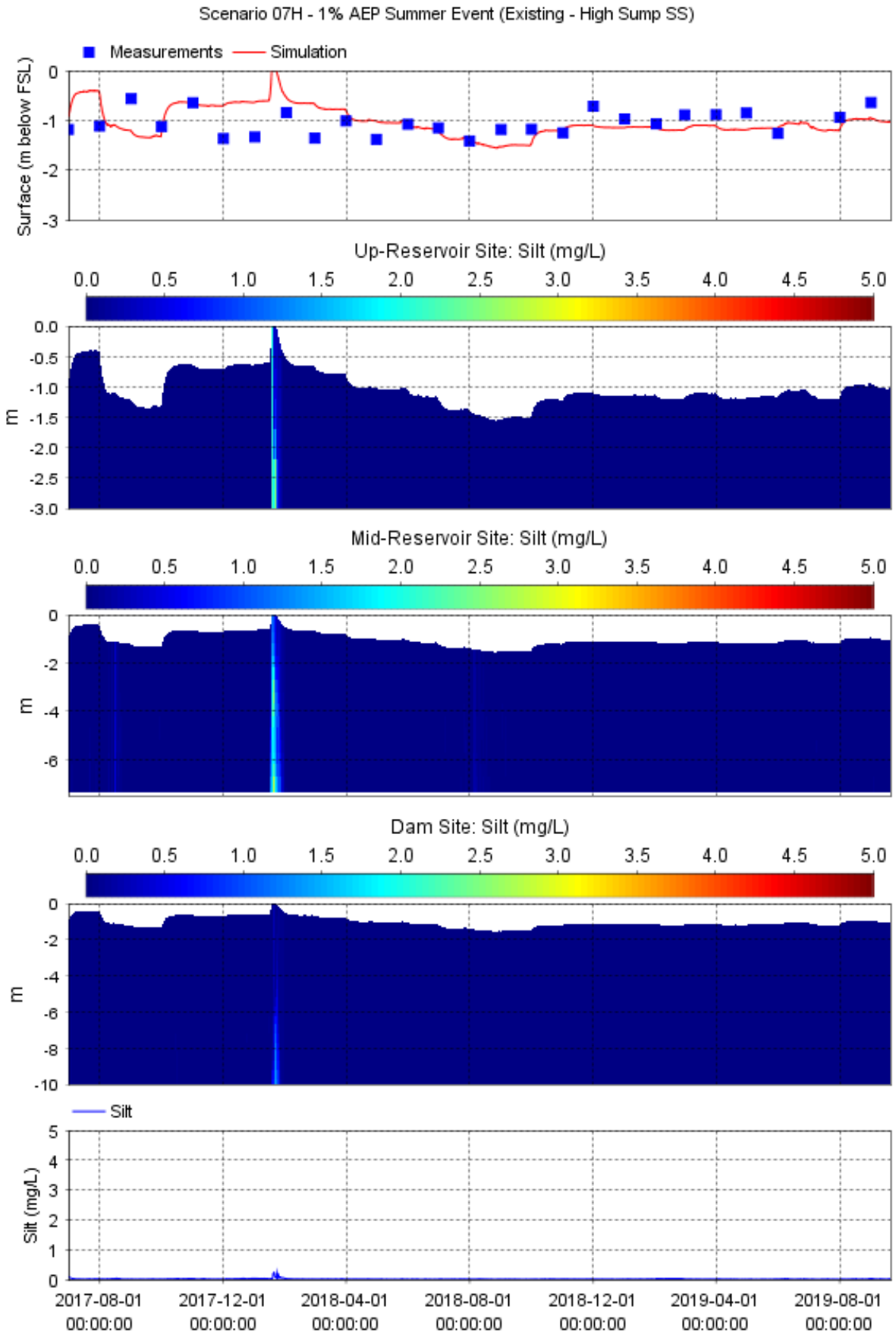


Figure 175 ***SPD simulated levels of silt for scenario 7H (summer existing case 1% AEP flood event) with high drainage failure SS levels.***

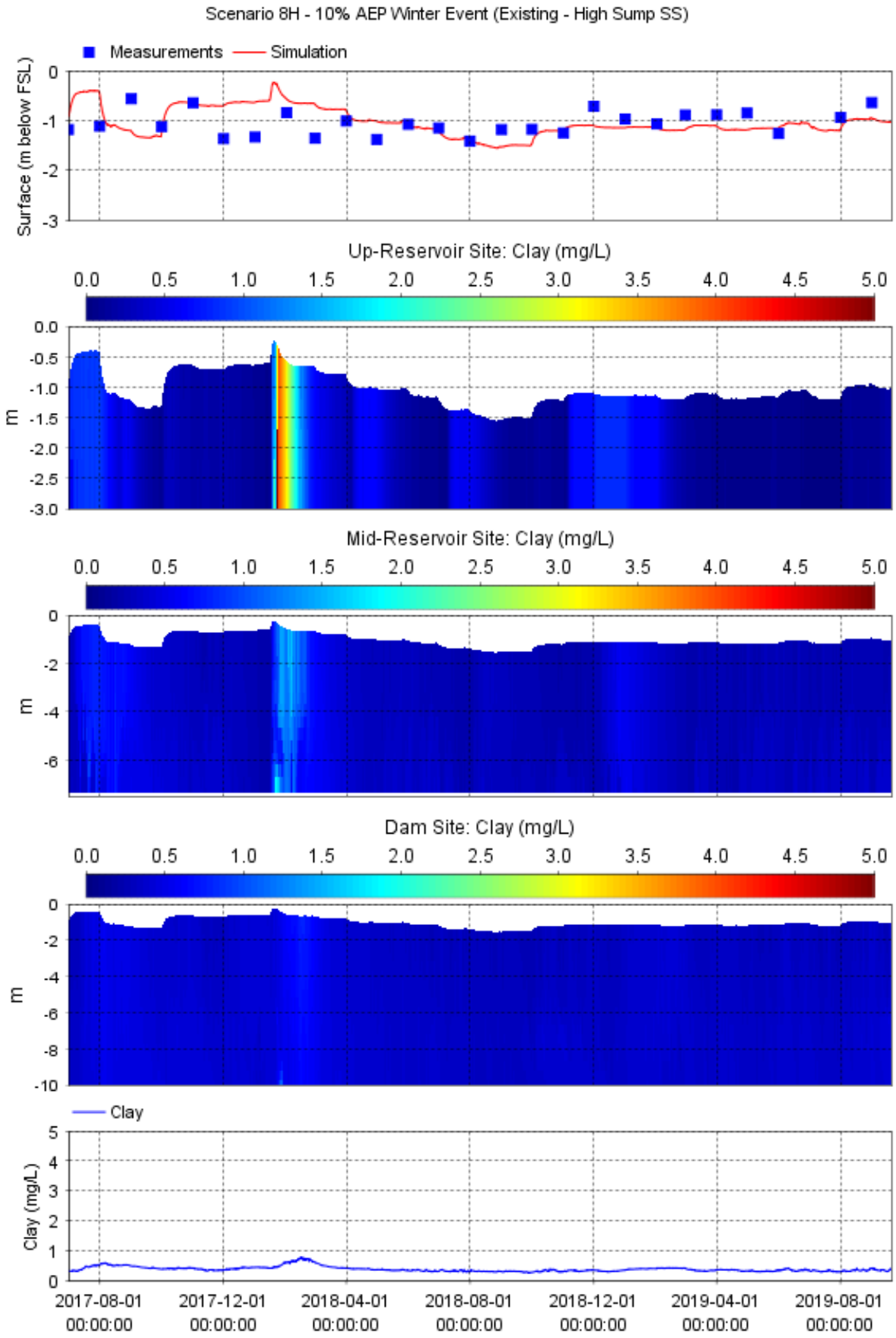


Figure 176 ***SPD simulated levels of clay for scenario 8H (summer existing case 10% AEP flood event) with high drainage failure SS levels.***

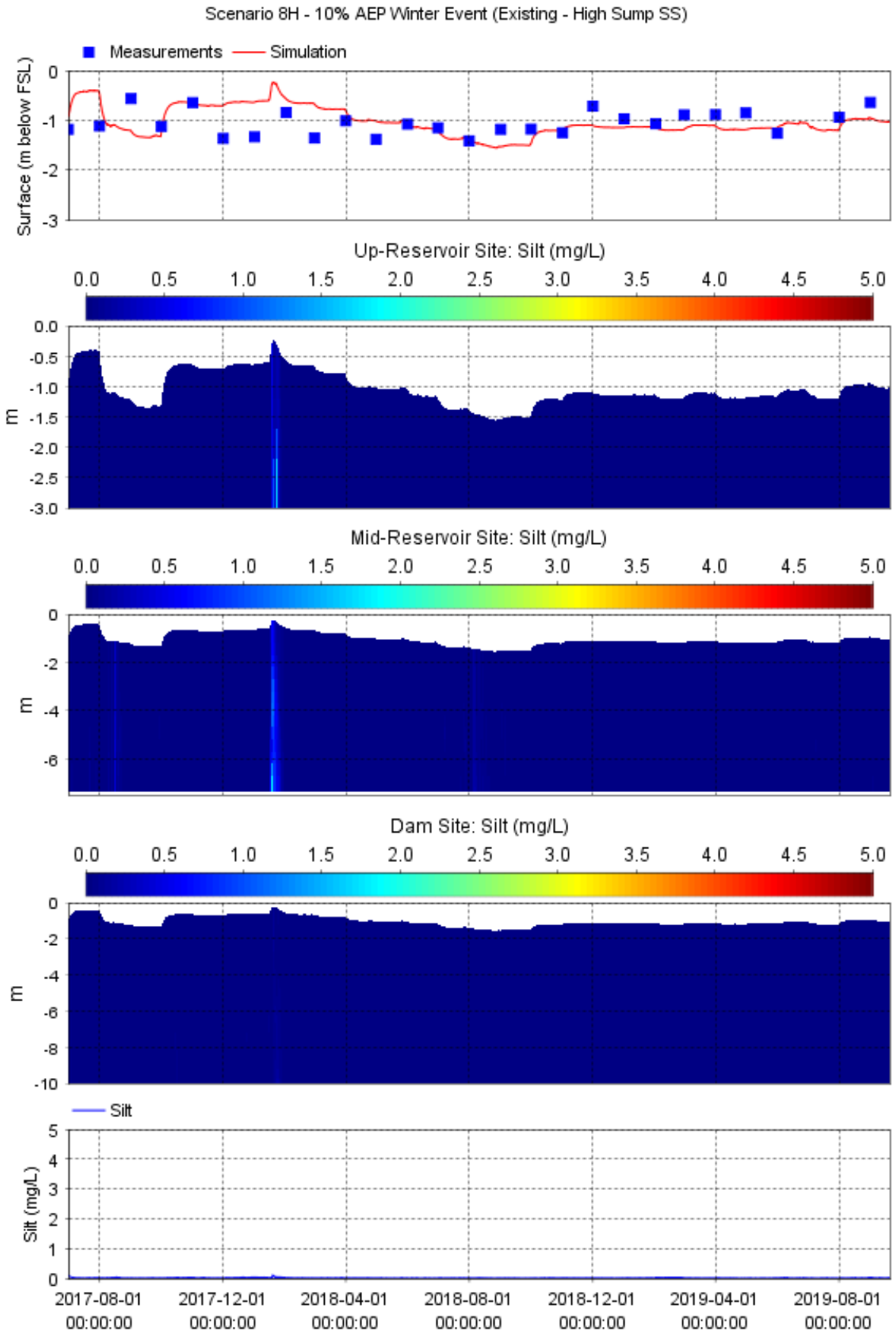


Figure 177 ***SPD simulated levels of silt for scenario 8H (summer existing case 10% AEP flood event) with high drainage failure SS levels.***

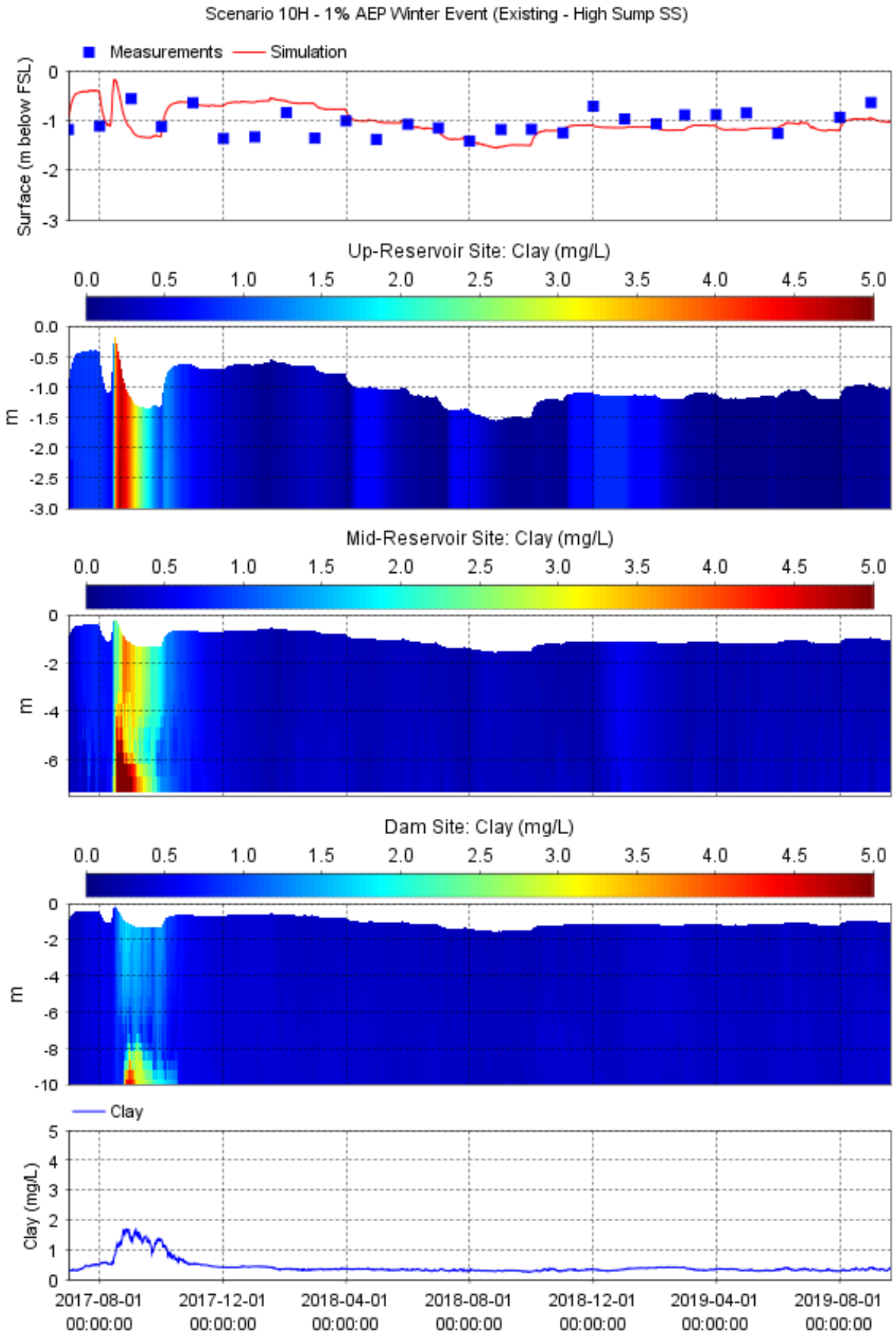


Figure 178 ***SPD simulated levels of clay for scenario 10H (winter existing case 1% AEP flood event) with high drainage failure SS levels.***

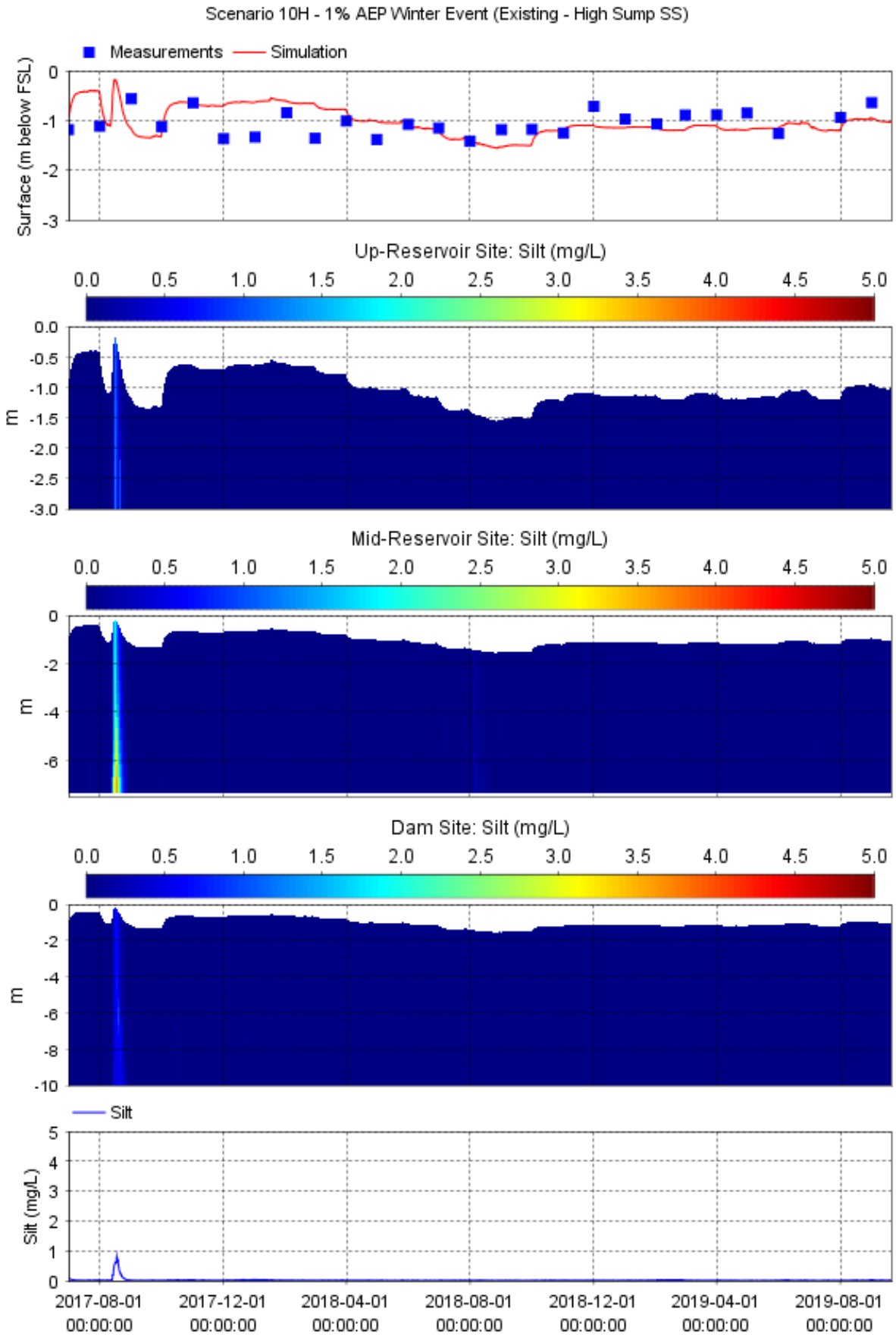


Figure 179 ***SPD simulated levels of silt for scenario 10H (winter existing case 1% AEP flood event) with high drainage failure SS levels.***

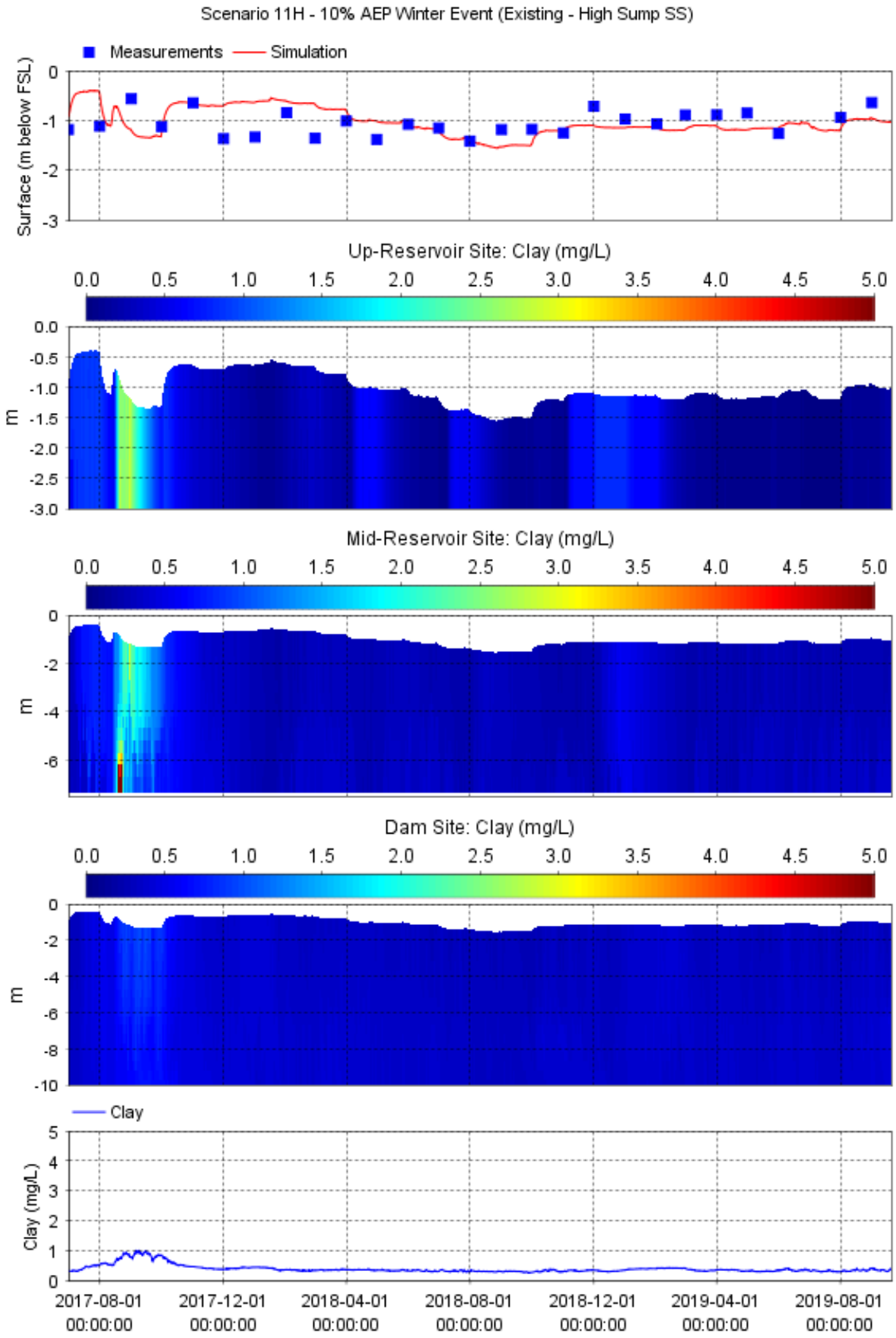


Figure 180 ***SPD simulated levels of clay for scenario 11H (winter existing case 10% AEP flood event) with high drainage failure SS levels.***

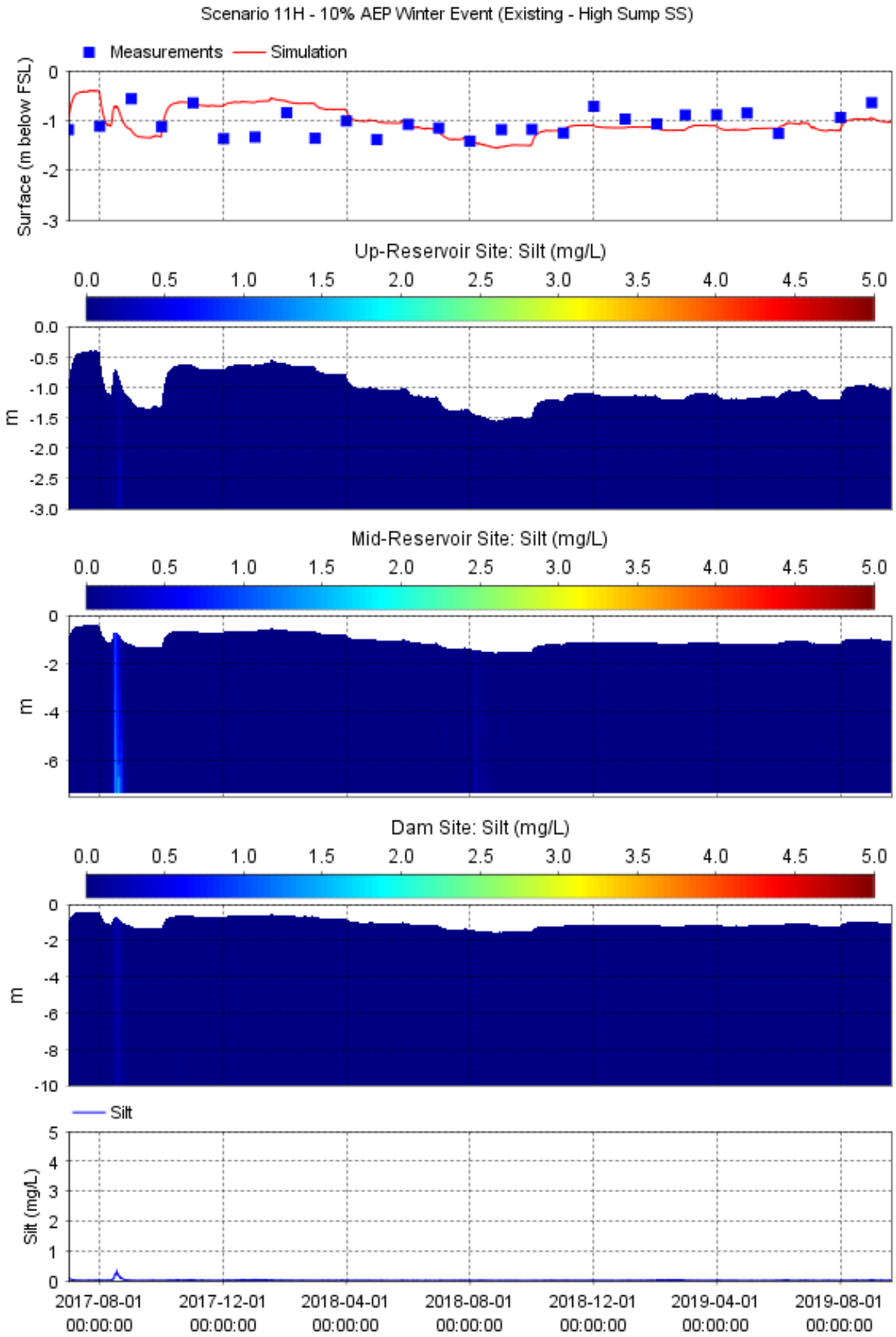


Figure 181 ***SPD simulated levels of silt for scenario 11H (winter existing case 10% AEP flood event) with high drainage failure SS levels.***



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Appendix G

Turbidity risk assessment workings

The turbidity modelling uses a wide range of input variables to assess the consequence of the hazardous event. Table G.17 qualitatively rates the likelihood and consequence of the model scenarios for the purpose of assigning an overall risk rating.

Table G.17 Scenario probabilities

Scenario ID	Catchment clearing	Synthetic flow event season	Synthetic Storm event and draimage failure rate[12]	Event likelihood
01	Baseline (No mining effects on SS)	2017 Summer	1% AEP with no drainage failures	Rare
02			10% AEP with no drainage failures	Unlikely
03			1 E.Y. with no drainage failures	Likely
04		2018 Winter	1% AEP with no drainage failures	Rare
05			10% AEP with no drainage failures	Unlikely
06			1 E.Y. with no drainage failures	Likely
07	Existing	2017 Summer	1% AEP with 75% drainage failures	Rare
08			10% AEP with 30% drainage failures	Unlikely
09			1 E.Y. with 5% drainage failures	Likely
10		2018 Winter	1% AEP with 75% drainage failures	Rare
11			10% AEP with 30% drainage failures	Unlikely
12			1 E.Y. with 5% drainage failures	Likely
13	Proposed	2017 Summer	1% AEP with 75% drainage failures	Rare
14			10% AEP with 30% drainage failures	Unlikely
15			1 E.Y. with 5% drainage failures	Likely
16		2018 Winter	1% AEP with 75% drainage failures	Rare
17			10% AEP with 30% drainage failures	Unlikely
18			1 E.Y. with 5% drainage failures	Likely

[12] Zero sump failure for areas with existing mining activity in all baseline scenarios.

Appendix H

Turbidity risk at other scales

Turbidity risk at other scales

Historically, the failure of individual drainage barriers and the associated turbid discharge events has been of little consequence to the drinking water system. The “Stone 3” in-pit containment failure on the 6th September 2020 discharged turbid runoff to a stream discharging to the Serpentine Reservoir. Alcoa’s instream turbidity monitor SE53 located 1.2 km downstream recorded peak turbidity in excess of 110 NTU between 6th and 7th September. Water quality measurements and sampling within the reservoir undertaken on the 9th September 2020 indicate turbidity levels of up to 3.5 NTU approximately 3 km downstream of the failure, decreasing to <1 NTU approximately 4.7 km downstream of the failure. No increase in turbidity was observed at the offtake during the subsequent 15th September monitoring round (<=0.3 NTU) nor on the 20th October monitoring round (<=0.2 NTU). Long term offtake turbidity measurements demonstrate that the despite a history of turbid discharge incidents, turbidity at the offtake has not changed from background levels.

Individual pit-scale drainage failures can increase local turbidity levels but are insufficient to impact drinking water quality. Assessing risk at the drinking water catchment scale is therefore the preferred approach for drinking water risk assessments, so that the impact of multiple failures at the critical offtake point can be understood. Nevertheless, there is value in assessing risk at the pit and sub-catchment scales to understand local environmental risks as described below.

Pit scale turbidity risk

There are a multitude of causal factors that may lead to a turbidity discharge event. These causal factors are currently under investigation by the Alcoa Mining and Management Program. Anecdotal evidence suggests that geographic factors such as catchment slope may increase the likelihood of a drainage failure and a turbidity event. Slope is a known factor for erosion rates and can increase the failure risk of drainage structures due to higher runoff velocities. However, soil loss is less sensitive to the slope length than to any other soil loss factor (Jain & Singh, 2003).

Alcoa long term planning method

It is reasonable to assume that the closer a drainage failure is to a sensitive receptor, the higher the consequence is to that receptor. Alcoa have developed a semi-quantitative draft long-term planning approach for assessing risk, that considers slope as a proxy for likelihood, and location factors as a proxy for consequence. The location factors include both administrative boundaries (e.g., RPZ), and proximity to stream zone vegetation. The risk assessment scoring procedure results in a risk score from low to high, with the very highest risk areas deemed too risky to be mined. It is important to note that this risk assessment approach is inconsistent with ADWG (NHMRC, 2011) and inconsistent with the approach adopted in this drinking water risk assessment report. However, the approach is useful for assessing the relative risk of mining pits, the relative requirement for barriers, and as an input for assessing sub-catchment scale risk.

Table H.1 Pit scale turbidity risk criteria (Alcoa, 2020)

Points	Pit risk rating	Location	Proximity to stream	Slope
0	Mining Exclusion Area	OCA1	1st & 2nd order streams: - 20m from edge of stream zone. - If no vegetation is present, 20m from grade changes defining water flow channels/centre of stream channel. 3rd order + streams (outside OCA2): - 30m beyond stream zone vegetation. 1000m upstream of top water level of PDWSA reservoirs: - 50m beyond stream zone vegetation.	>16°
1	High	RPZ or Serpentine Pipehead catchment	<200m beyond stream zone vegetation	8°-16°

Points	Pit risk rating	Location	Proximity to stream	Slope
2	Moderate	Proclaimed catchment, offsite environmentally sensitive surface water catchment, or private drinking water supply	200-500m beyond stream zone vegetation	3°-8°
3	Low	Offsite surface water catchment, nonenvironmentally sensitive	500-1000m beyond stream zone vegetation	1°-3°
4	Insignificant	Onsite water catchment	>1000m beyond stream zone vegetation	<1°

Table H.2 Pit scale risk scoring (Alcoa, 2020)

Total pit risk score	Pit risk rating
0-2	Extreme
3-5	High
6-8	Moderate
9+	Low

RUSLE method

A tool based on the Revised Universal Soil Loss Equation (RUSLE) was developed by GHD to estimate annual soil loss, described in detail in Appendix J. The tool is a quantitative alternative to the Alcoa long term planning method and can be used for both planning and design purposes. In the absence of site-specific evidence, the tool does not account for downstream factors presumed to cause attenuation and dilution, and ignores prescribed zones such as the RPZ. The tool has been applied to the proposed Holyoake and Myara North clearing areas, estimating erosion rates in tonnes per hectare per annum.

Results

Results of the pit scale assessment are plotted in Figure H.1 and Figure H.2, and mapped in Figure H.3 to Figure H.6 below. Note that the Holyoake pits are yet to be defined, large contiguous clearing areas have been assumed, and therefore erosion rates are likely to be overestimated.

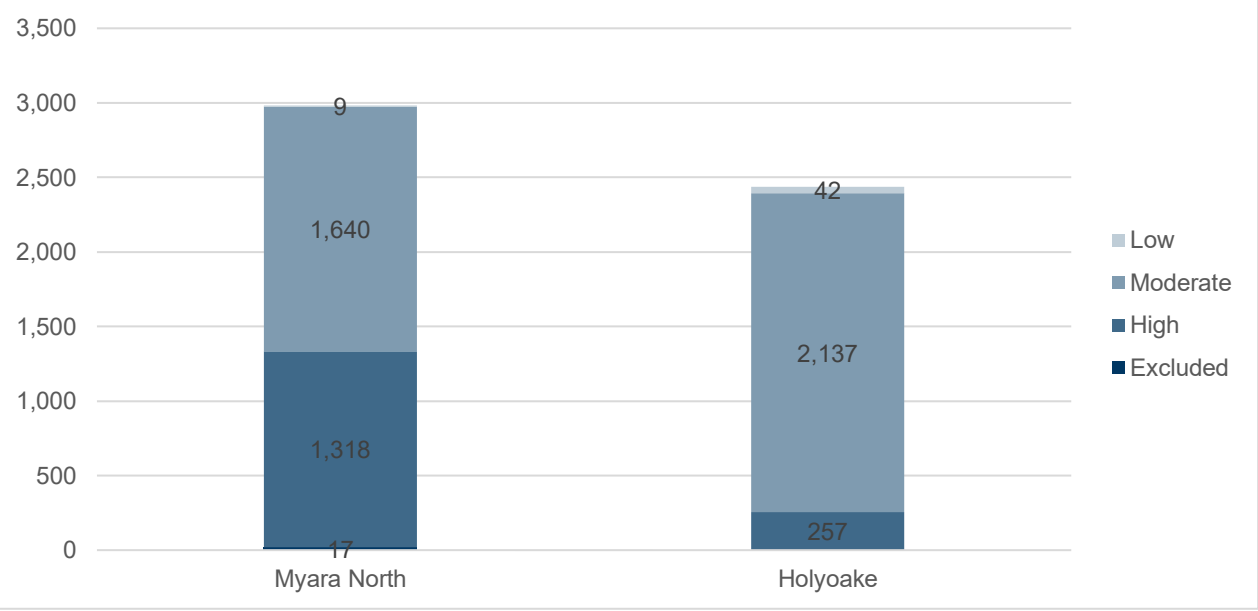


Figure H.1 Pit scale turbidity risk by mining region

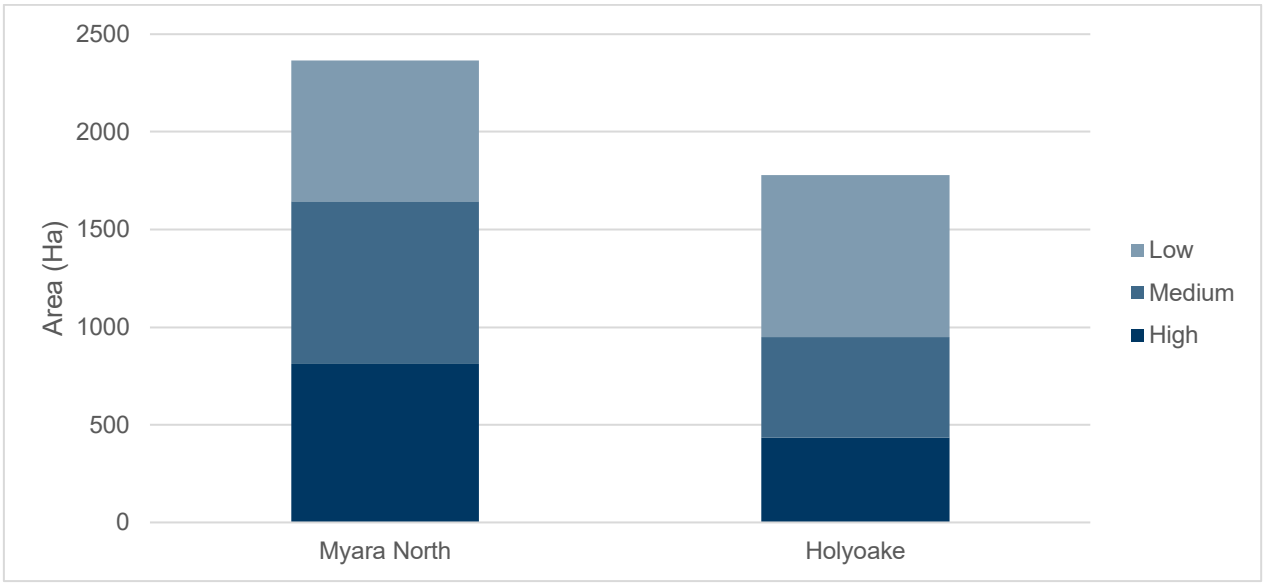


Figure H.2 Pit scale erosion rates by mining region

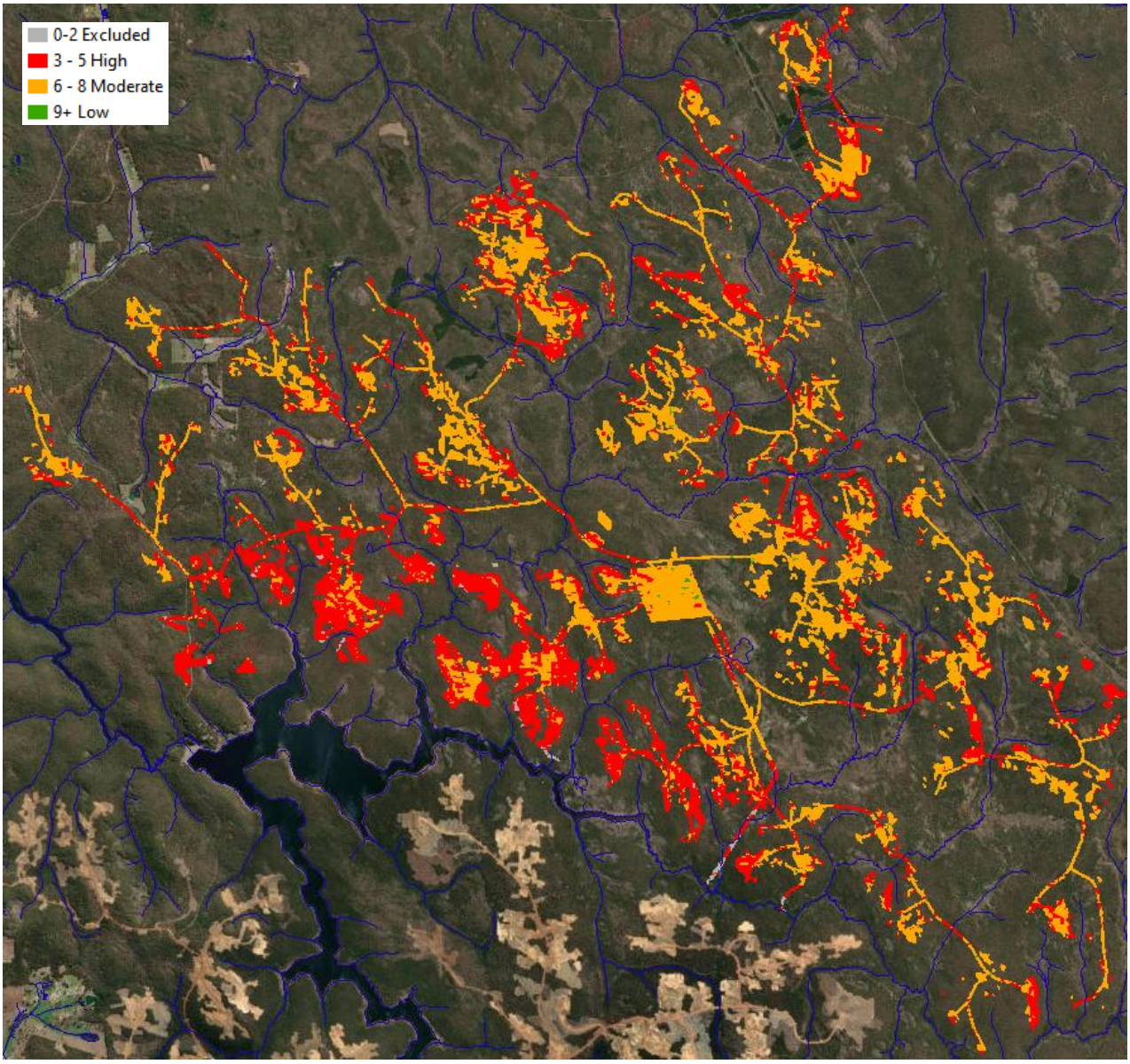


Figure H.3 Myara North pit scale turbidity risk (Alcoa long term planning method)

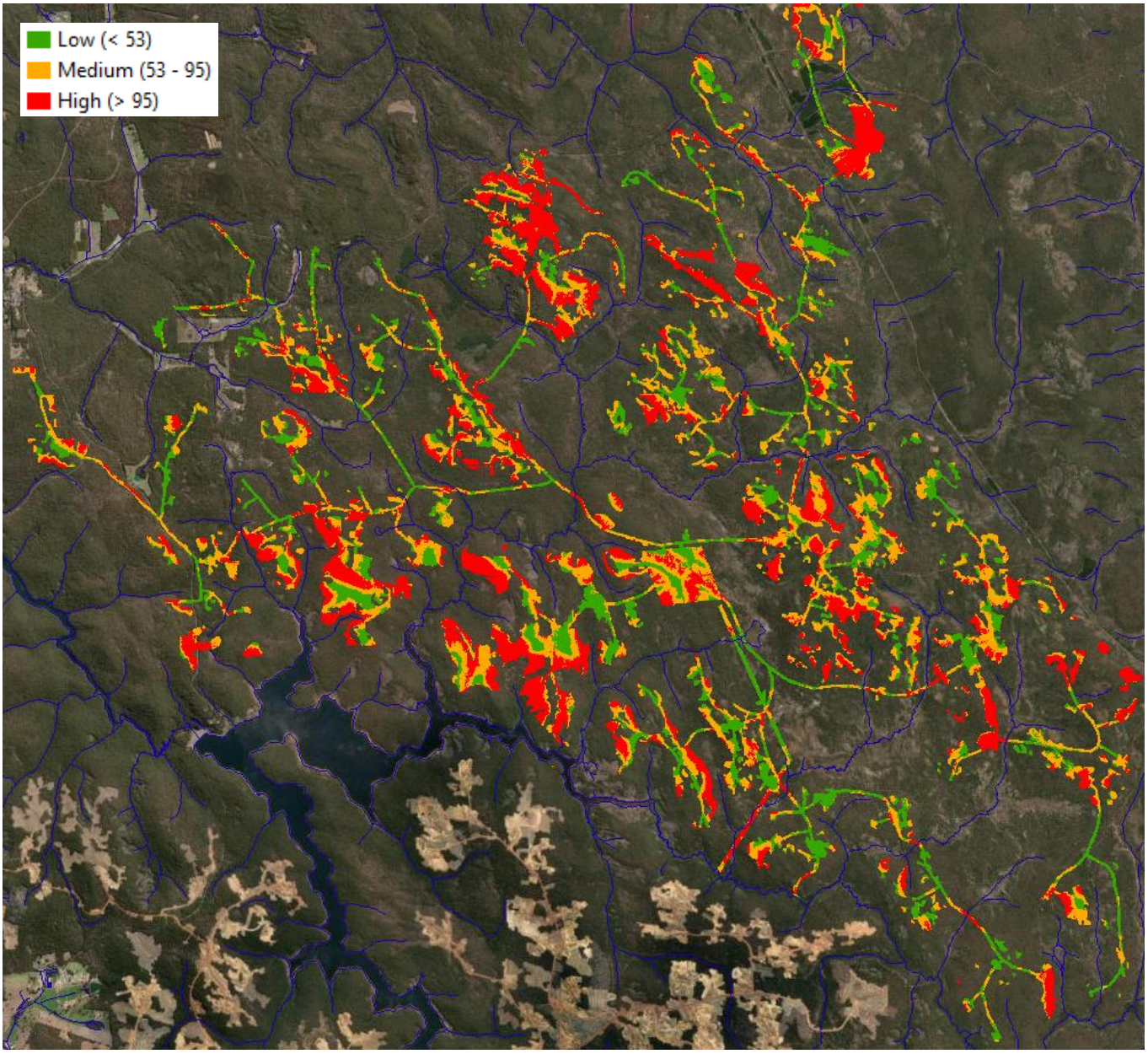


Figure H.4 Myara North pit scale erosion rate (t/ha/a, RUSLE method)

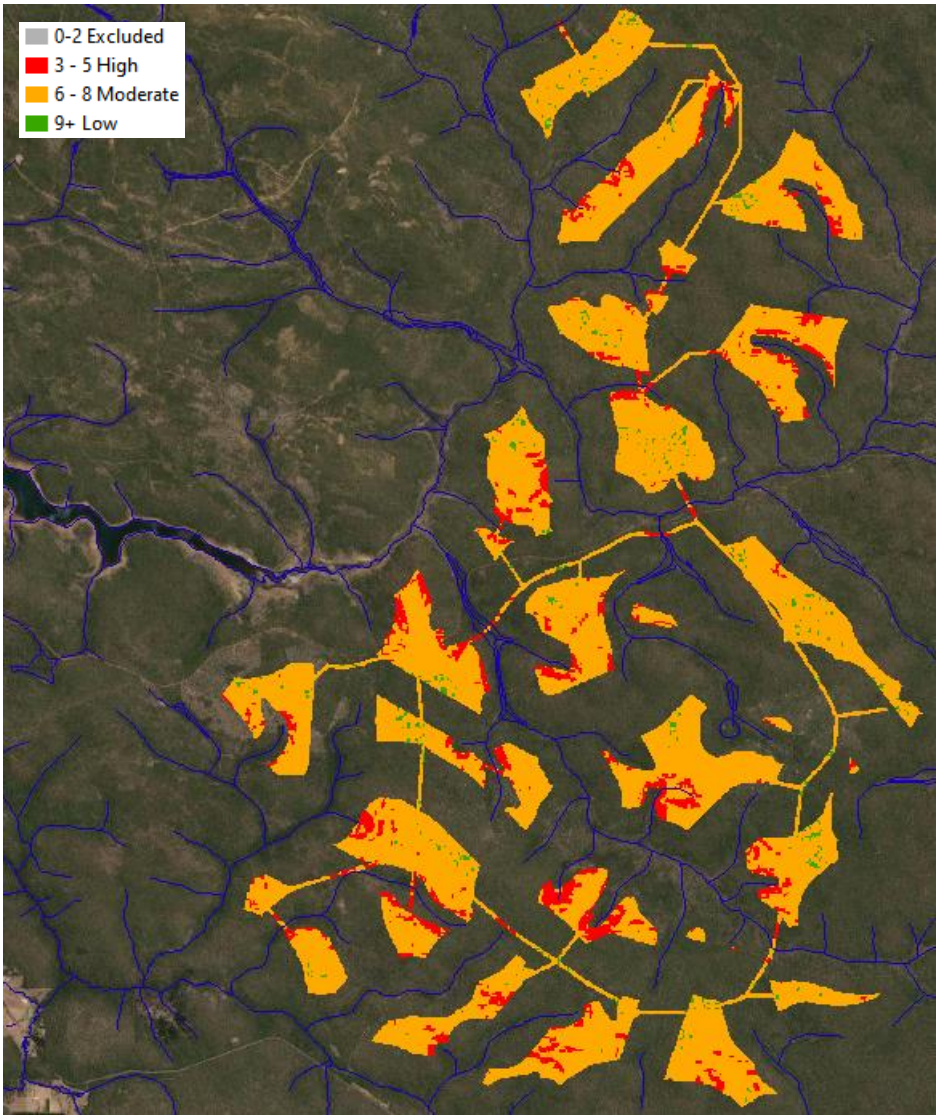


Figure H.5 Holyoake pit scale turbidity risk (Alcoa long term planning method)

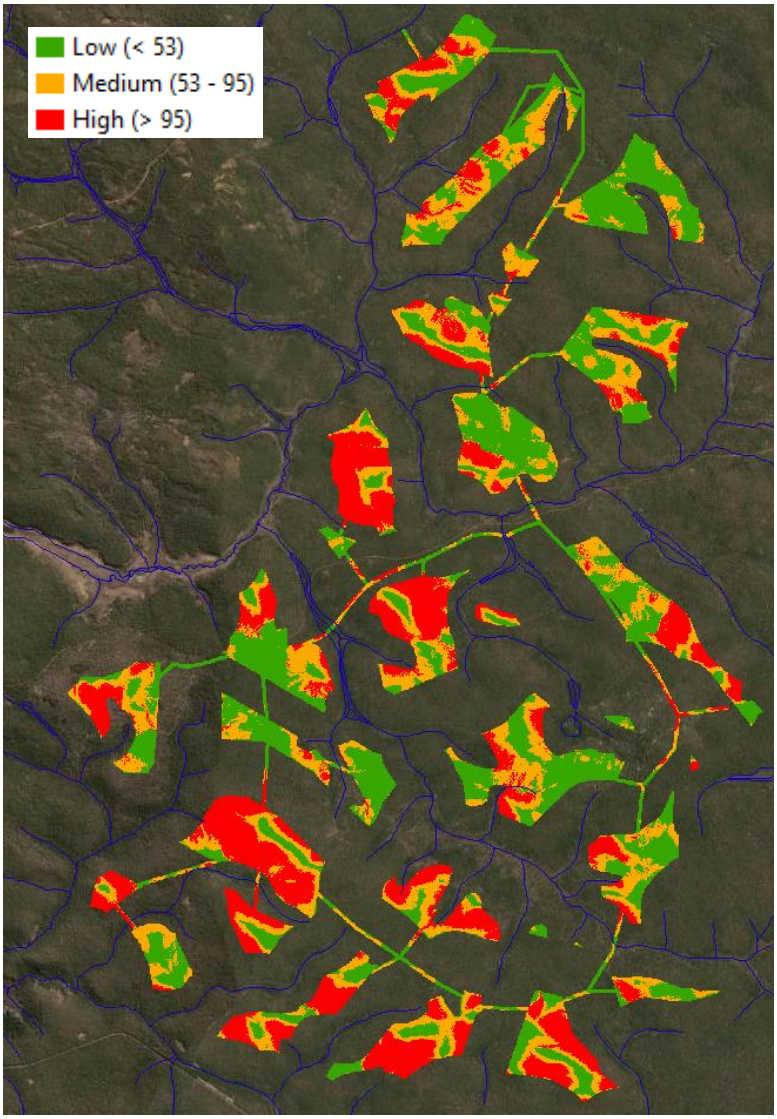


Figure H.6 Holyoake pit scale erosion rate (t/ha/a, RUSLE method)

Sub-catchment scale turbidity risk

RUSLE method

At the sub-catchment scale, pit-scale risks combine to produce a turbidity risk that may be higher or lower than the contributing pit-scale risks. A sub-catchment with a high proportion of clearing has a higher likelihood of generating turbid discharge. The consequence of such an event may also be higher, depending on the size and location of the sub-catchment.

A procedure for estimating sub-catchment scale turbidity discharge risk is currently under development by the MMP. In the absence of an agreed approach, the following approach is adopted. Note that this risk assessment approach is inconsistent with ADWG (NHMRC, 2011), inconsistent with the approach adopted in this drinking water risk assessment report, and is only suitable for assessing the relative risk of mining sub-catchments and the relative requirement for barriers. The scoring method presented in Equation H.1 and Table H.3 produces an even distribution of low, medium and high-risk catchments. Sub-catchments were supplied by Water Corporation and limit the analysis to the Serpentine and South Dandalup PDWSA's.

Equation H.1 Sub-catchment risk score

$$Sub-catchment\ unmitigated\ soil\ loss\ (t.ha^{-1}.a^{-1}) = \frac{Cleared\ area\ annual\ soil\ loss\ potential\ (t.a^{-1})}{Sub-catchment\ area\ (ha)}$$

Table H.3 Risk area criteria

Sub-catchment unmitigated soil loss (t/ha/a)	Relative risk
Bottom third (<5.1)	Low
Middle third (5.1-12.6)	Medium
Top third (>12.6)	High

Results

Results of the sub-catchment scale risk assessment are tabulated in Table H.4, plotted in Figure H.7, and mapped in Figure H.8 and Figure H.9 below.

Table H.4 Sub-catchment scale turbidity risk

Sub-catchment	Clearing area as a proportion of catchment area (%)	Sub-catchment unmitigated soil loss (t/ha/a)	Relative risk rating
HO01	0%	0.2	Low
HO02	31%	14.6	High
HO03	19%	9.8	Medium
HO04	3%	1.9	Low
HO05	26%	20.6	High
HO06	22%	10.3	Medium
HO07	13%	4.2	Low
HO08	14%	6.9	Medium
MN01	22%	17.1	High
MN02	3%	1.6	Low
MN03	25%	18.7	High
MN04	17%	14.5	High
MN05	14%	8.4	Medium
MN06	35%	42.7	High
MN07	22%	14.6	High
MN08	16%	8.9	Medium
MN09	20%	13.1	High
MN10	18%	11.5	Medium
MN11	3%	1.2	Low
MN12	6%	3.1	Low
MN13	5%	2.0	Low
MN14	14%	8.9	Medium
MN15	3%	1.4	Low

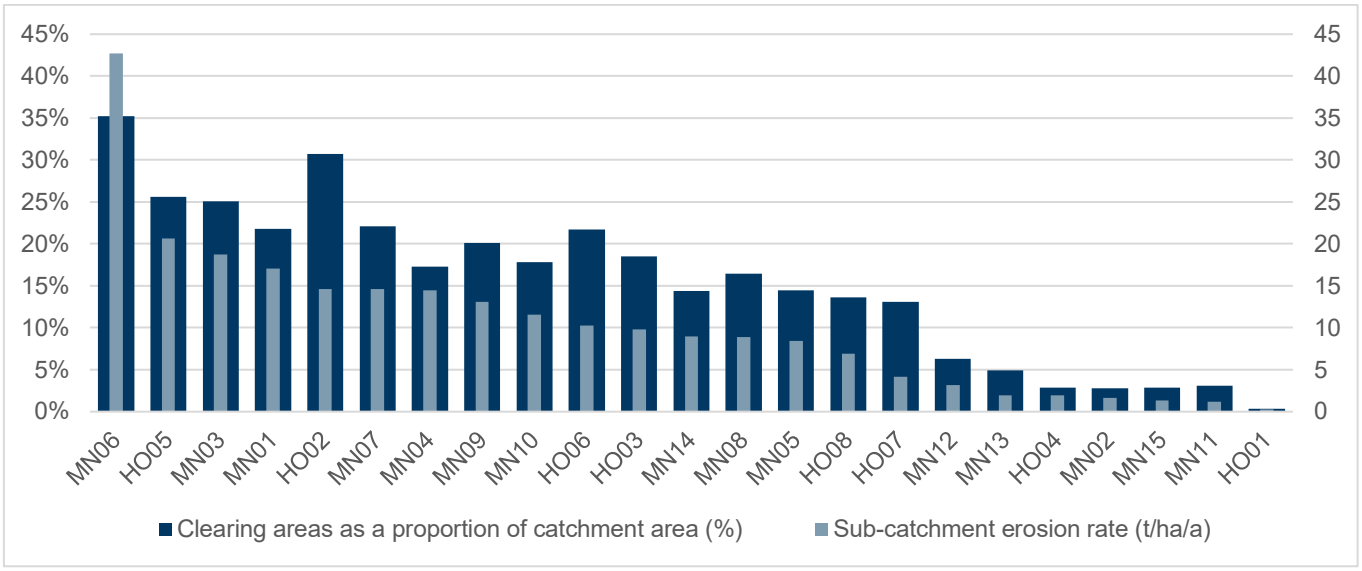


Figure H.7 *Sub-catchment scale turbidity risk*

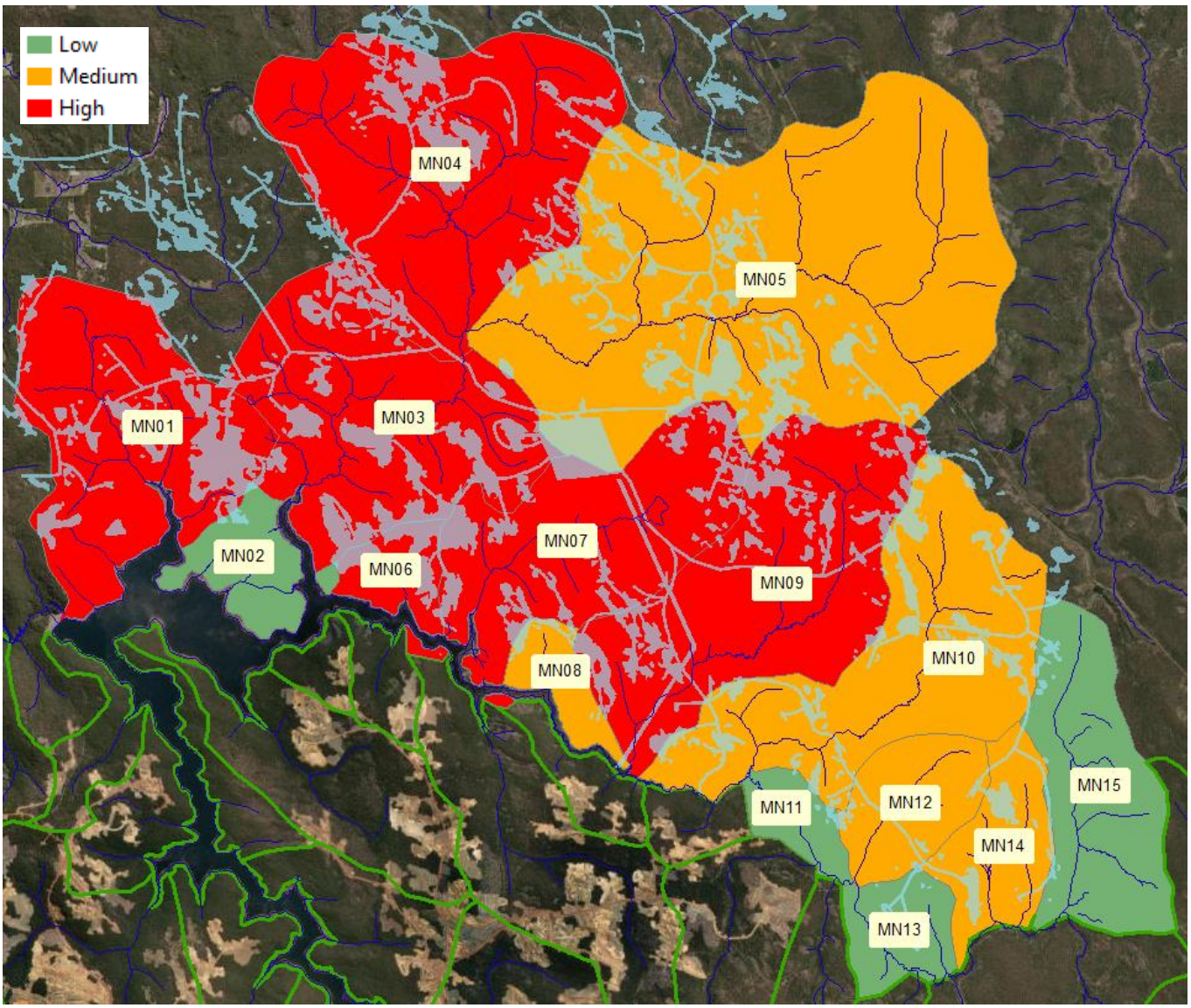


Figure H.8 *Myara North sub-catchment scale turbidity risk*

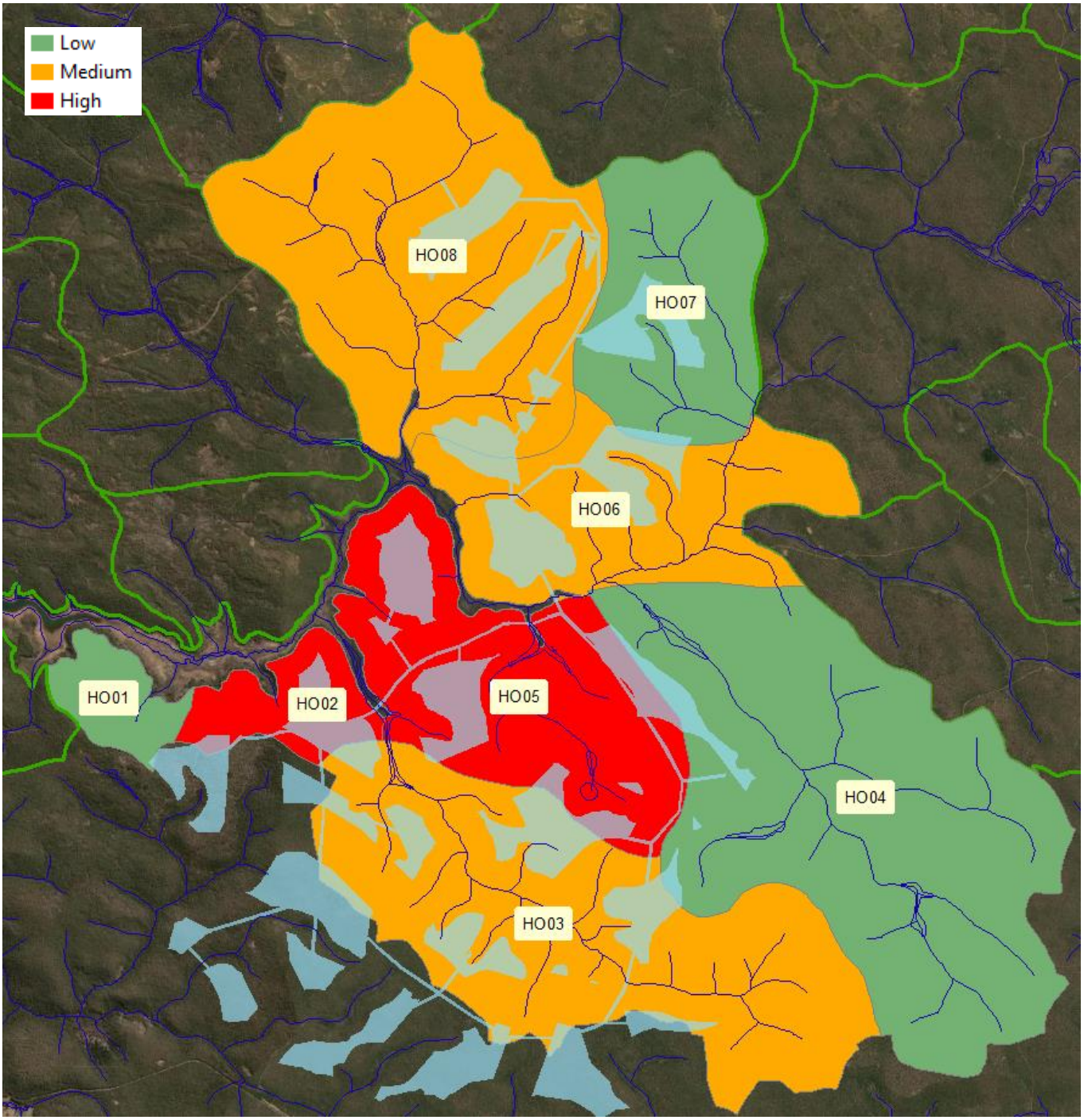


Figure H.9 Holyoake sub-catchment scale turbidity risk

Appendix I

Barriers

Table I-1 Likelihood criteria

	ADWG example description	Water Corporation Corporate Description	Water Corporation Corporate Frequency
ALMOST CERTAIN	Is expected to occur in most circumstances	The event is expected or known to occur more than once per year	Will occur more than once a year
LIKELY	Will probably occur in most circumstances	Known to re-occur approximately annually. Known to occur across like industries or within corporation.	Will occur once per year
POSSIBLE	Might occur or should occur at some time	The event should occur at some time. Has occurred several times across like industries.	Will occur once every 5 years
UNLIKELY	Could occur at some time	The event could occur at some time. Known to have occurred once or twice within industry.	Will occur once in 10 years
RARE	May occur only in exceptional circumstances	The event may occur in exceptional circumstances. An example of this has occurred historically, but is not anticipated.	Will occur once in 30 years or less

Note: These tables only list barriers upstream of the reservoir offtake. Whilst Australian Drinking Water Guidelines (NHMRC, 2011) require consideration of the system wholistically, other physical and procedural barriers downstream of the offtake under the responsibility of Water Corporation are not included. Failure likelihoods represent probability of failure of the individual barrier (in isolation). Overall likelihood of the hazardous event occurring is the combination of multiple barrier failures, many of which are sequential as illustrated in the accompanying figures. For events not 100% correlated, the joint probability is less than the individual probabilities. For example, the probability of a *Cryptosporidium* infected worker being on-site, ignoring inductions, not having work breaks, not using ablutions, not reporting illness, having access to sensitive parts of the catchment, not observing signage, defecating in these parts of the catchment, not bagging their waste, not reporting the incident, a rainfall event occurring soon after the waste event, and the buffers, streams and reservoir not sufficiently treating and attenuating the viral load has been conservatively rated as “Unlikely”, compared to higher probabilities for individual barrier failures.

Preventative barriers to pathogen discharge and transport

Table I-2 Barriers and preventative measures to pathogens – workforce in the field

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
1	Demountable ablution block (existing)	Crib room and ablution block provided within mine region at a location closer to active mine pits to support field workforce working away from mine facilities. Ablution block drains to a tank, which is periodically pumped out by a tanker for off-site disposal at a licensed facility.	**Crib room and ablution block, Myara mine region** 	1. Workforce do not travel to ablutions block. 2. Spillage during tank pump out, or from tank leakage or overflow. 3. Spillage from mine road accident during tanker transport.	**Failsafe:** • Mine road collision avoidance system, mine road berms and drainage capture spills. **Performance evidence:** Not available **Likelihood:** • **LIKELY** that some workforce members do not use ablutions block, including those in remote mine pits or exploration areas. • **UNLIKELY** that spillage occurs during tank pump out, or from tank leakage or overflow. • **RARE** that mine road accident occurs involving sewage tanker.	Document frequency and volume of tank pump outs. Additional barriers 6-9 proposed to prevent workforce toileting in the field.
2	Mandated work breaks (existing)	Work breaks provide opportunity for field staff to access ablutions block or mine facilities.	n/a	1. Workforce do not use work breaks to travel to ablutions block or mine facilities.	**Failsafe:** n/a **Performance evidence:** n/a **Likelihood: LIKELY**	Additional barriers 6-9 proposed to prevent workforce toileting in the field.

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
3	Haul truck refuelling at mine facilities (existing)	Haul truck refuelling provides opportunity for field staff to access ablutions at mine facilities.	n/a	1. Workforce do not use ablutions during refuelling operations.	**Failsafe:** n/a **Performance evidence:** n/a **Likelihood:** LIKELY	Additional barriers 6-9 proposed to prevent workforce toileting in the field.
4	Workforce education (existing)	Inductions for all staff and contractors at commencement and regular refreshers, including: • Drinking water catchment sensitivity • Pathogen risks • Mandatory procedures	n/a	1. Workforce do not understand or disregard induction information.	**Failsafe:** • Include in Alcoa's site induction requirements. **Performance evidence:** n/a **Likelihood:** POSSIBLE	Additional barriers 6-9 proposed to prevent workforce toileting in the field.
5	Workforce health monitoring / reporting (existing)	Employees and contractors are encouraged, and required, to not attend the workplace if unwell, particularly if experiencing specific gastrointestinal symptoms, or contact with individuals with gastrointestinal symptoms. This requirement is communicated in the inductions and regular refresher training.	n/a	1. Infected workforce member is asymptomatic and does not declare contact. 2. Infected workforce member is symptomatic and does not comply with requirements	**Failsafe:** • Include in Alcoa's Authority to Proceed HSE permitting process. **Performance evidence:** n/a **Likelihood:** LIKELY for asymptomatic worker, UNLIKELY for symptomatic worker	Additional barriers 6-9 proposed to prevent workforce toileting in the field
6	Waste bagging / removal (proposed)	A procedure where all human waste will be bagged and contained and disposed of off-site appropriately is proposed.	n/a	1. Human error / non-compliance with waste removal procedures.	**Failsafe:** • Include in Alcoa's Authority to Proceed HSE permitting process. **Performance evidence:** n/a **Likelihood:** POSSIBLE	n/a
7	Incident reporting / response (proposed)	All accidental human waste discharges to be reported and cleaned up consistent with a hazardous material spill.	n/a	1. Human error / non-compliance with incident response procedures.	**Failsafe:** • Include in Alcoa's Authority to Proceed HSE permitting process. **Performance evidence:** n/a **Likelihood:** POSSIBLE	n/a
8	Drinking water protection signs (proposed)	Hazard signs installed at active mine pits, with warning statement on drinking water protection and mandatory off-site waste disposal.		1. Human error / non-compliance with signs.	**Failsafe:** n/a **Performance evidence:** n/a **Likelihood:** POSSIBLE	n/a
9	Workforce access restrictions (proposed)	It is proposed that access within designated buffers from streams and reservoirs, is only permitted to those employees and contractors that have completed the appropriate training package,	n/a	1. Human error / non-compliance with access restrictions.	**Failsafe:** • Include in Alcoa's Authority to Proceed HSE permitting process. **Performance evidence:** n/a	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
		to understand the drinking water catchment sensitivity, and mandatory procedures to minimise those risk. Refresher training is to occur annually with acknowledgement of employee and contractor obligations.			**Likelihood:** POSSIBLE	
10	Riparian / reservoir buffers – overland flow attenuation (existing)	In the event of failure in barriers 1 to 9, a human stool will be deposited in the field, which may or may not be buried in soil. Pathogens will be attenuated over several months through natural processes. In the event of heavy rainfall and the stool being shallow buried or not buried, the stool may be washed out and pathogens travel downslope via overland flow. Pathogens will attenuate during overland flow due to filtration in Jarrah forest understorey vegetation and litter layer. Overland flow is unlikely to reach streams unless there are heavy rainfall / wet catchment conditions.	**Jarrah forest vegetation with an intact understorey and litter layer** 	1. Staff walk into buffer for privacy and stool is deposited closer to stream / reservoir. 2. Overland flow transitions to shallow channels with preferential flow that short-circuits filtration by vegetation and litter. 3. Jarrah forest understorey has a patchy surface coverage amongst a varying litter layer. 4. Litter layer is consumed by bushfire and thereafter recovers over a period of several years. 5. Presence of granite outcrops downslope, potentially limiting the filtration and increasing runoff.	**Fail safes:** n/a **Performance evidence:** n/a Studies of bushfires confirm increased runoff, turbidity and pathogens from burnt catchments. **Likelihood:** • **LIKELY** for staff to walk through buffer • **POSSIBLE** for heavy rainfall to occur within a few months following stool discharge. • **POSSIBLE** for limited filtration to occur downslope.	n/a
11	Seasonal stream attenuation (existing)	Streams flow seasonally for several months of the year and then are dry. Pathogens will attenuate if discharging to a dry stream and there is no flow for a few to several months. Limited attenuation may occur in flowing streams however travel time is likely to be in the order of minutes to hours until discharge into the reservoir.	**39 Mile Brook seasonally dry stream bed** 	1. Seasonal flow is likely to occur during winter/spring which is when stool washout and overland flow are most likely to occur.	**Fail safes:** n/a **Performance evidence:** Stream gauging confirms seasonal stream flow from June to December for 39 Mile Brook and Big Brook **Likelihood:** • **LIKELY** for streamflow to occur when stool washout and overland flow occurs.	n/a
12	Reservoir attenuation (existing)	Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Dilution and inactivation of pathogens due to natural mixing and retention processes in the reservoir.	**Serpentine Dam reservoir viewed from the dam wall** 	1. Short circuiting by stool discharges close to offtake at dam walls. 2. Thermal stratification during summer. 3. Low reservoir levels following a sequence of low rainfall years.	**Fail safes:** • No mining (and thus field activities) in Serpentine Pipehead Dam PDWSA. **Performance evidence:** n/a Hydrodynamic modelling with conservative assumptions (low reservoir water levels, summer discharge). **Likelihood:** • **POSSIBLE** for stool washout to result in exceedance of drinking water criteria at Serpentine Dam offtake. • **UNLIKELY** for stool washout to result in exceedance at South Dandalup Dam offtake.	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed

Table I-3 Barriers and preventative measures to pathogens – workforce at mine facilities

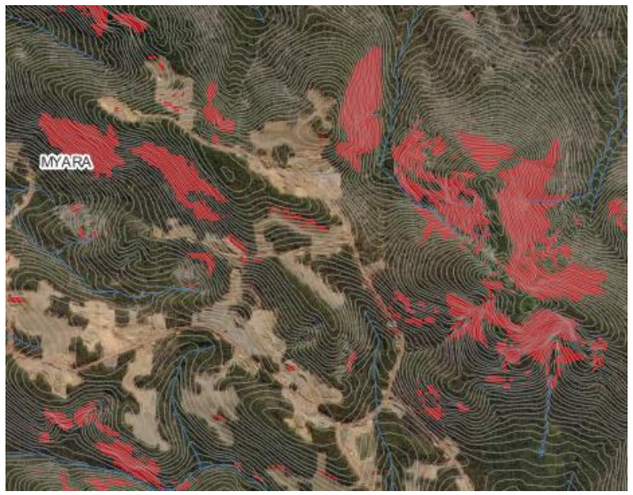
CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes , performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
1	Reservoir protection zone (existing)	Mine facilities are located outside of the RPZ, increasing travel pathways and attenuation for pathogens prior to discharge into the reservoir.	n/a	n/a	n/a	n/a
2	Sewage treatment and disinfection (existing)	Mine facilities sewage treated at a Sewage Treatment Plant (STP) and smaller ablution blocks (e.g. fuel bay facility) to an Aerated Treatment Unit (ATU).. Treatment comprises: • Primary and secondary treatment to reduce suspended solids and biological oxygen demand • Disinfection with chlorine.	**Biomax C100 unit at Myara mine facilities** 	1. Failure of mechanical systems such as aeration blower or irrigation pump causing overflow of semi or untreated sewage. 2. Chlorine disinfection (30 minutes contact) will reduce the load of bacteria, viruses and some protozoa, but will not reduce the load of some protozoa (e.g. *Cryptosporidium*).	**Fail safes:** • STP has an alarm and two days emergency storage in the event of a failure in the mechanical systems. • Gravity based chlorination reduces mechanical components. • Routine inspections and maintenance **Performance evidence:** Biomax report[2] minimum effluent quality as: • 30 mg/L suspended solids • 20 mg/L 5 day BOD 10 faecal coliform CFU per 100 mL **Likelihood:** • **UNLIKELY** for sewage overflow to occur from the STP emergency storage	n/a
3	Treated sewage effluent irrigation (existing)	Drip irrigation of treated effluent over Jarrah forest vegetation within the mine facilities complex. Water is lost to evapotranspiration, with some leaching of effluent to prevent build up of salts. Pathogens are captured in the shallow soil layer and die-off through natural processes.	**Effluent irrigation area at Myara mine facilities** 	1. Washout of irrigation area with upslope catchment runoff during a major storm event. 2. Shallow soils over rock causing ponding and runoff of effluent. 3. Irrigation over winter/spring results in ponding and runoff of effluent and/or leaching of effluent through the subsurface.	**Fail safes:** • Myara facilities irrigation area drains into surface drainage system that discharges into stormwater drainage ponds **Performance evidence:** n/a **Likelihood:** • **POSSIBLE** for irrigation area runoff	• Siting of irrigation area to minimise upslope catchment area. • Perimeter bund installed to divert upslope catchment runoff and retain irrigation area runoff from 1% AEP storm event. • Siting of irrigation area over a minimum soil depth of 1 m.
4	Overland flow attenuation (existing)	In the event of failure in barriers 2 or 3, sewage or treated effluent will travel via overland flow downslope of the STP or	**Jarrah forest vegetation with an intact understorey and litter layer**	1. Overland flow transitions to shallow channels with preferential flow that short-circuits filtration by vegetation	**Fail safes:** n/a **Performance evidence:** n/a Studies of bushfires confirm	• Effluent irrigation area will be located at least 100 m from nearest stream, and located to maximise the travel distance to drinking water

[2] https://biomax.com.au/products/

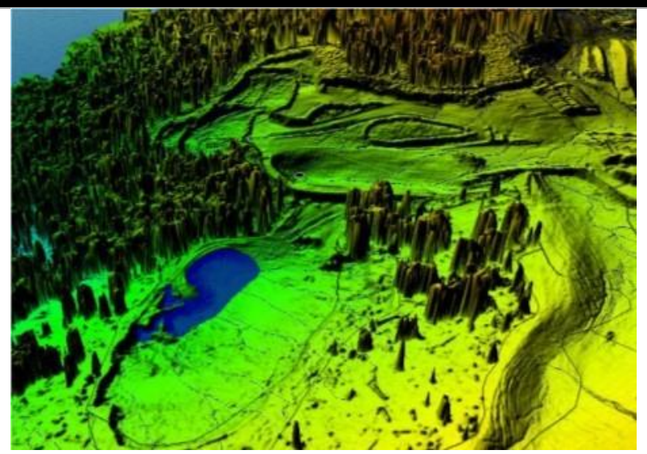
CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes , performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
		irrigation area. Pathogens will attenuate during overland flow due to filtration in Jarrah forest understorey vegetation and litter layer. Overland flow is unlikely to reach streams unless there is heavy rainfall / wet catchment conditions.		and litter. 2. Jarrah forest understorey has a patchy surface coverage amongst a varying litter layer. 3. Litter layer is consumed by bushfire and thereafter recovers over a period of several years. 4. Presence of granite outcrops downslope, potentially limiting the filtration and increasing runoff.	increased runoff, turbidity and pathogens from burnt catchments. **Likelihood:** • **LIKELY** for overland flow to occur if irrigation area overflow is occurring during a major storm event. • **POSSIBLE** for limited filtration to occur	reservoirs, as far as is practicable. • Effluent irrigation area will not be located upslope of granite outcrops.
5	Subsurface flow attenuation (existing)	In the event of performance of barriers 2 and 3, pathogens may be transported with infiltration through the unsaturated zone and then transported downslope with groundwater. Pathogens will be filtered in the subsurface matrix and attenuate through natural processes.	n/a	1. Downslope seepage faces where groundwater expresses during winter/spring, causing overland flow. 2. Presence of granite outcrops downslope, causing overland flow.	**Fail safes:** n/a **Performance evidence:** n/a **Likelihood:** • **UNLIKELY** for limited attenuation to occur	• Effluent irrigation area will not be located upslope of granite outcrops.
6	Seasonal stream attenuation (existing)	Streams flow seasonally for several months of the year and then are dry. Pathogens will attenuate if discharging to a dry stream and there is no flow for a few to several months. Limited attenuation may occur in flowing streams however travel time is likely to be in the order of minutes to hours until discharge into the reservoir.	**39 Mile Brook seasonally dry stream bed** 	1. Seasonal flow is likely to occur during winter/spring which is when irrigation area overflow and overland flow are most likely to occur.	**Fail safes:** n/a **Performance evidence:** Stream gauging confirms seasonal stream flow from June to December for 39 Mile Brook and Big Brook **Likelihood:** • **LIKELY** for streamflow to occur when other barriers are failing.	n/a
7	Reservoir attenuation (existing)	Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Dilution and inactivation of pathogens due to natural mixing and retention processes in the reservoir.	**Serpentine Dam reservoir viewed from the dam wall** 	1. Thermal stratification during summer. 2. Low reservoir levels following a sequence of low rainfall years.	**Fail safes:** n/a **Performance evidence:** Hydrodynamic modelling with conservative assumptions (low reservoir water levels, summer discharge). **Likelihood:** • **UNLIKELY** for STP or irrigation overflows transported overland or subsurface into reservoirs to result in exceedance of drinking water criteria.	n/a

Preventative barriers to sediment discharge and transport

Table I-4 Barriers and preventative measures to turbid discharge

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
1	Mine slope planning considerations (existing)	Mine planning currently exclude areas with slope exceeding 15.9 degrees due to safety and the ability to meet current completion criteria (physical and surface safety and stability). Slope is a demonstrated key factor in the generation of channelised flow, higher runoff velocities and volumes, and higher soil erosion.	**Aerial image illustrating areas in red where slope exceeds 16 degrees** 	n/a	**Fail safes:** n/a **Performance evidence:** n/a **Likelihood:** • **RARE** for slopes greater than 15.9 degrees to be mined.	n/a
2	Staged and seasonal approach to development and clearing (existing)	Mine development, mining and rehabilitation occurs in a staged manner within a mine region. The average timeframe between clearing and completion of mine rehabilitation is 3-4 years.	**Aerial image illustrating staged clearing, mining, and rehabilitation** 	• Potential for rehabilitation timeframes to exceed 4 years due to staging and resourcing.	**Fail safes:** n/a **Performance evidence:** Alcoa monitoring demonstrates that the majority of mine pits are rehabilitated within 3-4 years of clearing. **Likelihood:** • **LIKELY** that there will be turbid discharge for exposed soils over 3-4 years in the absence of other barriers.	n/a
3	Clearing contour windrows (existing)	Cleared wood waste is arranged in windrows on the contour, prior to burning or reuse. Windows intercept runoff to prevent flow concentration and subsequent erosion of mine pit and overflow of drainage	**Clearing windows, Myara mine region**	1. Temporary, seasonal barrier. 2. Non-engineered barrier of variable capacity, which may be overtopped by major storm events. 3. Placement off-contour causes concentrated runoff.	**Fail safes:** n/a **Performance evidence:** Alcoa has recorded failure of clearing contour windows at the Huntly Mine. **Likelihood:** • **LIKELY** for contour banks to	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
		protection shots. Clearing contour windrows are a temporary, seasonal barrier applied as cleared wood waste is available.		4. Damage by vehicles and machinery post placement.	fail based on the evidence	
4	In-pit drainage (existing)	Engineered and maintained mine drainage bunds and trenches intercept and convey runoff and sediment to in-pit sumps, preventing uncontrolled discharge	**n/a**	1. Defects in design or construction resulting in inadequate capacity to meet catchment runoff. 2. Damage by vehicles and machinery post placement.	**Fail safes:** • Inspection and maintenance. **Performance evidence:** There is documented and anecdotal evidence of structures performing as designed. **Likelihood:** • **POSSIBLE** for bunds and trenches to fail	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual
5	In-pit drainage protection shots (existing)	Drainage shots, also called water shots, comprise shallow (~1.8 m) blasted or ripped ground on the downslope perimeter of each mine pit. Drainage shots capture and infiltrated surface runoff within the blasted voids.	**Drainage protection shots, Myara mine region** 	1. Overflow due to incoming channelised / concentrated surface runoff that exceeds infiltrative / sediment capacity. 2. Overflow due to shallow groundwater reducing infiltrative capacity. 3. Overflow due to sediment accumulation over time. 4. Variability in regolith can affect infiltration capacity.	**Fail safes:** n/a **Performance evidence:** Alcoa has recorded drainage protection shot overflows each year at the Huntly Mine. **Likelihood:** • **LIKELY** for drainage protection slots to fail based on the evidence	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual
6	In-pit sumps (existing)	Some mine pits have in-pit sumps that collect runoff from pit floors and/or in-pit drainage. In-pit sumps are designed to retain runoff from major storm events.	**3D model illustrating in-pit storage shaded blue**	1. Sump overflow due to inadequate capacity to meet catchment runoff or groundwater conditions, or lack of maintenance.	**Fail safes:** • Sump inspection, pump out, sediment removal and repair. **Performance evidence:** Alcoa has recorded sump overflows each year at the Huntly Mine. **Likelihood:** **LIKELY** for in-pit storages to fail based on the evidence	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
						
7	Interception sumps (existing)	All paved areas at mine facilities and all haul roads drain to interception sumps. Paved areas upstream of major rivers (e.g. Big Brook) drain to triple interceptor sumps. All sumps are designed to retain rainfall from major storm events.	**Haul road sumps at Myara mine region**  	1. Sump overflow due to inadequate capacity to meet catchment runoff or groundwater conditions, or lack of maintenance.	**Fail safes:** • Sump inspection, pump out, sediment removal and repair. **Performance evidence:** Alcoa has recorded sump overflows each year at the Huntly Mine. **Likelihood:** • **LIKELY** for sump overflows.	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual
8	Rehabilitation revegetation prescription (existing)	Revegetation establishes a native understorey and overstorey with more than 80 per cent of the floristic diversity of un-mined forest. Substantial establishment of understorey coverage within five years.	**Five year old rehabilitation, Huntly Mine**	1. Drought or bushfire resulting in loss of saplings prior to re-establishment of a seed bank and lignotubers.	**Fail safes:** • Local reuse of topsoil that maintains floristic diversity. • Contemporary prescription has reduced fertiliser that reduces dominance of leguminous shrubs and increases floristic diversity.	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
					• Rehabilitation monitoring and completion criteria. • Remedial works following drought or bushfire. **Performance evidence:** Monitoring of rehabilitation has demonstrated that completion criteria are achieved in the majority of mine pits. **Likelihood:** • **UNLIKELY** for revegetation to fail completion criteria within a given mine pit.	
9	Rehabilitation substrate prescription (existing)	Rehabilitation substrate includes deep ripping of regolith, application of minimum 200 mm overburden/topsoil and ripping on the contour. Deep ripping promotes infiltration of runoff into the regolith. Application of minimum overburden provides a gravel-sand layer that protects finer grained regolith materials from erosion. Contour ripping creates a furrowed surface that promotes retention and infiltration of runoff.	**Rehabilitation substrate prior to revegetation, Myara mine region** 	1. Insufficient overburden placement can expose finer grained materials to erosion. 2. Ripping off contour can result in flow concentration and erosion.	**Fail safes:** • Exploration drilling defines overburden depths. • Local reuse of overburden within mine pits. • Revegetation completion within 12 months. **Performance evidence:** Ripping has been demonstrated to create a permeable substrate. Alcoa has recorded rehabilitation pit overflows each year at the Huntly Mine. **Likelihood:** • **LIKELY** for some rehabilitated pits to develop soil erosion.	n/a
10	Rehabilitation landscape prescription (existing)	Rehabilitation prescription limits final landform to slopes less than 16 degrees. Downslope toe of rehabilitated pits can have a reverse batter that creates a 'sunken' landform that retains surface runoff and prevents discharge.		1. Final landform does not meet prescription requirements. 2. Downslope toe grades to surrounding land or otherwise provides limited capacity to retain runoff.	**Fail safes: n/a** **Performance evidence:** LiDAR analysis of rehabilitated pits indicates that the majority may retain limited depths of runoff. **Likelihood:** • **POSSIBLE** for some rehabilitated pits to overflow	Rehabilitated mine pits designed and executed to prevent overflow during a 1 per cent 24hr AEP rainfall event.
11	Overland flow attenuation (existing)	In the event of failure in barriers 1 to 9, overflows from mine pits or haul road sumps will travel via overland flow downslope. Sediment will attenuate during overland flow due to filtration in Jarrah forest understorey vegetation and litter layer.	**Jarrah forest vegetation with an intact understorey and litter layer**	1. Mine pit or sump overflow discharge generates channelised flow through the slope that short circuits filtration. 2. Overland flow transitions to shallow channels with preferential flow that short-circuits filtration by vegetation and litter. 3. Jarrah forest understorey has a patchy surface coverage amongst a varying litter layer. 4. Litter layer is consumed by bushfire and thereafter recovers	**Fail safes:** • Operational Control Areas maintain minimum overland flow distances to streams or reservoirs. **Performance evidence:** n/a Studies of bushfires confirm increased runoff and turbidity from burnt catchments. **Likelihood:** • **LIKELY** for overland flow to occur when mine pit or haul	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
				over a period of several years.	road sump overflow occurs. • **POSSIBLE** for limited filtration to occur	
12	Stream attenuation (existing)	In the event of failure of barrier 10, sediment laden runoff will discharge into streams. Sediment in stream flow may be subject to deposition, filtration and dilution prior to discharge into the reservoir	**Serpentine River flowing in June 2020** 	1. Fine sediment fractions (e.g. clays) remain suspended in stream flows and are transported with higher stream velocities during major storm events in the catchment.	**Fail safes:** • Operational Control Areas maintain minimum stream distances to reservoirs. **Performance evidence:** n/a **Likelihood:** • **LIKELY** for fine sediments to remain suspended in stream flow during major storm events.	n/a
13	Reservoir attenuation (existing)	Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Dilution and settlement of sediment in the reservoir.	**Serpentine Dam reservoir viewed from the dam wall** 	1. Thermal stratification during summer. 2. Low reservoir levels following a sequence of low rainfall years. 3. Sediment is predominantly fine grained (i.e. clayey), reducing the effectiveness of reservoir settlement.	**Fail safes: n/a** **Performance evidence:** Water quality monitoring in Serpentine Dam and South Dandalup Dam from 2000-2020 demonstrates that mining and rehabilitation in the catchment does not causes any increasing trend in turbidity at the offtake. Hydrodynamic modelling with conservative assumptions (low reservoir water levels, summer discharge). **Likelihood:** • **RARE** for a failure of more than 50 per cent of all mine pits and sumps that results in turbidity at offtake to exceed drinking water criteria.	n/a

Preventative barriers to hydrocarbon discharge and transport

Table I-5 Preventative barriers to hydrocarbon discharge and transport

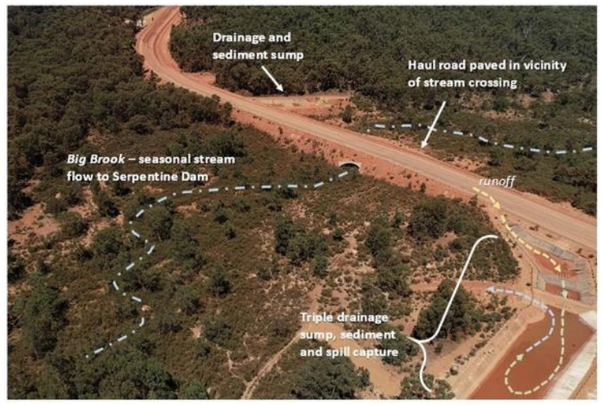
CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
1	Reservoir protection zone (existing)	Mine facilities are located outside of the RPZ, increasing travel and attenuation pathways for hydrocarbons prior to discharge into the reservoir.	n/a	n/a	n/a	n/a
2	Vehicle fuel bays (existing)	Mine facilities heavy and light vehicle fuel bays service haul trucks, other wheeled heavy vehicles and light vehicles. Fuel bays include: • Roofs to prevent ingress of rainfall. • Sealed floors to contain spills and leaks.	**Heavy vehicle fuel bay at Myara mine facilities – front**  **Heavy vehicle fuel bay at Myara mine facilities – rear**  **Light vehicle fuel bay at Myara mine facilities**	1. Spills or leaks during refuelling operations due to vehicle collision, ripped hose or dropped nozzle.	**Fail safes:** • Bollards and guide chains to prevent vehicle collisions / damage. • Automatic boom gate over heavy vehicle while refuelling to prevent vehicle departure causing ripped hose or free nozzle. • Automatic cut off valves to prevent spills in event of ripped hose or free nozzle. • Spill response kits. • Floors drain to the oily water treatment system. **Performance evidence:** Site monitoring of existing Huntly Mine drainage systems demonstrate that hydrocarbons are collected by the oily water system. **Likelihood:** • **POSSIBLE** for hydrocarbon spill during refuelling to occur outside of sealed floors. • **POSSIBLE** for hydrocarbon leak in fuel reticulation from fuel farm or drainage reticulation to oily water treatment system. • **RARE** for leaks through sealed floor into soils.	Detailed site investigation and (if required) remediation at decommissioning of mine facilities.

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
						
3	Vehicle washbays (existing)	Mine facilities heavy and light vehicle washbays service haul trucks, other wheeled heavy vehicles and light vehicles. Washbays include sealed floors to contain oily washwater and sediment,	**Heavy vehicle washbay at McCoy mine facilities** 	1. Washwater spray occurs outside of sealed washbay floors. 2. Overflow of washbay floor during heavy rainfall.	**Fail safes:** • Floors drain to the oily water treatment system. • Vehicle washing undertaken during periods when there is no heavy rainfall. **Performance evidence:** Site monitoring of existing Huntly Mine drainage systems demonstrate that hydrocarbons are collected by the oily water system. **Likelihood:** • **POSSIBLE** for washwater to overflow into adjacent unsealed ground. • **RARE** for leaks through sealed floor into soils.	Detailed site investigation and (if required) remediation at decommissioning of mine facilities.

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
4	Fuel farm (existing)	Fuel farm comprising above ground diesel and oil tanks with fuel tanker delivery bay. Tanker delivery bay is sealed to capture spills during delivery operations.	**Diesel fuel and oil storage tanks at Myara mine facilities**  **Fuel tanker delivery bay at Myara mine facilities** 	1. Leaks due to vehicle collision damage or corrosion. 2. Leaks/spills during tank refuelling	**Fail safes:** • Double walled tanks. • Bollards to prevent vehicle collisions / damage. • Regular inspection of tanks. • Delivery bay floors drain to the oily water treatment system. • Spill response kits. **Performance evidence:** Site monitoring of existing Huntly Mine drainage systems demonstrate that hydrocarbons are collected by the oily water system. **Likelihood:** • **POSSIBLE** for hydrocarbon spill to occur outside of sealed floors. • **POSSIBLE** for hydrocarbon leak in fuel reticulation from delivery bay or drainage reticulation to oily water treatment system. • **RARE** for undetected leaks to occur into soils.	Detailed site investigation and (if required) remediation at decommissioning of mine facilities.
5	Vehicle maintenance workshops (existing)	McCoy mine facilities maintenance workshops provide planned maintenance for haul trucks, other wheeled heavy vehicles and light vehicles. Workshops include: • Roofs to prevent ingress of rainfall. • Sealed floors to contain spills and leaks.	**Heavy vehicle maintenance workshops, McCoy mine facilities**  **Waste oil storage tanks, McCoy mine facilities**	1. Leaks during in-field planned maintenance for excavators, heavy equipment and unplanned breakdowns. 2. Leaks due to vehicle collision damage or corrosion. 3. Accumulation of hydrocarbons in sediments within drainage infrastructure.	**Fail safes:** • Hazardous materials and wastes will be stored at designated construction compounds or other storage facilities in accordance with Road Transport Reform (Dangerous Goods) Regulations 1997 as application to the specific materials. Storage will take into consideration the requirements of WQPN 56[3], Inland Waters commitment 8-23, and Terrestrial Environmental Quality commitment 7-17. All hazardous chemicals stored in lockers and bunded pallets. • Bulk oils and waste oils stored in double walled above ground tanks. • Regular inspection of storage	Detailed site investigation and (if required) remediation at decommissioning of mine facilities.

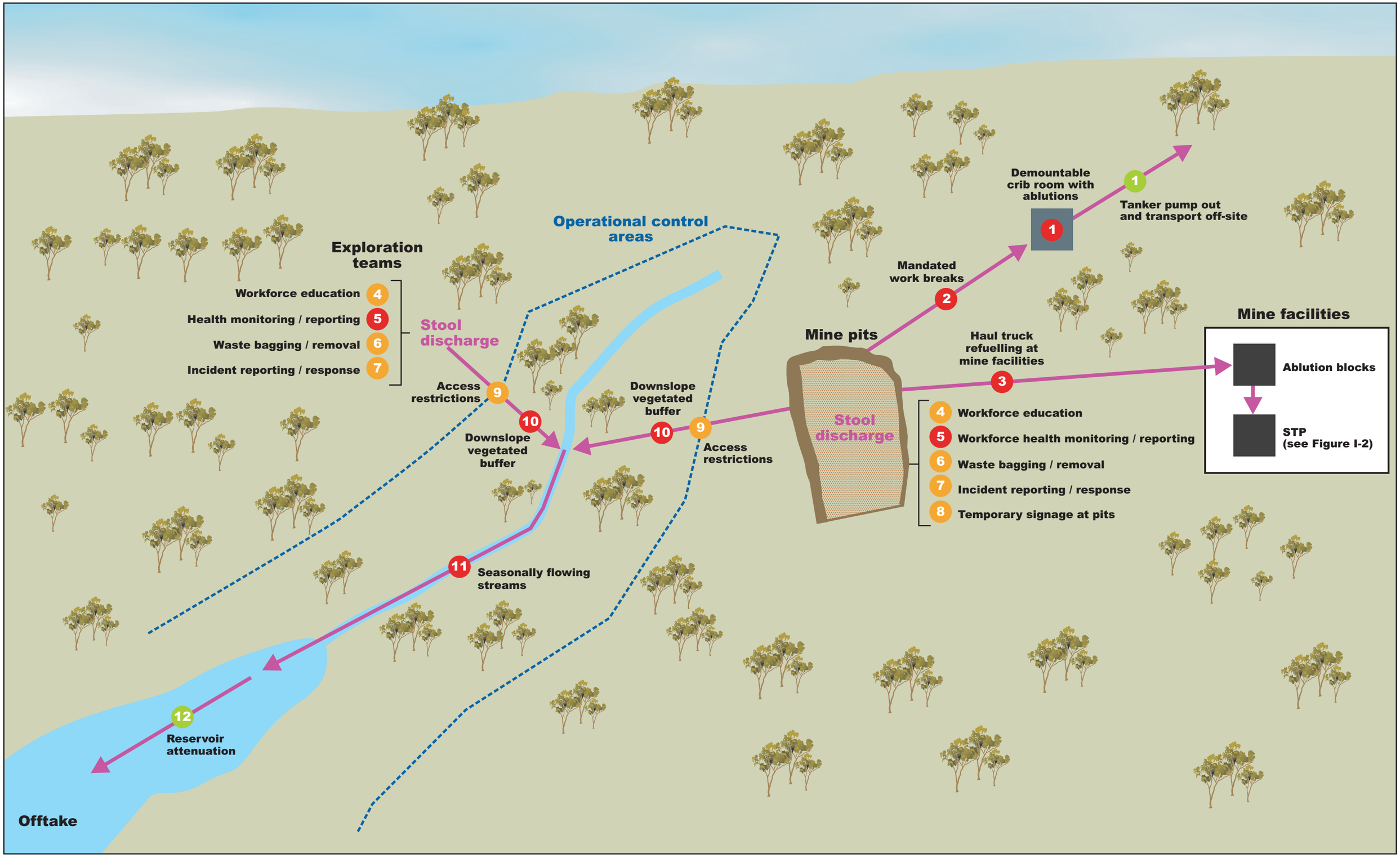
[3] Water Quality Protection Note 56, Department of Water and Environment Regulation (2018)

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
					areas. • Spill response kits (item 7) **Performance evidence:** Site monitoring of existing Huntly Mine drainage systems demonstrate that are collected by the oily water system. **Likelihood:** • **POSSIBLE** for hydrocarbon spill to occur during maintenance outside of workshops. • **POSSIBLE** for undetected leaks to occur into soils. • **RARE** for leaks through sealed floor into soils.	
6	Fuel transport limits over river crossings (existing)	15,000 litre diesel fuel capacity limit over major river crossings.	**Signage installed at Big Brook Crossing, Myara mine region** 	1. Signage deterioration over time and subsequent crossing of higher volume fuel capacity 2. Disregard of limits by fuel truck drivers	**Fail safes:** • Fuel delivery tankers to mine facilities use mine access roads that do not cross major rivers. • Mobile fuel tanker that supplies excavators and other heavy equipment has a capacity less than 15,000 litres. • Haul trucks, other heavy and light vehicles have fuel tanks well below 15,000 litres. • Mine vehicle collision warning system. • Mine vehicle driver training and induction. **Performance evidence:** n/a **Likelihood:** • **RARE** for fuel capacity limits to be exceeded	n/a
7	Spill response (existing)	All hydrocarbon spills identified at mine facilities (outside of oily water system) or in the field responded to. All captured spill material is disposed off site at licensed facilities. All soil at spill site identified as contaminated is excavated and disposed off site at licensed facilities. All hydrocarbon spills are reported internally.	**Fire truck and spill response trailer, McCoy mine facilities** 	1. Spills during heavy rainfall discharge with runoff off site prior to spill response. 2. Spills occur during fire or other hazardous circumstance that prevents or slows spill responses, discharging off site. 3. Undetected leaks/spills.	**Fail safes:** • Compacted haul road surface and ongoing haul road maintenance, preventing spills on haul roads from infiltrating to subsurface. • Haul road berms direct fuel spills into haul road sumps. **Performance evidence:** n/a **Likelihood:** • **POSSIBLE** for large spills to occur during heavy rainfall or hazardous events. • **UNLIKELY** for large spills to be undetected. • **LIKELY** for small spills or leaks to be undetected.	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
8	Stormwater drainage system (existing)	All paved areas at mine facilities and all haul roads drain to interception sumps. Paved areas upstream of major rivers (e.g. Big Brook) drain to triple interceptor sumps. All sumps are designed to retain rainfall from major storm events.	**Triple interceptor sumps at Big Brook, Myara mine region**  **Haul road sumps at Myara mine region** 	1. Sump overflow due to inadequate capacity to meet catchment runoff or groundwater conditions. 2. Leaks through base of unlined sumps. 3. Leaks through lining of lined sumps due to construction defects/lack of maintenance. 4. Accumulation of contaminated sediments in sumps acting as secondary source of contamination	**Fail safes:** • Lining of sumps upstream of major river crossings. • Sump pump out, sediment removal and repair. **Performance evidence:** Alcoa has recorded sump overflows each year at the Huntly Mine. **Likelihood:** • **LIKELY** for sump overflows. • **POSSIBLE** for undetected leaks to occur into soils.	Risk based mine drainage controls in accordance with Alcoa Drainage Management Manual
9	Oily water drainage system (existing)	Fuelbays, washbays and other potentially contaminated catchment drain to a network of open drains and underground drains and lined sumps. All sumps are designed to retain rainfall from major storm events.		1. Sump overflow due to inadequate capacity to meet rainfall or groundwater conditions. 2. Leaks through lining of lined sumps due to construction defects/lack of maintenance. 3. Accumulation of contaminated sediments in sumps acting as secondary source of contamination.	**Fail safes:** • Sump pump out, sediment removal and repair. **Performance evidence:** Site monitoring of existing Huntly Mine drainage systems demonstrate that are collected by the oily water system. **Likelihood:** • **POSSIBLE** for sump overflows. • **POSSIBLE** for undetected leaks to occur into soils.	n/a
10	Oily water treatment system (existing)	Oily water collected from fuelbays, washbays and other potentially contaminated catchments is treated at a Dissolved Air Flotation (DAF) plant. Treated water is stored in lined ponds and tested for oils, surfactants and metals prior to	**DAF Oily Water Treatment Plant at McCoy mine facilities**	1. Treatment system failure resulting in elevated oil content in treated water. 2. Overflow of ponds during heavy rainfall event. 3. Leak in pond liner due to construction defects/lack of maintenance	**Fail safes:** • Testing of treated water prior to reuse. • Pond freeboard to accommodate major storm rainfall and wave action. **Performance evidence:** Treated water test records.	n/a

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
		reuse for dust suppression at the Huntly Mine. The DAF plant and treated water discharge are managed and reported under Environmental Licence L6210/1991/10 under Part V of the EP Act.	 **DAF Oily Water Treatment Plant ponds at McCoy mine facilities** 		**Likelihood:** • UNLIKELY for treatment system failure combined with pond overflow or leakage.	
11	Overland flow attenuation (existing)	In the event of failure in barriers 2 to 10, hydrocarbons will travel via overland flow downslope of the spill, leak or overflow discharge area. Hydrocarbons will attenuate during overland flow due to filtration in Jarrah forest understorey vegetation and litter layer. Overland flow is unlikely to reach streams unless there is heavy rainfall / wet catchment conditions.	**Jarrah forest vegetation with an intact understorey and litter layer** 	1. Overland flow transitions to shallow channels with preferential flow that short-circuits filtration by vegetation and litter. 2. Jarrah forest understorey has a patchy surface coverage amongst a varying litter layer. 3. Litter layer is consumed by bushfire and thereafter recovers over a period of several years.	**Fail safes:** n/a **Performance evidence:** n/a **Likelihood:** • LIKELY for overland flow to occur if spill or overflow is occurring during a major storm event. • POSSIBLE for limited filtration to occur	Washbays, fuelbays, fuel and oil storage tanks, workshops and oily water treatment system will be located at least 100 m from nearest stream, and located to maximise the travel distance to drinking water reservoirs, as far as is practicable.
12	Subsurface flow attenuation (existing)	In the event of failure of barriers 2 to 10, hydrocarbons may be transported with infiltration through the unsaturated zone and then transported downslope with groundwater. Diesel and oil based	n/a	1. Downslope seepage faces where groundwater expresses during winter/spring, causing overland flow. 2. Presence of granite outcrops downslope, causing overland flow.	**Fail safes:** n/a **Performance evidence:** n/a **Likelihood:** • UNLIKELY for limited attenuation to occur	Washbays, fuelbays, fuel and oil storage tanks, workshops and oily water treatment system will be located at least 100 m from nearest stream, and located to maximise the travel distance to drinking water reservoirs, as far as is practicable.

CSM ref	Barrier	Description and function	Example	Potential barrier failures	Barrier fail-safes, performance evidence and residual likelihood of failure	How performance may be further improved, or uncertainties addressed
		hydrocarbons are expected to substantially adsorb in soils with subsurface flow is expected to be attenuated.				
13	Reservoir attenuation (existing)	Serpentine Dam is the downstream reservoir for the Myara and Myara North mine facilities. South Dandalup Dam is the downstream reservoir for the Holyoake mine facilities. Dilution of hydrocarbons and settling of contaminated sediment due to natural mixing and retention processes in the reservoir.	**Serpentine Dam reservoir viewed from the dam wall** 	1. Thermal stratification during summer. 2. Low reservoir levels following a sequence of low rainfall years.	**Fail safes:** n/a **Performance evidence:** Hydrodynamic modelling with conservative assumptions (low reservoir water levels, summer discharge). **Likelihood:** • **RARE** for hydrocarbon overflows transported overland or subsurface into reservoirs to result in exceedance of drinking water criteria.	n/a



LEGEND

Contaminant pathway

BARRIER RESIDUAL LIKELIHOOD OF FAILURE

- Likely
- Possible
- Unlikely
- Rare

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Huntly Mine Expansion

Job Number	12520591
Revision	0
Date	7 Jan 2022

Preventative barriers to pathogen discharge and transport - workforce in the field - conceptual model

Figure I-1

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Operational control areas

Downslope vegetated buffer

Overland flow

4

5

Subsurface flow

Seasonally flowing streams

6

7

Reservoir attenuation

Offtake

Reservoir protection zone

1

Mine facilities outside of protection zone

Mine facilities

Overflow

Leachate

Treated sewage effluent irrigation

3

Treated effluent

Ablation blocks

Sewage treatment and disinfection

2

Storage overflow

Emergency storage

LEGEND

Contaminant pathway

BARRIER RESIDUAL LIKELIHOOD OF FAILURE

- Likely
- Possible
- Unlikely
- Rare

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Drinking Water Risk Assessment
Serpentine, Serpentine Pipehead, South Dandalup and Wungong Brook Catchments

Job Number 12520591
Revision 0
Date 7 Jan 2022

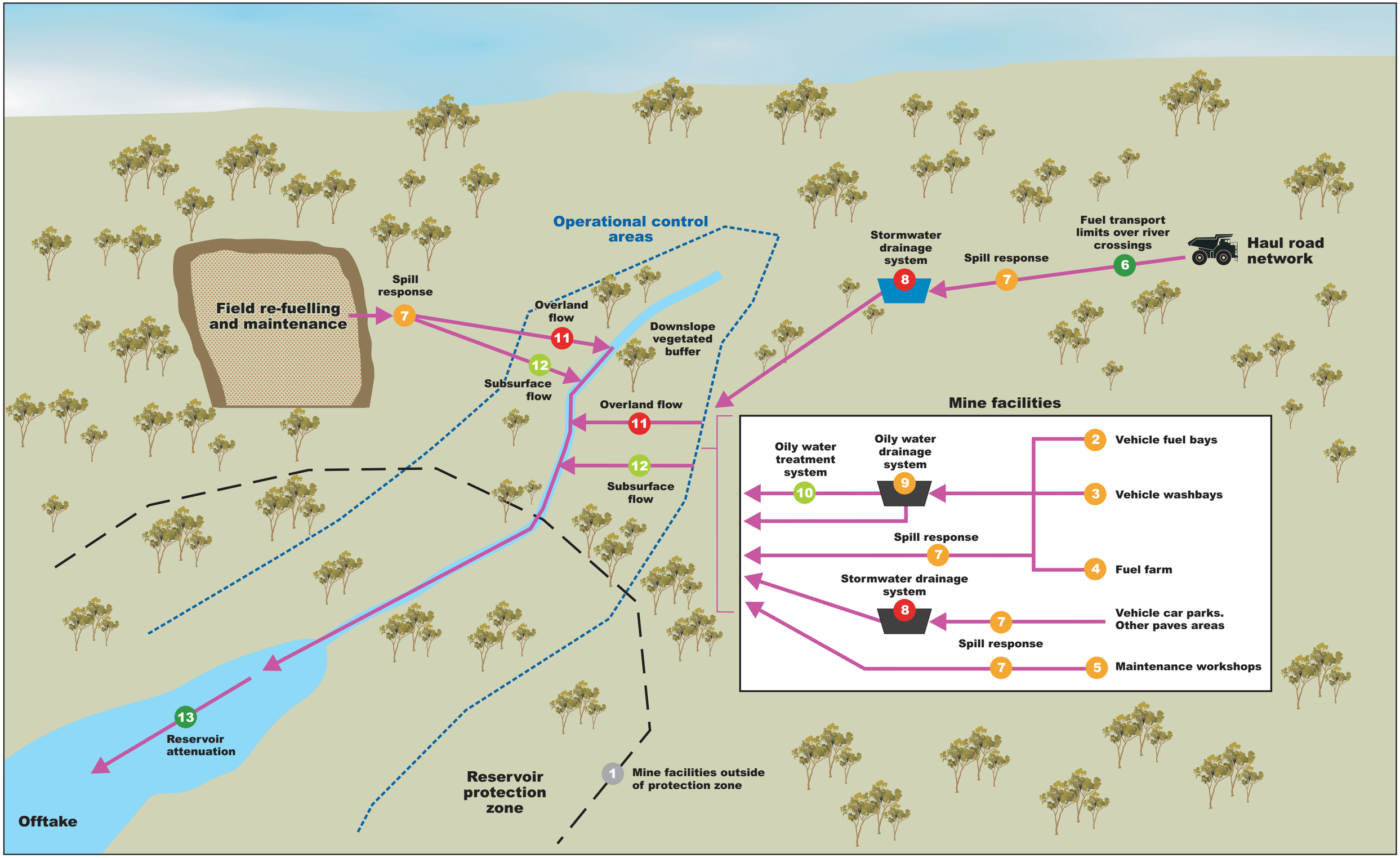
Preventative barriers to pathogen discharge and transport - workforce at mine facilities - conceptual model

Figure I-2

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LEGEND

Contaminant pathway

BARRIER RESIDUAL LIKELIHOOD OF FAILURE

- Likely
- Possible
- Unlikely
- Rare

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Drinking Water Risk Assessment
Serpentine, Serpentine Pipehead, South Dandalup and Wungong Brook Catchments

Job Number 12520591
Revision 0
Date 7 Jan 2022

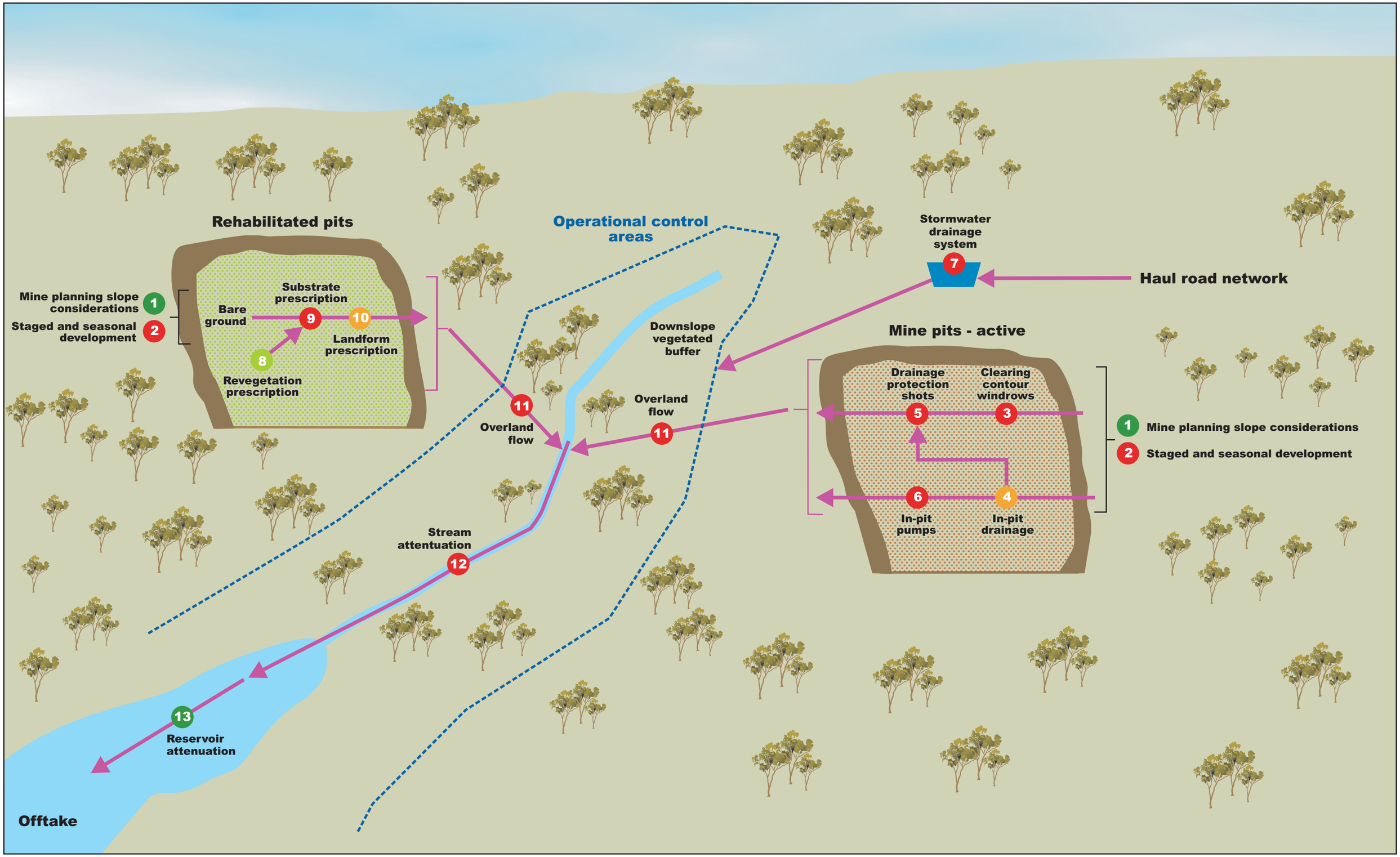
Preventative barriers to hydrocarbon discharge and transport - conceptual model

Figure I-4

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LEGEND

Contaminant pathway

BARRIER RESIDUAL LIKELIHOOD OF FAILURE

- Likely
- Possible
- Unlikely
- Rare

Conceptual diagram only - not to scale

Alcoa of Australia Pty Ltd
Drinking Water Risk Assessment
Serpentine, Serpentine Pipehead, South Dandalup and Wungong Brook Catchments

Job Number 12520591
Revision 0
Date 7 Jan 2022

Preventative barriers to sediment discharge and transport - conceptual model

Figure I-3

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Appendix J

RUSLE tool

Turbidity risk using RUSLE approach

A tool has been developed for Alcoa to estimate the raw (unmitigated) turbidity risk for a given catchment. The tool is based on the widely used Revised Universal Soil Loss Equation (RUSLE) to estimate annual sediment loads as a representation of turbid runoff.

Sensitivity analysis

A sensitivity analysis of the factors has been undertaken to understand the relative contribution of the variable to annual soil loss estimate. For each variable, the 10th, 50th (median) and 90th percentile of the variable has been calculated for the Huntly mine region. Table J.1 lists the impact of adopting the 90th percentile variable against the median value of the other variables. More information on the derivation of the variables is described in extracts from the tool in subsequent pages. Parameter P was not varied and represents the median combination of all parameters as a baseline.

Table J.1 Soil loss parameter sensitivity

Sensitivity factor	Median value	90th percentile value	Estimated annual average soil loss at 90th percentile, A (t/ha/yr)	Annual soil loss relative to median
Rainfall-runoff erosivity, *R*	3106	3382	40.2	8.9%
Soil erodibility, *K*	0.028	0.0375	50.4	36%
Length-Slope, *LS*	1.060	3.11	108.4	193%
Ground cover management, *C*	0.340	0.37	40.2	8.8%
Soil conservation practice, *P*	1.2	1.2	36.9	-

As can be seen from the sensitivity analysis:

– The range of length-slope factors, *LS* at Huntly is highly variable and causes the greatest increase in potential soil loss and turbidity, 193 per cent higher than the baseline. This indicates that *LS* is a high risk factor for consideration in planning and design of barriers.
– The range of ground cover management factors, *C* and rainfall runoff erosivity, *R* at Huntly is the least variable and causes the lowest increase in potential soil loss and turbidity, 8.8 per cent and 8.9 per cent higher than the baseline, respectively. This indicated that both *C* and *R* are of low risk and has little impact on the planning and design of barriers.

Relative risk ratings

Annual soil loss has been calculated for the range of variables measured across the Huntly mine region. A histogram of risk ratings has been derived for Huntly, assuming that:

– Mining can occur anywhere in the region.
– Soil erodibility for cleared areas represents the worst case soils, where the regolith is exposed, and that the regolith of future mined areas is similar to what is observed in the historically mined regions.
– Variables *R* and *LS* are spatially variable and known prior to any mining activity.
– Variable *C* is temporally variable depending on whether the cleared area is being mined or rehabilitated.
– No barriers are in place.
– Other minor assumptions as detailed throughout the tool.

By dividing the range of possible combinations into equal portions, the tool provides a relative risk rating to guide selection and implementation of barriers.



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